June 2024

Summer-Fall Habitat Action (SFHA) Monitoring and Science Plans and Structured Decision Making (SDM) Approach Peer Review

Letters to the Delta Science Program

Delta Science Program

DELTA STEWARDSHIP COUNCIL

Disclaimer

As requested by the California Department of Water Resources, this report combines into one repository document four individually authored peer review letters for the Summer-Fall Habitat Action, one from each panel member. Each letter reflects only the individual author's thoughts, opinions, and suggestions that address the Charge questions that the panel member was given for the peer review based on their expertise. Reviews focused on the methodology of the Monitoring and Science Plans conducted by ecological food webs and fisheries experts are presented first. Reviews focused on the scientific approach and structured decision making (SDM) process conducted by SDM experts are presented second.

Table of Contents

June 2024

Review of the Delta Smelt SFHA Monitoring and Science Plans

An individual letter review for the Delta Science Program

Prepared by

Isa Woo - U. S. Geological Survey, Western Ecological Research Center

Delta Science Program

DELTA STEWARDSHIP COUNCIL

Table of Contents

Executive Summary

The Delta Smelt Summer-Fall Habitat Action (SFHA) Monitoring and Science Plans are intended to improve key habitat conditions (i.e., salinity and zooplankton prey availability) during the Summer-Fall seasons, when suitable habitat is most limiting for juvenile and subadult Delta Smelt. A set of water flow management actions aim to improve habitat conditions by reducing salinity and maintaining a low salinity habitat around Suisun Marsh and Grizzly Bay when water temperatures are suitable, and to help facilitate prey subsidies in the Low Salinity Zone during non-critically dry years. These plans are designed to meet regulatory requirements, assess the effectiveness of these actions, and for science-led adaptive management to fill data gaps and ultimately improve management outcomes.

Strengths of the Monitoring and Science Plans

The Monitoring and Science Plans and supplemental material were reviewed and were comprised of many strengths. The goals and metrics were clear and the metrics to assess the effectiveness of management actions were clearly defined. While the Monitoring and Science plans clearly outline water flow triggers for management actions, they currently lack biological triggers for management actions. This may have been a deliberate omission because of the lack of biological triggers that can be feasibly monitored, or out of simplicity; however, further discussion on whether or when a biological trigger would be appropriate or feasible may be a way to focus monitoring efforts. In addition, documentation of the roadblocks or rationale for omitting biological triggers (or other triggers) may be useful when new tools or information can be used to overcome former barriers. The adaptive management approach embraces the process of using the best available science and incorporates new studies to fill data gaps and/or uses a large body of research to fill priority data gaps and inform decisions. The monitoring plans are ambitious and use multiple approaches to monitor physical habitat, prey availability, and Delta Smelt. Furthermore, the datasets generated from monitoring efforts are large and publicly available, facilitating data synthesis and collaboration.

Challenges to Overcome in the Monitoring and Science Plans

One of the biggest challenges to the Monitoring and Science Plans is the issue of detection. The extreme rarity of Delta Smelt poses unique challenges, especially when trying to infer the best suitable habitat or even refining bioenergetics and

distribution models. Furthermore, detecting an increase in zooplankton prey in the Low Salinity Zone and attributing that to a food web subsidy has proven difficult.

Opportunities for Improvement

Despite these challenges, there are a few themes in which clear opportunities remain. Advancements in modeling, model integration, and refinement can increase predictive power, especially for zooplankton populations. Advancements in monitoring science and detection, such as the detection of Delta Smelt using environmental DNA (eDNA) techniques with improved sensitivity of detection may help bolster traditional monitoring techniques. Similarly, advancements in automated detection using camera images processed by machine learning algorithms may provide a more rapid measure of zooplankton density, especially if issues with turbidity and error rates due to particles that are counted as zooplankton can be resolved. Other advancements include the incorporation of experimental caged cultured Delta Smelt or surrogate Wakasagi, which could be a powerful approach to address multiple data gaps (e.g., growth, survival, contaminant effects, habitat suitability, bioenergetic model refinement) if cage effects can be resolved. Analytical approaches such as food web studies that integrate the whole system can provide a deeper understanding of the linkages between detrital and pelagic food web pathways, and linkages of different carbon sources that sustain the secondary production of invertebrate prey. Compound-specific amino acid isotopes can provide greater specificity of the carbon that is assimilated in food webs and may provide insights into potential ways of enhancing carbon subsidies to support invertebrate production where most needed.

Although other conservation efforts for Delta Smelt were mentioned, an integrated approach with overarching conservation efforts throughout the Delta Smelt life cycle would be helpful to understand the various approaches holistically. For example, efforts to bolster the number of Delta Smelt entering the critical Summer-Fall seasons might be beneficial to the success of Summer-Fall management actions, and recovery of Delta Smelt.

Considering Future Uncertainty

The Monitoring and Science Plans outlined climate variability and other stressors on the estuary, including the introduction of an invasive clam which has resulted in the precipitous decline in zooplankton prey, causing cascading declines in pelagic fish. This dramatic change in the food web is likely irreversible. The Monitoring and Science Plans may benefit from the RAD (Resist, Accept, or Direct) framework that emphasizes managing for multiple future scenarios, and focuses on adaptability, rather than restoring a system to past conditions that may no longer be feasible. Some future scenarios may lead to novel conditions that may impact species and their food webs in unforeseen ways, such that the success in achieving primary goals may depend on the adaptability, nimbleness, and creativity of managers and scientists alike.

Overall, the Delta Smelt Summer-Fall Habitat Action Monitoring and Science Plans provide a robust framework for adaptive management. However, there are opportunities to improve the sensitivity of monitoring methods, integrate a broader understanding of the food web and potential future conditions, and consider an integrated Adaptive Management and RAD approach for managing change and uncertainty into the future.

General Comments

The report titled "Delta Smelt Summer-Fall Habitat Action (SFHA) Monitoring and Science Plans" which was prepared by the U.S. Bureau of Reclamation, Bay-Delta Office and California Department of Water Resources, Division of Integrated Science and Engineering, lays out the rationale of the science plan and monitoring in support of adaptive management for Delta Smelt during a critical stage in its life history. The environmental and biological goals of the SFHA Monitoring and Science Plans are clear and physical and biological metrics are clearly thought out. There is a large and growing body of science used to inform management decisions.

It is thought that the most pressing bottleneck period for Delta Smelt is during the Summer-Fall season, when temperatures are high and freshwater flow is low, pushing X2 further upstream, East, into the Delta. Confounding this thermal stress is the decline in zooplankton prey resources (Pelagic Organism of Decline; Sommer et al, 2007; MacNally et al. 2010), a decline in fall phytoplankton blooms that zooplankton feed upon in the Suisun region, contaminants, predation, etc.

The adaptive management process within the Monitoring and Science Plan is commendable, as it seeks input and review from multiple sources at regular intervals. The goals, hypotheses, and monitoring parameters are clear. This plan is supported by a large body of research, and datasets are publicly available, encouraging data synthesis of large datasets (DWR 2023). Potential scientific studies to fill critical data gaps have been identified so that learning is a built-in component.

Although it is outside the scope of the Monitoring and Science Plan that is focused solely on the Summer-Fall period, it would be helpful to see how this plan is integrated into the overall conservation and recovery efforts for the Delta Smelt. For example, efforts to bolster the number of Delta Smelt entering the critical Summer-Fall seasons may also be beneficial, in addition to Summer-Fall management actions. Advances in predictive modeling or life history traits may help managers take actions aimed at bolstering individual and population growth throughout their life cycle, incorporating all life history strategies, and identifying specific limiting life stages (Hobbs et al. 2019; Grimaldo et al. 2021, Polansky et al. 2024).

Furthermore, while it is understandable that critically dry years have insufficient water availability to generate any managed flow action; it is unclear whether critically dry years would trigger any other type of conservation action for Delta Smelt. Presumably, these critically dry water years may also be critical time periods for Delta Smelt survival, and during non-action years zooplankton prey is still limiting. It may be worth considering any opportunities to use zooplankton aquaculture to supplement target areas where Delta Smelt have been detected (potential use of emerging eDNA technologies; see Question 8). Although unconventional, an aquaculture subsidy might provide some benefits when populations might be most vulnerable. Additionally, a zooplankton aquaculture subsidy might also be an experimental way of learning the rate of detection of a known quantity of zooplankton at multiple distances from the release location, providing a measure of detection and diffusion to further refine and test current models. Lastly, in addition to studying ways to transport zooplankton prey more effectively from the North Delta to the Low Salinity Zone, are there possibilities of creating or enhancing appropriate habitat in the North Delta (where prey abundances are high) to sustain more Delta Smelt?

Specific Review Questions

The Panel was charged with addressing questions pertaining to two topical areas: Structured Decision Making and Monitoring & Science. *This review only addresses the questions set forth regarding the Monitoring and Science Plan, Questions #6-10.*

6. Are the current Monitoring and Science Plans well-designed to test the hypotheses, detect responses, and produce actionable results within the adaptive management framework? If not, what are the gaps in the monitoring plans to test their effectiveness?

The Monitoring and Science Plans are very ambitious and have accounted for the spatial and temporal variation in this dynamic system by focusing on the critical Summer-Fall habitat season. The primary purpose of the Monitoring and Science Plans is twofold: 1) to meet specific regulatory requirements set forth by the 2019 U.S. Fish and Wildlife Service Biological Opinion to develop a multi-year monitoring plan to support SFHA science and management activities using a structured decision making process; and 2) to create a framework to organize science activities for Summer-Fall actions to support Delta Smelt conservation. This review will focus on the latter goal.

The Monitoring and Science Plan focuses on monitoring the physical habitat parameters (primarily the maintenance of freshwater habitat) that is suitable for Delta Smelt during Summer-Fall, as well as biological attributes such as surveys to quantify phytoplankton and zooplankton prey, all of which influence Delta Smelt growth and survival.

Potential management actions are complex and involve two central hypotheses: 1) increasing the amount of freshwater flow in the Summer-Fall season (either by use of the 100 thousand-acre-feet (TAF) of outflow, or operation of the Suisun Marsh Salinity Control Gate [SMSCG]) as measured by the position of X2, will increase suitable habitat for Delta Smelt and increase zooplankton transport to the Low Salinity Zone in Suisun Marsh; and 2) increasing prey density by managing areas of high zooplankton production and facilitating downstream transport of prey via the Sacramento Deep Water Ship Channel Study, North Delta Food Subsidies and Colusa Basin Drain Study, or Roaring River Distribution System Food Subsidies

Study (currently on hold), will increase prey availability for Delta Smelt in the Low Salinity Zone.

The specific hypotheses for each of the management actions were presented in the SFHA Comprehensive Monitoring Plan for 2023. The hypotheses were clearly presented and appear logical, and relevant. The hypothesis for the Fall X2, 100 TAF, and SMSCG actions are similar in terms of managing water during the Summer-Fall to maximize the area of appropriate water quality conditions for Delta Smelt, primarily salinity and temperature. The high density of water quality stations and sophisticated hydrodynamic modeling (Zhang et al. 2016) appear robust, and my specific comments in the latter sections are primarily focused on the biota components.

The SMSCG is operated to reduce salinities in the major channels and Suisun Marsh, providing more favorable salinities for Delta Smelt in the larger channels and thereby providing access to habitat that has greater prey resources in those channels. To assess the benefit of SMSCG actions, conditions in Suisun Marsh will be compared to Grizzly Bay and Confluence regions; conditions will be compared before, and after SMSCG operations; and conditions during SMSCG operations will be compared to similar historical hydrological conditions. The comparison using before- and after- SMSCG operations, paired with comparisons to nearby regions provides a way to differentiate regional trends from that of the SMSCG actions. While there is no appropriate control site, this approach does attempt to account for overall environmental trends that may be attributed to environmental trends in the region.

Flow management actions of the Sacramento Deep Water Ship Channel Study and the North Delta Food Subsidies and Colusa Basin Drain Study are seen as a way to transport prey from more productive areas to the Low Salinity Zone, which is prey-poor. This managed transport of prey subsidies is intended to increase prey availability to Delta Smelt in the Low Salinity Zone to ultimately enhance Delta Smelt growth and survival.

The Monitoring and Science Plans clearly lay out the hypothesis, performance metric, and how results would either support or refute given hypotheses. In particular, the plans include experimental approaches (cultured or surrogate fish cage study), and other scientific investigations to fill data gaps. The monitoring and science plans seem well designed to detect and model physical water quality responses to flow actions; however, the response of biota has greater uncertainty. Although the monitoring plans are ambitious, there are confounding issues of detecting an effect, in particular a biological response (i.e., zooplankton or Delta Smelt response), and attributing the effect to a management action due to high spatial, vertical, and temporal variability.

Water management options and action triggers are well-laid out and have clear environmental triggers during particular water years; however, I do not see any type of biological trigger that would result in a particular action. Consider whether a biological trigger, such as a particular phytoplankton or zooplankton abundance, would be appropriate at this time, given the current state of knowledge and data gaps.

7. Are the metrics suitable or sensitive enough to test our questions and hypotheses? If not, how can they be improved?

Due to the spatial and temporal variability in zooplankton, and the patchiness and vertical movements of copepods, it can be challenging to detect differences in prey subsidies and attribute them to a managed flow action (Bennette et al. 2002; Kimmerer et al. 2002). Although recent advances have combined hydrodynamic and particle-tracking modeling with Bayesian analysis to improve understanding of how zooplankton could be dispersed downstream (Kimmerer et al. 2014 and 2019; Hasrick et al. 2023), the 2019 North Delta Food Subsidy action of redirecting agricultural return water into the Yolo Bypass, resulted in a localized increased in plankton and nutritious diatoms in the Yolo Bypass, and did not increase food availability downstream in the Cache Slough Complex or Lower Sacramento River (Twardochleb et al. 2021 *in* DWR 2023). It is therefore unclear whether an effect of food subsidies can be detected through monitoring, how far downstream an effect can be detected at particular flow rates, and how many samples would be needed to detect a flow action effect on zooplankton, highlighting critical data gaps. A spatially explicit power analysis might help inform the sample size needed to detect an increase of zooplankton due to flow action (e.g. Southwell et al. 2019). Current zooplankton sampling appears spatially dispersed, and surveys are conducted every 2 weeks, which can be overwhelming for folks processing invertebrates in the lab. I wonder if it would be helpful to stratify samples in such a way that prioritizes the processing/reporting of zooplankton samples by increasing distance from the food source? So, at least some information may become available earlier. An automated, continuous zooplankton observation, detection, and enumeration method using repeated photographs and machine learning shows promise, especially if issues with turbidity, detritus, and other pieces of organic matter, and further refinements of training datasets can be better resolved (K. Ross presentation, IEP 2024 Workshop).

Another way to approach the issue of prey subsidies would be to ask the question, "How much subsidized prey is needed to produce a measurable outcome in terms of Delta Smelt growth potential?" Using the Delta Smelt bioenergetics model may be a good start in determining how much prey would be needed for each 1mm of growth potential for Delta Smelt, given plausible scenarios of water temperature and salinity. Then, by using a targeted amount of zooplankton, I wonder if it would be possible to work backward with the hydrodynamic/particle tracking zooplankton transport model to determine how much prey subsidy and flow rates are required to transport zooplankton prey so that Delta Smelt in the Low Salinity Zone can grow a targeted amount. This may help determine the next course of action for prey subsidies. Other unknowns would be zooplankton detection rates given greater diffusion into the water column with increasing distance.

Due to the extreme rarity of Delta Smelt, the detection of the species from set monitoring stations is challenging, given very low detections at the monitoring stations (zero detections in the past few years). At densities this low, not all suitable habitat may be occupied, and occupancy can be variable due to changing suitable habitat, governed by freshwater flow actions, water temperature, turbidity, and prey resources. Sampling designs that are conducted at regular spacing intervals or set distances apart (e.g. every 25 km apart) may not be efficient for detecting rare or patchily distributed species (Lindenmayer et al. 2020). Monitoring programs may need to keep abreast of and incorporate innovative tools and technologies, or risk becoming logistically unfeasible, extremely expensive, or uninformative (See Question 8).

8. Are there other methods (e.g., new technologies) or analyses (including for data comparability) that should be incorporated?

Adaptive monitoring is similar to the concept of adaptive management but is specific to the decisions of a monitoring program. It includes a way for a monitoring program to be nimble and respond to new questions, new information, novel conditions, or new techniques/tools/protocols to increase the effectiveness of the monitoring program (Lindenmayer & Likens 2009, Lindenmayer et al. 2011). Innovative approaches, such as using environmental DNA (eDNA) can be an effective tool to augment/supplement gaps in the existing Monitoring framework for Delta Smelt. eDNA is a relatively new tool and approach that has been used to detect rare and endangered fish species (Thomsen et al. 2012, Duarte et al. 2023, Holmes et al. 2024). eDNA methods, particularly quantitative polymerase chain reaction (qPCR) and metabarcoding, have shown high sensitivity in detecting rare aquatic species, including fish, and can be more effective than traditional sampling methods for monitoring rare fish, even in turbid water (Nester et al. 2023). Recent advances include optimizing eDNA sampling techniques and filter types to process a greater volume of water (Pochon et al. 2024; Bowen et al. in press) and the use of specific marker regions to enhance detection rates (McCarthy et al. 2023). Approaches using other nucleic acids, such as RNA may be promising in providing a shorter temporal timeframe of detection, and microRNA (miRNAs) may help infer stress responses in fish (Ikert et al. 2021, Yates et al. 2023).

In terms of detecting Delta Smelt, traditional eDNA detection methods are limited both by turbidity and very low amount of DNA shed into the environment (very limited numbers of individual Delta Smelt and their small body size; Holmes et al. 2024). Holmes et al. (2024) determined that a prefiltration process improved the detection of Delta Smelt in turbid water. Furthermore, a new eDNA processing approach using clustered regularly interspaced short palindromic repeats (CRISPR)-based tools resulted in greater sensitivity and specificity with the ability to detect about 3 copies per reaction compared to ~300 in a typical assay (Nagarajan et al. 2024). This improved eDNA detection assay named SHERLOCK (Specific High-Sensitivity Enzymatic Reporter Unlocking) was able to detect Delta Smelt eDNA from field samples, highlighting its potential to be used as part of a monitoring tool to determine Delta Smelt presence, which could then refine occupancy or habitat suitability models.

9. Are there areas (metrics or analysis) that should be prioritized, adjusted, or dropped to improve science evaluations

The Monitoring and Science Plans are comprehensive and incorporate new studies to promote learning and fill data gaps. The amount of peer-reviewed literature on the processes that impact Delta Smelt including hydrology and hydrodynamics, nutrients, phytoplankton, and zooplankton in the San Francisco Estuary is impressive and is an exemplary example of the incorporation of science to inform adaptive management.

The section titled, Topics for Potential Action Work Plan Modifications or Directed Studies, summarized primary data gaps that came out of DCG discussions on current science and monitoring of the SFHA components.

It is unclear how the Delta Smelt Habitat Suitability Index (HSI) would vary from the Delta Smelt Bioenergetics model, or would the Bioenergetics model inform the HSI on a spatial scale? Integrating or expanding the Delta Smelt Bioenergetics model to a spatially explicit model would provide a way of analyzing scenarios of varying temperatures, varying salinities, and food production spatially (Davis et al. 2021).

The SFHA Comprehensive Monitoring Plan for 2023 included an experimental study using caged cultured Delta Smelt or surrogate fish. Assessing Delta Smelt response to SFHA actions is hampered by the scarcity of wild fish and the ability to observe and detect them. As a result, Delta Smelt models such as the Individual Based Model and bioenergetics models have a relatively high level of uncertainty. Caged studies can be tremendously powerful in addressing data gaps in Delta Smelt detection, growth, and survival. In particular, if cage effects issues can be overcome, caged studies may be well-suited to address questions and data gaps such as:

- How do sites where modeled high growth rate potential vary from one another?
- How well would a surrogate species such as Wakasagi approximate Delta Smelt response?
- Are there contaminant impacts to caged fish in areas that receive agricultural return water?
- How does the detection of cultured Delta Smelt vary with distance using improved eDNA methods (such as SHERLOCK; Nagarajan et al. 2024)?
- How does caged fish growth vary with distance from food web subsidy?
- How well does caged fish growth approximate modeled bioenergetics? There may be opportunities to refine, test, and assess errors in the models.
- If there is a known area of Delta Smelt habitat “hotspot” (perhaps the Deepwater Ship Channel), caged fish placed at varying distances away from

that hotspot may yield important insights into the variables that are important for survival and growth.

- Saving and preserving all fish tissues for other analysis such as: stomach contents for diet, muscle fin clip or liver tissue for stable isotope analyses is already indicated in the Monitoring and Science Plan. Also, consider saving and preserving eye lenses for growth and isotope analyses (Wallace et al. 2023), and a portion of the liver may be useful for contaminant studies.
- Is there a physiological measurement that can be an indication of or proxy for starvation?

Studies on food web ecology and the interaction or connectivity between detrital and algal pathways can further clarify how the lower trophic food webs have changed. The following citations are examples and not intended to be an exhaustive literature search.

Many studies have focused on the dissolved and particulate carbon and phytoplankton, indicating the importance of detrital carbon as well as algal carbon (Sobczak et al. 2002, Hernes et al. 2020), but fewer studies have shown the integration of detrital and pelagic pathways, linking fish, prey, and carbon sources (Grimaldo et al. 2009, Jeffres et al. 2020, Young et al. 2021). A recent study (Rogers et al. 2024) used structural equation modeling to examine abiotic and biotic interactions within both top-down and bottom-up drivers of food webs. The authors found that zooplankton abundance was influenced more strongly by bottom-up effects in freshwater upstream regions; however, in brackish downstream regions top-down effects became stronger, supporting water flow and prey subsidy actions (Rogers et al. 2024).

Food web studies can provide key ecological information on tracing carbon sources of consumed prey and studies that relate the impact of restoration in providing food web support in terms of direct foraging or allochthonous carbon subsidies can be helpful for promoting a diversified foraging portfolio, especially in a changing climate (e.g., Woo et al., 2019, Davis et al., 2021, Davis and Woo et al. 2024). Although the study was based in a different system, Woo et al. (2021) found that carbon sources common in target fish diets varied by location. For example, invertebrates found in marsh habitats incorporated a wider variety of carbon sources than invertebrates collected in riverine or outer delta habitats. These results support the concept that multiple carbon sources fuel invertebrate production from multiple habitats. Therefore, activities that promote wetland restoration and habitat connectivity can help increase the foraging portfolio of fish within lower trophic food webs (Woo et. al. 2019). This connectivity of the food web and basal carbon resourced may be better visualized as a diagram, with relative contributions of primary producers to invertebrate prey indicated by the thickness of the arrows (Figure 1; Davis and Woo et al., 2024), which may be helpful as just one example of the importance of habitat connectivity for autochthonous and allochthonous food subsidies that support fish prey.

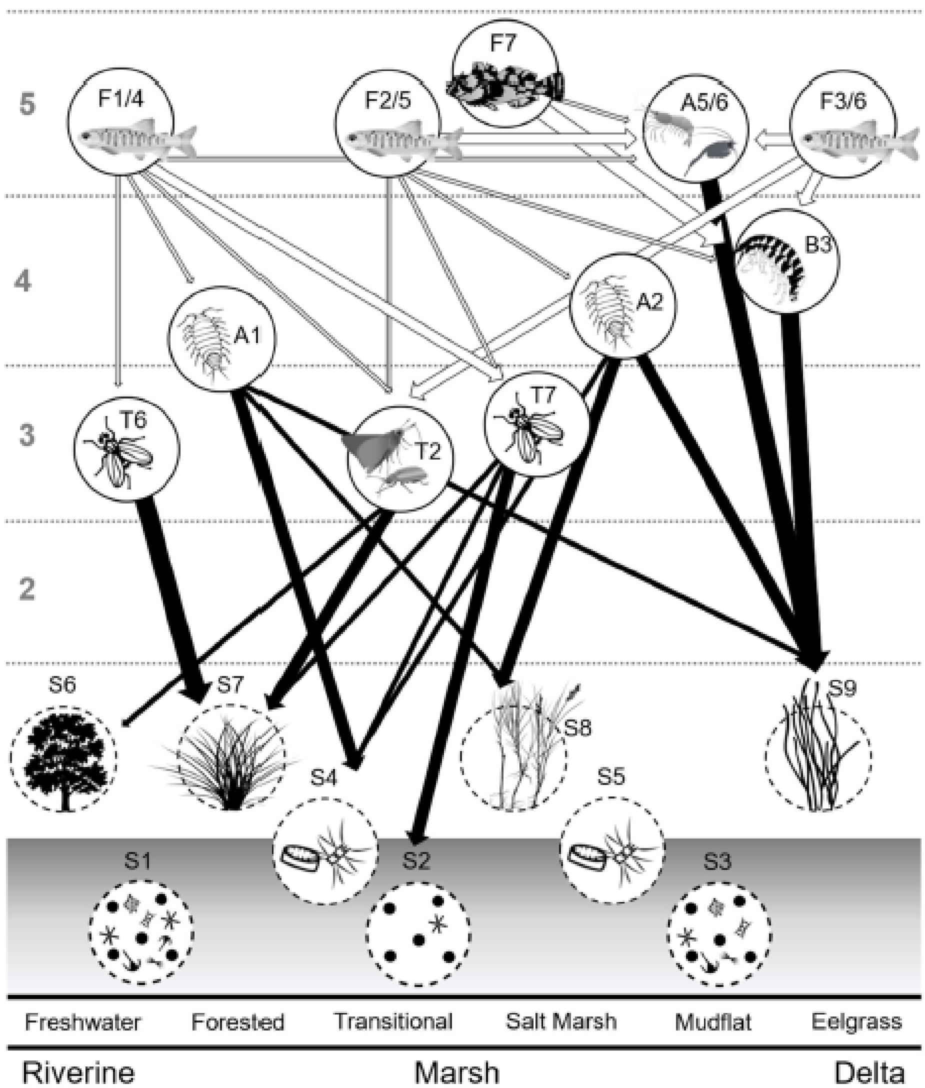

Figure 1. Food web linkages of primary producers, invertebrates, and fish, from multiple habitat types within the Nisqually River Estuary and Delta, WA. Habitat types along a salinity gradient are shown on the X axis ranging from freshwater riverine forests, brackish transitional marsh, salt marsh, and mudflat and eelgrass

habitats in the outer delta. Prey and consumer linkages across multiple habitats are depicted using arrows. White arrows show the diets of fish consumers, while black arrows show the diets of invertebrate consumers. The relative contribution of prey items to consumer diet was quantified using a Bayesian mixing model. These results are illustrated by the thickness of the arrows. Thin arrows represent 10–24% contribution to diet; while medium and thick arrows represent 25–50%, and >50% contribution to diet, respectively. This work highlights the importance of multiple carbon sources from nearby habitats for supporting invertebrate prey consumed by fish (Davis and Woo et al. 2024).

Caged studies are particularly well suited for food web analyses, using bulk stable isotopes of Carbon, Nitrogen, and Sulfur (as in Jeffres et al. 2020). Compound-specific amino acid isotopes may be better suited to differentiate carbon sources from primary producers such as algae, seagrass, terrestrial plants, bacteria, fungi, and detritus (Larsen et al. 2013, Riekenberg et al. 2022, Yun et al. 2022, Bruno et al. 2023) and can further clarify our understanding of how the changes in lower food web is impacting Delta Smelt growth in different regions.

10. How well are the Science and Monitoring Plans and SDM approach being integrated into the adaptive management of Delta Smelt Summer-Fall habitat?

Some management agencies, such as the U.S. Fish and Wildlife Service and the National Park Service, are using Resist, Accept, or Direct (RAD) concept integrated into the Adaptive Management framework to help resource managers make decisions, especially when ecosystems are shifting towards an uncertain novel future, and past conditions are no longer applicable (Williams 2022, Lynch et al., 2022). The integrated RAD and Adaptive Management concepts emphasize iterative learning and flexibility in the face of unprecedented ecosystem uncertainty to better achieve sustainable management outcomes over the long term (Lynch et al. 2022). The incorporation of the RAD approach is meant for scientists and managers to think about and manage change and to consider multiple future scenarios. Although I have not reviewed the Strength of Influence diagram, the RAD approach may dovetail nicely with existing efforts with the Strength of Influence diagram or mapping. Specifically, it may be useful in terms of revisiting older established environmental relationships that are changing and may not be as strong of predictors as they were in the past.

For example, the San Francisco Estuary has undergone a dramatic shift from the lower trophic food web dominated by pelagic plankton to epibenthic food resources in a relatively short amount of time, with cascading effects on zooplankton and fishes that rely on this pelagic prey (Cole and Cloern 1984, Lehman 2022). Future climate variability and times of water scarcity, exacerbate the cumulative impacts of multiple stressors for native fishes in the estuary (Colombano et al. 2022). Together, these stressors may impact the previously known environmental relationships to the extent that past conditions may no longer reflect current or future conditions. The importance of benthic and detrital processes on epibenthic animals was supported by the increased growth of epibenthic species such as amphipods and demersal fish that use detritus as a food resource in the upper San Francisco Estuary (USFE; Brown et al. 2016). Early work on food webs using stable isotopes in littoral habitats indicated food resources originated from epibenthic species, particularly amphipods, instead of the traditional pelagic zooplankton in USFE (Grimaldo et al. 2009). The importance of the interaction of the benthic-detrital and pelagic pathways entering the food web may be critical in understanding the functioning of the lower trophic food web and its impact on zooplankton and other prey resources (Lehman 2022).

10a. Are the current Monitoring and Science Plans going to reduce the uncertainties in the SDM performance metrics and improve confidence in the decision?

I defer to SDM reviewers to provide input and thoughts on whether the Monitoring and Science Plans will reduce the uncertainties in SDM performance metrics and improve confidence in the decision.

10b. How well do the Monitoring and Science Plans and SDM approach (influence diagram and performance metrics) support the evaluation of management objectives for the Summer-Fall Habitat Action? Are the Monitoring and Science Plan and SDM-approach likely to achieve the intended results? What are recommendations for improvement?

I defer to SDM reviewers to provide input and feedback regarding the SDM approach.

Abiotic and biotic management objectives, response measurements, and performance metrics are clearly presented by action type in Table 2 of the Delta

Smelt SFHA Monitoring and Science Plan. While the monitoring and science for quantifying and predicting physical habitat metrics are well-developed, there is more uncertainty regarding the biological responses, such as phytoplankton and zooplankton responses to food subsidy actions, and those impacts on Delta Smelt growth and survival. These uncertainties are acknowledged in the Monitoring and Science Plans, which incorporates iterative learning within an adaptive management and decision making process. In particular, the use of experimental studies (caged fish) as well as advances in monitoring tools and techniques, hold great promise to inform addressing unknowns and improving model performance in support of decision making (See responses to Questions 6, 7, 8, and 9).

References

Arciszewski, T.J., Munkittrick, K.R., Scrimgeour, G.J., Dubé, M.G., Wrona, F.J., and Hazewinkel, R.R., 2017. Using adaptive processes and adverse outcome pathways to develop meaningful, robust, and actionable environmental monitoring programs. *Integrated Environmental Assessment and Management*, 13(5): 877-891.

Bennett, W.A., Kimmerer, W.J., and Burau, J.R., 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. *Limnology and Oceanography,* 47: 1496–1507.

Bowen, L., Waters, S., Rankin, L., Thorne, K., Gille, D., De La Cruz, S., Woo, I., Lewis, L., Karpenko, K., Dean, C., and Schumer, G. *In press*. A comparison of eDNA sampling methods in an estuarine environment on presence of longfin smelt (*Spirinchus thaleichthys*) and fish community composition. *Environmental DNA*.

Brown, L.R., Kimmerer, W., Conrad, J.L., Lesmeister, S., and Mueller–Solger, A., 2016. Food webs of the Delta, Suisun Bay, and Suisun Marsh: an update on current understanding and possibilities for management. *San Francisco Estuary and Watershed Science*, 14(3).

Bruno, D.O., Riccialdelli, L., Acha, E.M., and Fernández, D.A., 2023. Seasonal variation of autochthonous and allochthonous carbon sources for the first levels of the Beagle Channel food web. *Journal of Marine Systems*, 239: 103859.

Chen, X., Li, S., Zhao, J., and Yao, M., 2024. Passive eDNA sampling facilitates biodiversity monitoring and rare species detection. *Environment International*, 108706.

Cole, B.E. and Cloern, J.E., 1984. Significance of biomass and light availability to plankton productivity in San Francisco Bay. *Marine Ecology Progress Series,* 17, 15–24.

Colombano, D.D., Carlson, S.M., Hobbs, J.A., and Ruhi, A., 2022. Four decades of climatic fluctuations and fish recruitment stability across a marine-freshwater gradient. *Global change biology*, 28(17), 5104-5120.

Cook, C.N., de Bie, K., Keith, D.A., and Addison, P.F., 2016. Decision triggers are a critical part of evidence-based conservation. *Biological Conservation*, 195, 46-51.

Davis, M. J., Woo, I., Ellings, C. S., Hodgson, S., Beauchamp, D.A., Nakai, G., and De La Cruz, S.E.W., 2021. A climate-mediated shift in the estuarine habitat mosaic limits prey availability and reduces nursery quality for juvenile salmon. *Estuaries and Coasts* 45, 1445–1464. https://doi.org/10.1007/s12237-021-01003-3.

Davis, M.J., Woo, I., De La Cruz, S.E., Ellings, C.S., Hodgson, S., and Nakai, G., 2024. Allochthonous marsh subsidies enhance food web productivity in an estuary and its surrounding ecosystem mosaic. *Plos One*, 19(2), p.e0296836.

Department of Water Resources (DWR), 2023. Workplan for operations and monitoring of the North Delta Food Subsidies Action. California Department of Water Resources, Division of Integrated Science and Engineering. April 26 revision.

Duarte, S., Simões, L., and Costa, F.O., 2023. Current status and topical issues on the use of eDNA-based targeted detection of rare animal species. *Science of The Total Environment*, 166675.

Grimaldo, L.F., Smith, W.E., and Nobriga, M.L., 2021. Re-examining factors that affect Delta Smelt (*Hypomesus transpacificus*) entrainment at the State Water Project and Central Valley Project in the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 19(1).

Grimaldo, L.F., Stewart, A.R., and Kimmerer, W., 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(1), 200-217.

Hassrick, J.L., Korman, J., Kimmerer, W.J., Gross, E.S., Grimaldo, L.F., Lee, C., and Schultz, A.A., 2023. Freshwater flow affects subsidies of a copepod (*Pseudodiaptomus forbesi*) to low-salinity food webs in the upper San Francisco estuary. *Estuaries and Coasts*, 46(2), 450-462.

Hernes, P.J., Dyda, R.Y., and Bergamaschi, B.A., 2020. Reassessing particulate organic carbon dynamics in the highly disturbed San Francisco Bay Estuary. *Frontiers in Earth Science*, 8, 185.

Hobbs, J.A., Lewis, L.S., Willmes, M., Denney, C., and Bush, E., 2019. Complex life histories discovered in a critically endangered fish. *Scientific Reports*, 9(1), 16772.

Holmes, A.E., Baerwald, M.R., Rodzen, J., Schreier, B.M., Mahardja, B., and Finger, A.J., 2024. Evaluating environmental DNA detection of a rare fish in turbid water using field and experimental approaches. *PeerJ*, 12, e16453.

Ikert, H., Lynch, M.D., Doxey, A.C., Giesy, J.P., Servos, M.R., Katzenback, B.A., and Craig, P.M., 2021. High throughput sequencing of microRNA in rainbow trout plasma, mucus, and surrounding water following acute stress. *Frontiers in Physiology*, 11, 588313.

Jeffres, C.A., Holmes, E.J., Sommer, T.R., and Katz, J.V., 2020. Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. *PloS One*, 15(9), e0216019.

Jerde, C.L., Mahon, A.R., Chadderton, W.L., and Lodge, D.M., 2011. “Sight-unseen” detection of rare aquatic species using environmental DNA. *Conservation Letters*, 4(2), 150-157.

Kahma, T.I., Norkko, A., and Rodil, I.F., 2023. Macrofauna Community Dynamics and Food Webs in the Canopy-forming Macroalgae and the Associated Detrital Subsidies. *Estuaries and Coasts*, 46(5), 1345-1362.

Kimmerer, W., Burau, J.R., and Bennett, W., 2002. Persistence of tidally oriented vertical migration by zooplankton in a temperate estuary. *Estuaries,* 25, 359–371.

Kimmerer, W.J., Gross, E.S., and MacWilliams, M.L., 2014. Tidal migration and retention of estuarine zooplankton investigated using a particle-tracking model. *Limnology and Oceanography,* 59, 901–916.

Kimmerer, W.J., Gross, E.S., Slaughter, A.M., and Durand, J.R., 2019. Spatial subsidies and mortality of an estuarine copepod revealed using a box model. *Estuaries and Coasts,* 42, 218–236.

Kline, M.D. and Laidley, C.W., 2015. Development of intensive copepod culture technology for Parvocalanus crassirostris: Optimizing adult density. *Aquaculture*, 435, 128-136.

Larsen, T., Ventura, M., Andersen, N., O'Brien, D.M., Piatkowski, U., and McCarthy, M.D., 2013. Tracing carbon sources through aquatic and terrestrial food webs using amino acid stable isotope fingerprinting. *PloS One*, 8(9), e73441.

Lehman, P., 2022. The increase of cyanobacteria and benthic diatoms over 43 years in upper San Francisco Estuary, California. *Estuarine, Coastal and Shelf Science*, 275, 107988.

Lindenmayer, D., Woinarski, J., Legge, S., Southwell, D., Lavery, T., Robinson, N., Scheele, B. and Wintle, B., 2020. A checklist of attributes for effective monitoring of threatened species and threatened ecosystems. *Journal of Environmental Management*, 262, 110312.

Lindenmayer, D.B. and Likens, G.E., 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology & Evolution*, 24(9), 482-486.

Lindenmayer, D.B., Likens, G.E., Haywood, A., and Miezis, L., 2011. Adaptive monitoring in the real world: proof of concept. *Trends in Ecology & Evolution*, 26(12), 641-646.

Lynch, A.J., Thompson, L.M., Morton, J.M., Beever, E.A., Clifford, M., Limpinsel, D., Magill, R.T., Magness, D.R., Melvin, T.A., Newman, R.A., Porath, M.T., Rahel, F.J., Reynolds, J.H., Schuurman, G.W., Sethi, S.A., and Wilkening, J.L., 2022. RAD Adaptive Management for Transforming Ecosystems. *BioScience,* 72, 45–56. https://doi.org/10.1093/biosci/biab091

McCarthy, A., Rajabi, H., McClenaghan, B., Fahner, N.A., Porter, E., Singer, G.A., and Hajibabaei, M., 2023. Comparative analysis of fish environmental DNA reveals higher sensitivity achieved through targeted sequence-based metabarcoding. *Molecular Ecology Resources*, 23(3), 581-591.

Mac Nally, R., Thomson, J.R., Kimmerer, W.J., Feyrer, F., Newman, K.B., Sih, A., Bennett, W.A., Brown, L., Fleishman, E., and Culberson, S.D., 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). *Ecological Applications,* 20, 1417–1430.

Nagarajan, R.P., Sanders, L., Kolm, N., Perez, A., Senegal, T., Mahardja, B., Baerwald, M.R., and Schreier, A.D., 2024. CRISPR-based environmental DNA detection for a rare endangered estuarine species. *Environmental DNA*, 6(1), e506.

Nester, G.M., Heydenrych, M.J., Berry, T.E., Richards, Z., Wasserman, J., White, N.E., De Brauwer, M., Bunce, M., Takahashi, M., and Claassens, L., 2023. Characterizing the distribution of the critically endangered estuarine pipefish

(*Syngnathus watermeyeri*) across its range using environmental DNA. *Environmental DNA*, 5(1), 132-145.

Piggott, M.P., Banks, S.C., Broadhurst, B.T., Fulton, C.J., and Lintermans, M., 2021. Comparison of traditional and environmental DNA survey methods for detecting rare and abundant freshwater fish. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31(1), 173-184.

Pochon, X., Laroche, O., von Ammon, U., and Zaiko, A., 2024. Filter no more: A modified plankton sampler for rapid in-water eDNA capture. *Methods in Ecology and Evolution*, 15(1), 60-68.

Polansky, L., Mitchell, L., and Nobriga, M.L., 2024. Identifying minimum freshwater habitat conditions for an endangered fish using life cycle analysis. *Conservation Science and Practice*, e13124.

Riekenberg, P.M., van der Heide, T., Holthuijsen, S.J., van der Veer, H.W., and van der Meer, M.T., 2022. Compound-specific stable isotope analysis of amino acid nitrogen reveals detrital support of microphytobenthos in the Dutch Wadden Sea benthic food web. *Frontiers in Ecology and Evolution*, 10, 951047.

Robinson, N.M., Scheele, B.C., Legge, S., Southwell, D.M., Carter, O., Lintermans, M., Radford, J.Q., Skroblin, A., Dickman, C.R., Koleck, J., and Wayne, A.F., 2018. How to ensure threatened species monitoring leads to threatened species conservation. *Ecological Management & Restoration*, 19(3), 222-229.

Rogers, T.L., Bashevkin, S.M., Burdi, C.E., Colombano, D.D., Dudley, P.N., Mahardja, B., Mitchell, L., Perry, S., and Saffarinia, P., 2024. Evaluating top-down, bottom-up, and environmental drivers of pelagic food web dynamics along an estuarine gradient. *Ecology*, 105(4), e4274.

Rojahn, J., Gleeson, D.M., Furlan, E., Haeusler, T., and Bylemans, J., 2021. Improving the detection of rare native fish species in environmental DNA metabarcoding surveys. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31(4), 990-997.

Ross, K., 2024. Continuous Zooplankton Observation, Detection, and Enumeration. Oral Presentation at the Interagency Ecological Program 2024 Annual Workshop. Apr 23, 2024. https://www.youtube.com/@CaliforniaDFW/search

Skelton, J., Cauvin, A., and Hunter, M.E., 2023. Environmental DNA metabarcoding read numbers and their variability predict species abundance, but weakly in non-dominant species. *Environmental DNA*, 5(5), 1092-1104.

Sobczak, W.V., Cloern, J.E., Jassby, A.D., and Muller-Solger, A.B., 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. *Proceedings of the National Academy of Sciences,* 99(12), 8101–8105. DOI: 10.1073/pnas.122614399.

Sommer, T., Armor, C., Baxter, R., Breuer, R., Brown, L., Chotkowski, M., Culberson, S., Feyrer, F., Gingras, M., and Herbold, B., 2007. The collapse of pelagic fishes in the upper San Francisco Estuary: *Fisheries,* 32, 270–277.

Southwell, D.M., Einoder, L.D., Lahoz-Monfort, J.J., Fisher, A., Gillespie, G.R., and Wintle, B.A., 2019. Spatially explicit power analysis for detecting occupancy trends for multiple species. *Ecological Applications*, 29(6), e01950.

Thomsen, P.F., Kielgast, J.O.S., Iversen, L.L., Wiuf, C., Rasmussen, M., Gilbert, M.T.P., Orlando, L., and Willerslev, E., 2012. Monitoring endangered freshwater biodiversity using environmental DNA. *Molecular Ecology*, 21(11), 2565-2573.

Twardochleb, L., Maguire, A., Dixit, L., Bedwell, M., Orlando, J., MacWilliams, M., Bever, A., and Davis, B., 2021. North Delta Food Subsidies Study: Monitoring Food Web Responses to the North Delta Flow Action, 2019 Report. Department of Water Resources, Division of Environmental Services. *In* DWR 2023. Workplan for operations and monitoring of the North Delta Food Subsidies Action. California Department of Water Resources, Division of Integrated Science and Engineering. April 26 revision.

Wallace, A.A., Ellis, G.S., and Peebles, E.B., 2023. Reconstructions of individual fish trophic geographies using isotopic analysis of eye-lens amino acids. *Plos one*, 18(3), e0282669.

Williams, J.W., 2022. RAD: A paradigm, shifting. *BioScience*, 72(1), 13-15. https://doi.org/10.1093/biosci/biab123

Woo, I., Davis, M.J., Ellings, C.S., Hodgson, S., Takekawa, J.Y., Nakai, G., and De La Cruz, S.E.W., 2019. A mosaic of estuarine habitat types with prey resources from multiple environmental strata supports a diversified foraging portfolio for juvenile Chinook salmon. *Estuaries and Coasts*, 42, 1938–1954. https://doi.org/10.1007/s12237-019-00613-2.

Woo, I., Davis, M.J., De La Cruz, S.E.W., Windham-Myers, L., Drexler, J.Z., Byrd, K.B., Stuart-Haentjens, E.J., Anderson, F., Bergamaschi, B.A., Nakai, G., Ellings, C.S., and Hodgson, S., 2021. Carbon flux, storage, and wildlife co-benefits in a restoring estuary: case study at the Nisqually River Delta, Washington, USA. *Chapter 5 in* Krauss, Zhu, and Stagg (Eds) Wetland Carbon and Environmental Management. Wiley Publishers. https://doi.org/10.1002/9781119639305.ch5.

Yang, J., Zhang, L., Mu, Y., and Zhang, X., 2023. Small changes make big progress: A more efficient eDNA monitoring method for freshwater fish. *Environmental DNA*, 5(2), 363-374.

Yates, M.C., Furlan, E., Thalinger, B., Yamanaka, H., and Bernatchez, L., 2023. Beyond species detection—leveraging environmental DNA and environmental RNA to push beyond presence/absence applications. *Environmental DNA*, 5(5), 829-835.

Young, M., Howe, E., O'Rear, T., Berridge, K., and Moyle, P., 2021. Food web fuel differs across habitats and seasons of a tidal freshwater estuary. *Estuaries and Coasts*, 44, 286-301.

Yun, H.Y., Larsen, T., Choi, B., Won, E.J., and Shin, K.H., 2022. Amino acid nitrogen and carbon isotope data: Potential and implications for ecological studies. *Ecology and Evolution*, 12(6), e8929.

Zhang, Y., Ye, F., Stanev, E.V., and Grashorn, S., 2016. Seamless cross-scale modeling with SCHISM. *Ocean Modelling,* 21, 71-76.

June 2024

Review of SFHA Monitoring and Science Plan

A report to the Delta Science Program

Prepared by

Dr. Lars G Rudstam,

Rudstam Consultants LLC.

Delta Science Program

DELTA STEWARDSHIP COUNCIL

Table of Contents

Executive Summary

The Summer-Fall Habitat Action (SFHA) plan is designed to improve habitat and growth of the endangered Delta Smelt. The plan guides the science and monitoring needed to support a structured decision making process for future operations of the Suisun Marsh Salinity Control Gate (SMSCG) action and the North Delta Food Subsidy (NDFS) action, as well as provides background for a Sacramento Deep Water Ship Channel (SDWSC) study and a wetland production study. This document is a review of the SFHA Science and Monitoring Plan and its components by Senior Scientist Dr. Lars G. Rudstam, owner of Rudstam Consultants LLC and also a Professor in Fisheries and Aquatic Sciences at Cornell University, the Director of the Cornell Biological Field Station, and between 2012 and 2022 the Principal Investigator of a large biological monitoring program in all five of the Laurentian Great Lakes (currently co-PI).

The SFHA plan uses existing monitoring programs in the Sacramento-San Joaquin Delta (hereafter the Delta) conducted by several agencies and institutions. These existing monitoring programs provide a comprehensive view of the Delta food web and allow for comparisons with historic conditions, a clear strength of the program. Additional monitoring is planned for the time period when the SMSCG and the NDFS actions are operating, which should increase learning about the effect of these two actions. The listing of explicit hypotheses for effects of the management actions is particularly helpful to increase learning. Suggestions for consideration by the Delta Coordination Group (DCG) and the ITP Adaptive Management Team (AMT) related to the monitoring and science questions asked to be addressed are summarized below with more details given in the reviews of the program element (SMSCG, NDFS, SDWSC, Wetland study), in a section on simplified use of the bioenergetics models, and as "Final Thoughts".

Both the SMSCG and NDFS action plans are well conceived and should, with time, yield information to evaluate if the SFHA benefits Delta Smelt with no major gaps (Charge question 6). Potential adjustments and additions (Charge questions 7 and 8) include (1) more low-cost temperature/salinity sensors for better spatial coverage to evaluate SMSGC operations and models used for predictions of SMSCG actions, (2) a Fluoroprobe that provides direct measurements of major phytoplankton groups, (3) measurements of the toxin (microcystin) directly, (4) add *in situ* light measurements to ^{13}C incubation experiments, (5) simplifying zooplankton counting some, but adding length measurements, (6) decrease zooplankton tow length to avoid net clogging, and (7) add night sampling of

zooplankton to assess biases associated with zooplankton migrations. These suggested modifications to the proposed sampling plans are minor. The main difficulty for the program to answer the hypotheses on resulting Delta Smelt growth response (Charge question 10) is the limited number of Delta Smelt in the area. This precludes direct evaluation of Delta Smelt responses, especially as comparisons between modified and control habitats cannot rely on historic data due to year-to-year variability in growth responses. Adding enclosures with fish in both modified and control habitats is the best proposed solution. Stable isotope (SI) analysis is less likely to yield useful results and a pilot study should be done to evaluate if the differences in SI signatures in zooplankton are sufficient to be a useful indicator of Delta Smelt resource use. This analysis also needs to consider tissue turnover in the fish.

As for data evaluation (Charge question 9), merging zooplankton data from different programs into one database would simplify analyses and explicitly consider differences in methodologies (as done for fish data). Expectations of the effects of the actions and the ability of the program to detect changes in zooplankton and fish growth should be explored by power analyses and the results better explained in the plan. Ideally, the sampling design should be able to detect changes in zooplankton that would result in a "meaningful" increase in Delta Smelt growth rates, perhaps 2-3 mm between measurements. An estimate of what zooplankton increase is needed for such a response can be obtained using the existing bioenergetics model (example provided in the Bioenergetics section below). Explicitly consider temperature and zooplankton community changes associated with the actions when evaluating the growth response of Delta Smelt as both factors may be as important as total zooplankton biomass in regulating Delta Smelt growth rates.

The SDWSC study and the Wetland study would benefit from pilot studies of the methods before full implementation (Charge question 6). Although the fish sampling method proposed in the SDWSC study has been tested, the SDWSC project should also demonstrate the zooplankton counting technique planned and add zooplankton net tows in addition to environmental DNA (eDNA) to validate both the video analyses and the eDNA method for zooplankton. Also, consider adding additional sensors like the Fluoroprobe to the data collection stream on the boat. The Wetland study should evaluate the replicability of the zooplankton production and mesocosm experiments and calculate the number of experiments needed to detect some assumed differences of interest between wetland types before a larger-scale project is initiated.

Other suggestions for the DCG and AMT to consider are to add bivalves to the sampling and analyses as this group is likely, at least partly, the cause of the decline in pelagic organisms that the actions are trying to reverse. It is also important to evaluate the potential for successful restoration of Delta Smelt in a longer-term perspective given climate change, especially as the available information suggests the species is sensitive to high temperatures. Consider funding experiments to evaluate both temperature and turbidity effects on Delta Smelt feeding and growth rates.

Overall, this is a well-designed program with appropriately stated hypotheses, especially for the SMSCG and NDFS actions (Charge question 10). But without a detailed power analysis, it is difficult to evaluate what magnitude of change resulting from the SFHA can be detected and therefore how well the given hypotheses can be addressed with the current monitoring program. Information on variability in the sampled metrics obtained by the monitoring program will improve this power analysis over time, which will be useful for future evaluations of the program. The design of the SDWSC and Wetland study would improve with results from pilot studies of the techniques.

Introduction

Brief Background

The Delta Smelt (*Hypomesus transpacificus*) is a small, short-lived planktivore endemic to the Sacramento-San Joaquin Delta (hereafter the Delta). Its main prey are zooplankton, in particular calanoid copepods. The habitat for Delta Smelt was much reduced due to the conversion of vast wetlands to agriculture in the 1800s and the availability of low-salinity habitat preferred by Delta Smelt is likely limiting the population size. Further declines occurred in the mid-2000s associated with the Pelagic Organisms Decline (POD, Mac Nally et al. 2010). This decline included the native Delta Smelt and Longfin Smelt (*Spirinchus thaleichthys*), and the non-native Striped Bass (*Morone saxatilis*) and Threadfin Shad (*Dorosoma petenense*). The POD event also included a decrease in several open-water zooplankton species, and reduced prey availability likely contributed to the decline in the planktivorous fish and the predators that feed on them. Currently, Delta Smelt are difficult to find and most of the Delta Smelt caught are from supplemental stocking. The species is now classified as endangered by the State of California and as threatened by the Federal Government.

The concern about Delta Smelt has led to several management actions, one of which is the Summer-Fall Habitat Action (SFHA). Because declines in both habitat and zooplankton may be limiting Delta Smelt, the SFHA Monitoring and Science Plan was designed to increase both zooplankton production and the availability of low-salinity habitat preferred by Delta Smelt, thereby hopefully increasing growth and survival of this endangered fish species.

Review Methods

This review uses the information provided by the California Department of Water Resources (DWR), information in reports and scientific publications, and the author's experiences with monitoring programs, food web interactions, and bioenergetics modeling. The available literature on the Delta and the Delta Smelt is large and several comprehensive reviews on the complex management issues associated with managing Delta Smelt provided background information (e.g. Luoma et al. 2015, Moyle et al. 2018, Sommer 2020). The FLOAT-MAST white paper (FLOAT-MAST 2022) was particularly useful as this report summarizes information on the Delta and the Delta Smelt in topic chapters written by specialists. Clearly, scientists and managers in the Delta region have spent considerable time thinking and analyzing this problem and continue to do so.

After getting some background on the management issues, I reviewed the material on the Delta Smelt Summer-Fall Habitat Action (SFHA) Monitoring and Science Plan in detail. This document includes appendices describing the Suisun Marsh Salinity Control Gate (SMSCG) action and the North Delta Food Subsidy (NDFS) action, as well as background for a Sacramento Deep Water Ship Channel (SDWSC) study and a wetland production study. I address each of these four programs separately. As my expertise is in food webs and fisheries, this letter review specifically addresses the science and monitoring program for the SFHA including the monitoring program's potential for providing needed information to evaluate the hypothesized effects of proposed management action.

This letter review is one of four that independently provided a review of the SFHA program and concluded in the Spring of 2024. I have discussed the topics with the other panel member with expertise on food webs (Isa Woo) several times, but we have not coordinated our letter reviews. The approach used to convey information for a structured decision making process is addressed by the other two members of the review panel.

Suisun Marsh Salinity Control Gates (SMSCG) Action

The operation of the SMSCG is intended to provide more low-salinity habitat — the preferred habitat of Delta Smelt — in the Suisun Marsh area, an area believed to be an important nursery habitat for juvenile Delta Smelt. The SMSCG action is to be implemented in below normal and above normal water years. The action involves opening gates during ebb tides and closing gates during flood tides, thereby minimizing the amount of higher salinity water entering the Suisun Marsh (hereafter the Marsh) and freshening the Marsh. Additionally, 100 TAF (thousand acre feet) of water can be used to further increase the low-salinity habitat. The operation of the gates was tested in August and September of 2018 and found to successfully decrease the salinity in the Suisun Marsh, thereby providing additional habitat for Delta Smelt.

This action is intended to continue for the next ten years and undergo a detailed evaluation of the action after four years. This evaluation will be critical, as most information on the operation appears to be from the 2018 pilot study. One year of successful implementation is not sufficient as each water year is different, both in the amount of water and in the seasonal timing of water inflow. Thus, there is not yet enough data to conclude that this action will work. The SFHA plan should be able to provide the needed information over time.

I particularly appreciate the approach taken to evaluate the monitoring data against *a priori* predictions of responses to the SMSCG action. These predictions are listed in Tables 1 and 2 of the 2023 plan (Appendix B). Evaluation of the predictions will use four approaches. Three are based on comparisons of monitoring data: (1) before-during-after the SMSCG action, (2) comparisons of three areas (Suisun Marsh, Grizzly Bay, and the Sacramento River at the confluence to Rio Vista), and (3) comparisons to historical records. The fourth approach is comparisons of model prediction with and without the SMSCG action. The limitations of each approach are clearly stated in the work plan and are not repeated here. These limitations necessitate a weight-of-evidence approach as there is not enough replication possible in this complex system for a standard statistical evaluation. Consistency across approaches will improve confidence in the interpretation of the effect of the SMSCG action. In addition to the goal of evaluating management actions, learning is identified explicitly as an important goal of the SFHA plan which I appreciate.

It is encouraging that the Delta Smelt habitat (lower salinity zone) did increase with SMSCG operations in 2018. Higher phytoplankton biomass and production are predicted in the Marsh with SMSCG action, and this was observed in 2018. An increase in phytoplankton is predicted to cause higher zooplankton production. However, it is not clear that zooplankton biomass in that habitat will increase from the SMSCG action as the results on zooplankton from 2018 were inconclusive. But even without higher zooplankton abundance, Delta Smelt growth rates may be better in the Marsh due to higher turbidity. The fish can spend more time foraging in turbid environments because of lower predation risk (Pangle et al. 2012, Manning et al. 2014), although feeding rates could decrease at very high turbidity (Wellington et al. 2010). Experiments on Delta Smelt support improved survival in turbid environments (Ferrari et al. 2013) although the difference found by Ferrari et al. was not large. Additional experiments on the effects of turbidity on Delta Smelt feeding and survival would be useful.

The plan proposes to continue monitoring during years with no action to provide more baseline data. This is important for water years when the action could have been implemented to improve available baseline data. However, monitoring during water years when no action is planned, such as wet years when the salinity is expected to be low anyway or dry years when salinity is expected to be high in the Marsh, but additional water is not available, are not that useful for evaluating the effect of the SMSCG action. If program reductions are needed, consider decreasing monitoring efforts during those no-action years.

Monitoring abiotic factors - SMSCG

The low salinity habitat preferred by Delta Smelt is predicted to increase as a result of the SMSCG action based on model analysis with and without the SMSCG action. I note that predictions of the magnitude of this increase as well as its timing depend on the model used. Therefore, further evaluations comparing the different models against field observations will be useful. This requires continuously recording sensors for salinity (and temperature) in the Marsh. This is indeed planned, and the information gained should be sufficient to evaluate the changes in the abiotic factors associated with SMSCG operations. But additional continuous recorders are better. One option is to add low-cost sensors. For the Oneida Lake monitoring program, we use low-cost temperature logging units ("HOBO" data loggers, Onset Corporation, approximate cost of $175) to continuously measure temperature at depth. They are deployed in May and retrieved in November without any servicing during the deployment period. This has worked well for 20+ years. A network of 20 such low-cost sensors that measure both temperature and salinity could be deployed in the Marsh in July and retrieved in November for a more complete picture of the freshening of the Marsh and the predictions of the models. As they are inexpensive, a few lost sensors are not a big problem except for the loss of data.

It is also important to consider temperature, even though the prediction is that temperature will not be affected by the operations. I do expect that the temperature in the shallower waters will increase with climate change, especially in dry years. Water temperatures are already higher in the Marsh than in the Sacramento River (hereafter the River). Temperature is a concern because of the expected high sensitivity of Delta Smelt to increases in temperature above 23^{o}C (at least according to the bioenergetics model by Rose et al. 2013a). Temperatures in July are close to 23^{o}C, and any further increase could negatively affect Delta Smelt. A network of low-cost sensors would help reveal if colder water refugia are available in the Marsh.

The proposed use of multiparameter sondes is a good approach. This could be complemented with a Fluoroprobe during standard sampling. We have had good success separating diatoms and cyanophytes with the bbe Fluoroprobe (Kring et al. 2014) in Oneida Lake, a lake with a relatively high abundance of phytoplankton. Standard in situ fluorometers suffer from quenching issues during the day (e.g. Scofield et al. 2020) and if used, it may be better to limit the data analyzed to nighttime recordings. The proposed collection of discrete water samples when servicing the in-situ sondes complements the continuous data.

Overall, the planned sampling for abiotic factors is comprehensive and should provide needed information to evaluate the action, but adding more low-cost sensors would allow for better calibrations of the hydrodynamics models as well as a better evaluation of the available temperatures in the Marsh. This is a complex, interconnected flow system and the more sampling locations, the better the model calibration. A Fluoroprobe would allow immediate assessment of the main phytoplankton of concern, the cyanophytes, on the same day the samples are taken.

Monitoring phytoplankton and zooplankton - SMSCG

Predicted effects of SMSCG operations on phytoplankton are primarily based on the difference in salinity tolerance of different species. Lower salinity may increase cyanophytes like *Microcystis* with possible increases in the toxin microcystin. *Microcystis* will be classified into several discrete classes, from no colonies to complete coverage on a Petri dish. This is fine, but if microcystin is of concern, why not measure microcystin directly? This is not overly expensive (e.g. Perri et al. 2015). Not all *Microcystis* populations produce microcystin.

Fresher conditions in the Marsh should lead to more freshwater calanoid copepods, the main prey of Delta Smelt. However, this was not observed in 2018 and the results for zooplankton were inconclusive. This suggests that any change in zooplankton may be small and therefore difficult to detect due to the variability among sites. Typical variability in zooplankton tows at different stations in the same water body often have coefficients of variation (CVs) (standard deviation (SD)/mean) of 30% to 50% (Evans and Sell 1983). As an example, we collected 10 whole water column tows for zooplankton with a similar net to the one used in the Delta in a New York lake last year (Keuka Lake, Rudstam, unpubl. data). The calanoid zooplankton biomass averaged 21 mg/m^3 dry weight with a SD of 7 yielding a CV of 33%. This variability was too high to detect a 20% increase using a standard statistical test (would need a minimum of 30% change). I recommend adding more details on a power analysis to the report to evaluate what change can be detected with the planned monitoring effort. A power analysis has apparently been done but was not clearly reported in the text.

Zooplankton and phytoplankton sites are sampled by five surveys (Environmental Monitoring Program, 20mm Survey, Summer Townet, Fall Mid-water Trawl, Fish Restoration Project). Sampling methods vary, and although densities can be calculated with the sampling used by each survey, a standard sampling method for all programs would be an improvement. Monthly sampling is probably a minimum in this dynamic system, and I am pleased the frequency of sampling has been increased to every two weeks during the SMSCG action – a common sampling interval in zooplankton monitoring programs. This will be accomplished by coordination between the groups involved. Another goal should be to merge the zooplankton datasets into one database if that has not yet been done. This is not a simple task, but it is an important one that should make analyses across sampling programs easier. The process of combining data from different sampling programs also forces the users to evaluate possible issues due to methodological differences between the five surveys.

Mesh sizes used for zooplankton sampling are 160 and 500 μm. The 500 μm sample is only useful for mysids and other macrozooplankton and there is no need to count the 500 μm sample for copepods. The method for zooplankton counting used is to count several 1 mL aliquots of the 160 μm samples. The method described calls for 6-10% of the whole sample to be counted. This may not be necessary. Counting a total of 400 animals from a sample is sufficient for understanding community composition and estimating densities. The U.S. Environmental Protection Agency (EPA) Great Lakes standard operating procedure calls for counting 400-800 individuals in each sample (U.S. EPA 2017).

For the evaluation of the SMSCG action, it will be important to separate the copepod species since Delta Smelt appear to prefer and grow better consuming some species than others. I suggest that zooplankton community composition be added to the planned analyses, it is not listed in the work plan. I also suggest that up to 20 individuals of each species per sample are measured to check calculations of biomass using standard equations (e.g. U.S. EPA 2017, Watkins et al. 2011, or equations developed specifically for the Delta species). Currently, a standard carbon content is applied to each zooplankton group.

Monitoring fish - SMSCG

The growth response of Delta Smelt is critical for evaluating the success of the action plan but was not evaluated during the 2018 SMSGC pilot study as only 7 Delta Smelt were captured in the Marsh and none elsewhere. As the management actions are primarily for the benefit of Delta Smelt, this is a serious problem. There is not enough Delta Smelt caught, nor can sampling be increased given the endangered status of this species, to evaluate their distribution, growth rates, and condition in different habitats. The solutions proposed in the plan are to use enclosures with hatchery fish, to use a surrogate species, or hope that supplemental stocking increases the population enough to allow a reasonable number of fish to be caught with the current sampling intensity. I suggest conducting a power analysis to evaluate how many fish need to be caught to detect a given growth difference between habitats. The distribution of Delta Smelt lengths at the end of the season must be available from earlier years of the monitoring program and can be used for this purpose. Note that year-to-year variation of age-0

Delta Smelt length in fall midwater trawls is substantial (55 to 65 mm, Rose et al. 2013a). Therefore, comparisons have to be made between locations collected in the same year, not between years. In Oneida Lake, the CV for age-0 yellow perch in October is relatively constant at 7 to 13% but year-to-year variation in average length is large. It has ranged from 67 to 93 mm over the last two decades related to density, zooplankton abundance, and temperature, factors that vary between years (Jordan et al. 2023).

The combined fish sampling effort involves several fishing methods. Gear has to change as fish grow, so I am not concerned about different fishing methods used for different age groups. I applaud the merging of the data from the different sampling programs into a comprehensive database but also caution that comparing different fishing gear is difficult given the different catchabilities of fish species to different gear and gear deployments. This is a problem for fisheries scientists and managers everywhere. One approach is to keep time series data of catches in different gear separate and put these time series on the same scale by calculating the proportion of the maximum catch in the time series (Gibson-Reinemer et al. 2017, see Brooking et al. 2022 for an example using Round Goby, *Neogobius melanostomus,* in Oneida Lake). Even so, evaluating if Delta Smelt is using the area during SMSCG operations may not be possible without more fish present in the system.

North Delta Food Subsidy (NDFS) Actions

The North Delta Food Subsidy project intends to augment zooplankton abundance and production in the North Delta by diverting some water to the Yolo Bypass and releasing that water with supposedly higher zooplankton abundance through the Toe Drain to the downstream regions. The amount of water in question is 15-35 TAF during 2 to 6 weeks in the summer. An increase in phytoplankton was observed after positive flows through the Yolo Bypass in 2011, 2012, and 2016, but not in 2018 or 2019. Sources of water were different as the 2018 and 2019 flow action was based on agricultural return flows whereas the 2016 flow action was based on a diversion of Sacramento River water. To further complicate the picture, additional flows in 2011, 2013, and 2015 were through non-managed agriculture activities and one of the three years (2011) resulted in increased phytoplankton, the other two did not. As pointed out in the work plan, each year is different, and it is important to understand why the years are different for evaluating the usefulness of the NDFS action.

The objectives for monitoring are to assess abiotic and biotic responses to flow pulses (managed or not) (1) in different regions, (2) before, during, and after flow pulses, (3) for different flow pulse types, and (4) for different water years. Embedded in these objectives is the hypothesis that managed flows through the Yolo Bypass will increase food availability for Delta Smelt in the North Delta. Several sub-hypotheses are listed in the work plan about which type of managed flow will produce the highest increase in food availability given the allocated water supply. The monitoring program is designed to test these hypotheses. Similar to the SMSCG project, this will be done using observations comparing across habitats, comparing before-during-after flow pulses, and comparing across years. In addition, a hydrodynamic model is used to evaluate effects with and without managed flows for each year. As with the SMSCG, predictions of responses are made a priori. A weight-of-evidence approach is necessary as only one flow regime can be evaluated each year with observations, and years can be very different from each other in the Delta. The layout of hypotheses and approaches in the work plan is done well.

The planned monitoring is appropriate with 6 upstream and 5 downstream sites. These sites are sampled from July to October to encompass before, during, and after managed flow actions. Continuous sensors are used when possible and other measurements are done every two weeks.

In addition to phytoplankton composition, primary production and nitrogen uptake rates will be measured six times at each of the ten sites. Primary production will be measured with ^{13}C isotopes. This should provide interesting data on whether or not primary production is indeed higher in the Yolo Bypass than the River, and by how much. Measurements of light levels during the in-situ incubations would be useful to separate differences in primary production associated with incident light (cloudy versus clear days) from differences associated with site and season, but I did not see if and how light levels will be measured in the review materials. It may be possible to use cheap continuously recording light meters (e.g. HOBOnet Solar Radiation Sensor, Onset Corporation) or use values from nearby airports.

Zooplankton will be sampled with 5-minute surface tows using a standard 0.5 m diameter net equipped with a flow meter every two weeks. These samples are fixed in formalin and transferred to Lugol for long-term storage. A 5-minute surface tow is proposed. This may be too long and lead to clogging of the mesh. With a tow speed of 0.5 m/s, the tow length is 150 m filtering 30 m^3 of water. This is a lot of water in a surface tow. Although I do not know the densities of particles in this system, I expect that a 2-minute tow (12 m^3) is sufficient. Therefore, I suggest evaluating shorter tows. Also, I am surprised by the transfer to Lugol solution. Is that due to a requirement to avoid formalin-preserved samples during processing? In our biomonitoring program in the Great Lakes, we preserve in formalin with Rose Bengal, and keep samples in that preservative for long-term storage. Recently, we went back to samples collected 25 years ago and found them well-preserved. As for zooplankton counting, 400 individuals counted per sample should be sufficient. In addition, I recommend measuring the first 20 individuals per species to allow for checks on biomass estimates (see discussion in the SMSCG section above).

All zooplankton samples are collected during the day and daytime tows may underestimate the zooplankton present due to diel vertical migration. This is true even when whole water column vertical tows are collected in lakes (Doubek et al. 2020). This can be tested using nighttime collections at these stations, perhaps once per month as suggested in the SDWSC study. Although this issue is recognized in the work plan, I did not see night sampling included.

Even with this massive effort of zooplankton sampling, it is likely going to be difficult to detect changes due to the variability between sites (see the SMSCG section). I understand that a power analysis was completed. That analysis is reported to indicate that the power of detecting a change is low, but details on the magnitude of change that can be detected are lacking. The sampling design should ideally have high enough power to detect a change in zooplankton that could produce a meaningful growth response in Delta Smelt (maybe 2-3 mm, see below section on bioenergetics).

Unfortunately, it is difficult to directly evaluate the effect on Delta Smelt growth rates. The suggestion in the plan is to use enclosures with Delta Smelt deployed for four to six weeks during and after flow pulses and to evaluate stable isotope (SI) signatures of various food web components including primary producers, zooplankton in enclosures, outside enclosures, and in the Yolo Bypass as well as fish in enclosures. The SIs of interest are nitrogen, phosphorus, and sulfur. My experiences with SIs in lakes indicate that these signatures vary among sites and among seasons, making inferences difficult. I do not expect SIs to be useful for this particular question unless the signature in zooplankton in the Yolo Bypass is quite different from the North Delta. This should be checked with a pilot study and preliminary analyses before relying on SIs in a larger project. In these analyses, it is also important to consider tissue turnover in the fish, especially since the Delta Smelt in the enclosure come from the hatchery and thus have a commercial feed SI signature. The analysis will therefore be based on changes in the SI signature which depend on growth rates and tissue turnover. We found that 50% of white muscle tissue turnover took about 1 month for small, relatively fast-growing fish (Round Goby, Poslednik et al. 2023), which is in line with other studies (e.g. McIntyre and Flecker 2006, Weidel et al. 2011) The evaluation of SI results would have to consider tissue turnover rates. Due to these issues, I do not expect the SI analysis will be helpful. Measurements of growth rate changes in the cages deployed in different areas are more likely to yield useful information.

Sacramento Deep Water Ship Channel (SDWSC) Food Study

This project is intended to provide data on the SDWSC in anticipation of future connections between the SDWSC and the Sacramento River (hereafter the River). Such connections could increase the amount of food available to Delta Smelt if prey density in the SDWSC is higher than in the River. Additional actions may include the addition of nutrients to the SDWSC to enhance phytoplankton and zooplankton biomass before exporting this biomass to the River. Potential issues include the transport of contaminants and toxic cyanophytes into the River.

The research questions listed in the work plan are exploratory and aimed at better understanding the fish, zooplankton, and phytoplankton distributions in the SDWSC. This includes studies on how zooplankton and phytoplankton vary seasonally along the channel, how they are affected by weather events, how they vary between littoral and pelagic areas, and whether the distribution of fish, zooplankton, and phytoplankton are correlated. This study would provide the information needed to evaluate the SDWSC as a source of pelagic prey for Delta Smelt. Interestingly, the SDWSC is an area where Delta Smelt are still present.

Evaluating the distribution of fish, zooplankton, and phytoplankton is planned to be conducted with a sampling platform that funnels fish through a live box to be video graphed. While sampling fish, water quality data and eDNA water samples will be collected. eDNA samples will be used to validate species videography. Sampling would occur biweekly from May to October during the day and once a month during the night along the whole SDWSC. The fish and zooplankton sampler consists of a 3 m^2 opening net with a funnel that moves fish and zooplankton by a video camera. The sampling is continuous and data from a Geographic Positioning System (GPS) unit is synched with the video to provide the exact location and time of each video frame. The net samples the top meter of water. Merz et al. (2021) published a description of the method and showed that fish could be successfully monitored along a transect. However, they did not discuss zooplankton.

I like this approach as continuous sampling allows for exploring details in distributions along the SDWSC and comparisons between littoral and pelagic habitats. I also appreciate the nighttime sampling proposed to account for diel movement towards the surface during the night and possible horizontal migration from the littoral zone. This could be important as vertical and horizontal migrations are known for both fish and zooplankton. However, I have two suggestions to consider for this particular study.

First, I did not find documentation that zooplankton can be evaluated with the proposed method. I expect that zooplankton need to be funneled through a smaller opening than fish, and that counting and identifying will be difficult. Species identification is not always possible for fish, making it questionable how well it will work for zooplankton, although group assignments may be possible (like copepods and cladocerans). Therefore, I recommend that net tows for zooplankton are added when eDNA samples are taken. If net tows are added, physical zooplankton samples will be available for identification and enumeration to complement the video analysis and compare with eDNA samples. Zooplankton shed less material into the water compared to fish and may be more difficult to identify at the species-level with eDNA. In the Great Lakes, we have had some success with metabarcoding of zooplankton, but only when using actual animals from a net sample.

Second, I expect that the algae groups present are of interest, in particular the amount of cyanophytes. Cyanophyte blooms that may be toxic should probably not be discharged into the River. Therefore, I recommend adding a Fluoroprobe or another sensor that can identify cyanophytes to the sensors used. Fluoroprobes are useful for separating cyanophytes from diatoms and the price of a Fluoroprobe is in the order of $35,000 (last I checked), a small addition given the cost of this project. It could also be useful to include a deep and a shallow water intake and two sets of sensors to separate surface blooms from phytoplankton at 1 m depth.

Wetland Production Study

This study proposes to investigate the drivers of phytoplankton and zooplankton production in managed wetlands with the goal of devising management actions that can increase this production. Questions listed in the description of this study are (1) what are the differences in plankton biomass and production between three types of wetlands (seasonally managed wetlands, perennially managed wetlands, tidally restored wetlands), (2) how do biomass and production vary seasonally in these wetland types, and (3) how does seasonal production align with the needs of different life stages of Delta Smelt. Predictions are that seasonally managed wetlands will have higher zooplankton biomass and production during the periods of inundation than perennial and tidal wetlands.

This study relies heavily on incubations in the laboratory for both phytoplankton productivity (24 hours using water from each wetland) and zooplankton (week-long growth experiments). Since the water used in experiments would come from each specific wetland, it is expected that production will reflect field conditions in these wetland types. Before implementing this study, I recommend conducting a pilot study investigating whether these incubations will produce useful information. The short-term phytoplankton productivity incubation with ^{13}C should work as this has been done before. I am more concerned with the week-long zooplankton incubation experiment as I expect variability between replicates will be high and may mask differences between wetland types. I did not see any information in the materials provided about how many replicates are planned. Results from a pilot study can be used to determine the precision of this experimental setup, and this data can then be used to evaluate the number of replicates needed to detect expected differences.

The mesocosm experiment will be even harder to control as sediment and wetland plants will be added. I assume here that sediments will be mixed thoroughly before addition to replicate mesocosms, but this also breaks down the sediment structure. Also, I saw no information on how and if bivalves and other benthic animals would be removed. Bivalves can have large effects on the outcome (e.g. Mei et al. 2016) and are likely important in the Delta.

I do think the proposed field sampling will provide interesting results and should be sufficient to measure differences in zooplankton biomass and production among wetland types even without the zooplankton incubation experiments. With some assumptions, copepod individual mass and temperature can be used to estimate production per unit biomass (see Shuter and Ing 1997, Stockwell and Johannsson 1997 for reviews and standard equations for inland lakes; similar equations may be available for estuaries). It would be interesting to compare such calculations with results from the pilot incubation experiments to check if incubation experiments are needed in the future.

Bioenergetics

Given the limited number of Delta Smelt caught in recent years, the growth response of Delta Smelt to an increase in zooplankton has to be evaluated with models. Using the bioenergetics model developed by Rose et al. (2013a), the Delta Smelt growth response to recent NDFS efforts was predicted to be ~0.5 mm, which is not detectable in the field nor biologically relevant. If this is the response that can be achieved, it is hard to argue that the NDFS action is worth doing. Therefore, it would be useful to estimate the required increase in zooplankton biomass necessary for a given Delta Smelt growth increase, perhaps 2-3 mm. This value can then be compared with what could be achieved with the NDFS action. The bioenergetics model can be used also for such calculations.

The bioenergetics model by Rose et al. (2013a) for Delta Smelt was based on an existing model for Rainbow Smelt (*Osmerus mordax*, Lantry and Stewart 1993). Rose et al. (2013a) adjusted the Rainbow Smelt parameters to give reasonable growth rates for Delta Smelt when the proportion of maximum daily consumption (known as "P-value") is between 0.7 and 0.8. The adjusted parameters are reported in Rose et al. (2013a, Table 1). Note that the respiration weight multiplier in their parameter table is in units of gO_2/day and has to be converted to J/day, which is done by multiplying the value in the table by an oxycaloric coefficient of 13540 J/gO_2 (Rose et al. did that but did not elaborate on it in the paper). The bioenergetics model is also described in the Delta Coordination Group SDM Process Document draft provided (Arend et al. 2022), but without the parameter values. I did my calculations on an excel spreadsheet set up for my class. The growth response can also be calculated using the R version of the Wisconsin bioenergetics model (Deslauriers et al. 2017) or the R program described in the Delta Smelt Growth info-sheet by Arend et al. (2022).

As an example, I estimated the effect of a 20% increase in calanoid copepod biomass on Delta Smelt growth using this model. Increasing zooplankton biomass leads to an increased consumption by Delta Smelt, calculated using a functional response. Rose et al. (2013a) used a multispecies functional response model that predicts the proportion of maximum consumption (P-value) based on the biomass of six zooplankton species (their Equation 10). However, Rose et al. (2013a) did not derive separate values for the different calanoid copepod species, so an equation based on the summed calanoid biomass will give similar results. The vulnerability term, V, in the Rose et al. (2013a) equation was set to 1 for juveniles feeding on any prey and can therefore be excluded when using the model for juveniles. A simplified equation relating the P-value to calanoid biomass then becomes:

(1) P-value = (PD/K)/(1+(PD/K))

where PD is prey biomass density (in mg Carbon/m^3) and K is the half-saturation constant (K=0.6 for juvenile Delta Smelt feeding on calanoid copepods according to Rose et al. 2013a, Supplement K). With Equation (1), a zooplankton biomass of 1.4 mgC/m^3 results in a P-value of 0.7. If prey biomass increased 20% to 1.7 mgC/m^3, this would increase the P-values to 0.74. It is now possible to calculate the potential increase in growth rate. I chose to run the bioenergetics model for 2 months at 20^{o}C and start the fish at 1 g. With these assumptions and the length-weight equation of Kimmerer et al. (2005), the length on day 60 would increase 1.9 mm following a 20% increase in zooplankton abundance (from 71.4 mm to 73.3 mm, Table 1). The effect depends on initial zooplankton abundance and ranges from a 0.8 mm to a 2.3 mm increase in length (Table 1). That can be compared to the range of lengths found in the midwater trawl surveys in different years (between 55 and 65 mm for the years 1995 to 2005, Rose et al. 2013a).

Table 1. Changes in Delta Smelt length and weight given a 20% increase in prey abundance at different initial prey biomass densities. The end weight and length are based on running the Delta Smelt model for 60 days at 20°C, starting at 1 g using the first of the two P-values given. The increase in end weight and length represents the increase associated with a 20% change in prey biomass density for each initial prey mass (and calculated with the second P-value given). To calculate end weight given the 20% increase, add end weight and increased weight columns. For example, for a zooplankton density of 5.4 mg C/m³*, the end weight with a 20% increase in zooplankton was 5.17 + 0.17 = 5.34 g and the end length was 81.4 + 0.8 = 82.2 mm.*

Initial Prey Mass (mg C/m³)	P-value initial/increased	End weight (g)	End length (mm)	Increased weight (g)	Increased length (mm)
5.4	0.9/0.91	5.17	81.4	0.17	0.76
2.4	0.8/0.83	4.17	76.4	0.26	1.39
1.4	0.7/0.74	3.32	71.4	0.30	1.89
0.9	0.6/0.64	2.60	66.4	0.29	2.09
0.6	0.5/0.55	2.00	61.5	0.26	2.25
0.4	0.4/0.44	1.50	56.5	0.21	2.21

This kind of "back of the envelope" calculation could be helpful as this simplified model can be easily run for any combination of increased zooplankton abundance and other factors (see below). If the possible increase in zooplankton biomass that can be achieved is known, the model gives the growth response and this growth response can then be evaluated for biological relevance using more complex population models such as the Rose et al. (2013a) individual-based model or the Maunder et al. (2011) stage-based model, both of which use the relationship between observed average age-0 length and the recruitment of Delta Smelt the following year. Conversely, if the possible increase in zooplankton biomass can be estimated, the model can be used to calculate the likely growth response of Delta Smelt. Whether even a 2 mm increase in length is sufficient to improve Delta Smelt survival given the multitude of factors that govern fish recruitment and the high variability in year class strength among years is questionable. However, Rose et al. (2013b) and Kimmerer and Rose (2018) found food levels to be one of the most important factors contributing to population growth rates in Delta Smelt. Their model contains the core bioenergetics model used here but also includes various assumptions on movement, habitat changes, and entrainment in pumping stations. The simpler approach used here is relevant to the evaluation of the growth response of Delta Smelt to increased zooplankton in one particular location (one spatial box in the Rose et al. 2013a model), which is the question at hand for the Summer-Fall habitat actions.

Another useful application of bioenergetics models is to relate the changes in growth rates associated with an increase in food availability to the changes associated with an increase in temperature. The Rose et al. (2013a) model has a very steep decline in consumption associated with increases in temperature over 23°C. A temperature increase from 23 to 25°C would decrease consumption rates by 90% and given the model, Delta Smelt would not be able to grow at 25°C even if zooplankton were highly abundant. And there is some indication that Delta Smelt food intake decrease already at 20°C (Arend et al. 2022). Therefore, the interaction between temperature and copepod availability will affect predictions of a growth response and increased temperatures may negate the positive effects of a management action that increases food availability. It is therefore important to evaluate if the SMSCG action increases water temperature in the Marsh.

Other changes to explore with a simple bioenergetics model are changes in the energy density of the prey. If the water action plan moves prey with lower energy density to the Delta Smelt preferred habitat, this may decrease growth rates. A decrease in average prey energy density of 10% would result in 4 to 5 mm shorter fish after 60 days compared to the baseline (Table 1, P-values of 0.7 and 0.8). Delta Smelt is known to grow less on a diet of cyclopoid copepods, and it is therefore important that the Summer-Fall habitat actions do not result in lower-quality prey. Such a change may offset any benefit from an increase in prey biomass. Thus, zooplankton community composition may be as important as zooplankton biomass.

Final Thoughts

A striking similarity between the situation in the Delta and lakes I have been studying for decades is the decline in pelagic production following the proliferation of invasive bivalves. In lakes, the introduction of the invasive bivalves (zebra mussels *Dreissena polymorpha,* and quagga mussels *Dreissena rostriformis bugensis)* caused declines in chlorophyll levels, increases in water clarity, and declines in zooplankton abundance (Higgins and Vander Zanden 2010, Mayer et al. 2014, Karatayev and Burlakova 2022). Changes in rivers after the dreissenid mussel invasion are similar to changes in lakes, although water clarity changes less due to sediment resuspension (e.g. Hudson River, Strayer et al. 2014). These changes may be reversible to some degree if mussel densities decline and/or the system adapts to the invaders. We did observe a recovery 10-15 years after zebra mussel invasions in a recent analysis of long-term data series from polymictic shallow lakes (Karatayev et al. 2023). But these lakes did not return to their pre-invasion state and were further perturbed by the subsequent arrival of the quagga mussels.

The changes in the Delta following the increase in non-native bivalves are similar and point to changes that are largely irreversible. The importance of bivalves as filter-feeders on phytoplankton has been pointed out by scientists working in the Delta. Kimmerer and Thompson (2014) found that grazing on phytoplankton by clams and microzooplankton exceeded replacement rates. Kimmerer and Lougee (2015) even found that bivalve predation on copepod nauplii is an important mortality source for pelagic copepods. Thus, I find it likely that the invasive bivalves are a major cause of the decline in zooplankton associated with the POD and therefore of the decline in Delta Smelt. It is possible, maybe even likely, that action plans geared towards improving zooplankton abundance by increasing phytoplankton in the Delta will end up mainly feeding non-native bivalves. Although the importance of bivalve filter-feeding was discussed in several places in the SFHA plan, I did not see any bivalve sampling or an attempt to quantify the effects of bivalves included in the work plan. If possible, that would be a good addition to the program.

The temperature effect was not discussed as much as I expected. Given likely increases in temperature with climate change, it is important to evaluate if Delta Smelt are as sensitive to high temperatures as suggested by the bioenergetics model. If temperatures increase to 24 - 25^{o}C in the Marsh area, this area will likely be avoided by Delta Smelt. If so, there is no reason to attempt to increase the habitat or food resources in those areas, at least for Delta Smelt. In upstate New York, summer lake temperature has increased by 0.5^{o}C per decade since 1975 (O'Reilly et al. 2015, Rudstam et al. 2016), and this trend continues. If similar increases occur in the Delta, Delta Smelt may not be able to subsist there in a few decades. I recommend that studies be funded to explore the effect of higher temperatures on this fish species using laboratory experiments with hatchery fish. Those experiments coupled with climate change scenarios for the Delta should be able to inform managers if attempts to increase food resources and habitats for Delta Smelt have a chance of being successful in the longer term. Perhaps the future of Delta Smelt is in reservoirs where colder water is available in the summer.

Having gone through a large amount of material on this topic this spring, I am impressed with the level of thought that has gone into the SFHA and the effort to save Delta Smelt. The large number of organizations involved, including state, federal, non-governmental, and academia, could have been problematic, but coordination seems to be working. Although I expect that many of my suggestions have already been considered by scientists and managers familiar with the Delta, I hope some of them are useful. This has been an interesting program to review, and I thank the Delta Stewardship Council for the opportunity.

Lars Rudstam
Senior Scientist
Rudstam Consultants LLC
1005 Lorena Parkway,
Madison WI 53713

References

Arend, K., Mahardja, B., Nobriga, M., Smith, W., 2022. PM InfoSheet - Delta Smelt Growth, Delta Coordination Group SDM Decision Process Document, 86-101.

Brooking, T.E., Rudstam, L.G., Jackson, J.R., VanDeValk, A.J., Holeck, K.T., Hotaling, C.W., Cooper, J.E., 2022. Effects of Round Goby on the benthic invertebrate community and on diets and growth of Yellow Perch and White Perch in Oneida Lake, New York. Trans. Am. Fish. Soc. 151, 641-654.

Deslauriers, D., Chipps, S.R., Breck, J.E., Rice, J.A., Madenjian, C.P., 2017. Fish Bioenergetics 4.0: An R-Based Modeling Application. Fisheries 42, 586-596.

Doubek, J.P., Goldfarb, S.K., Stockwell, J.D., 2020. Should we be sampling zooplankton at night? Limnol. Oceanogr. Letters. DOI: 10.1002/lol2.10151.

Evans, M.S., Sell, D.W., 1983. Zooplankton sampling strategies for environmental studies. Hydrobiologia 99:215-233.

Ferrari, M.C.O., Ranåker, L., Weinersmith, K.L., Young, M.J., Sih, A., Conrad, J.L., 2013. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environ. Biol. Fish. 97, 79-90.

FLOAT-MAST (Flow Alteration - Management Analysis and Synthesis Team), 2022. *White papers providing a synthesis of knowledge relating to Delta Smelt biology in the San Francisco Estuary, emphasizing effects of flow.* Interagency Ecological Program, Sacramento, CA. IEP Technical Report #98.

Gibson-Reinemer, D.K., Ickes, B.S., Chick, J.H., 2017. Development and assessment of a new method for combining catch per unit effort data from different fish sampling gears: multigear mean standardization (MGMS). Can. J. Fish. Aquat. Sci. 74, 8-14.

Higgins, S.N., Vander Zanden, M.J., 2010. What a difference a species makes: a meta-analysis of dreissenid mussel impacts on freshwater ecosystems. Ecol. Monogr. 80, 179-196.

Jordan, P.D.B., Figary, S.E., Brooking, T.E., Holeck, K.T., Hotaling, C.W., VanDeValk, A.J., Rudstam, L.G., 2023. The effects of *Bythotrephes longimanus* invasion on diets and growth of age-0 yellow perch in Oneida Lake, New York. Ecol. Freshw. Fish 32, 712-723.

Karatayev, A.Y., Burlakova, L.E., 2022. What we know and don't know about the invasive zebra (*Dreissena polymorpha*) and quagga (*Dreissena rostriformis bugensis*) mussels. Hydrobiologia, 1-74.

Karatayev, V.A., Rudstam, L.G., Karatayev, A.Y., Burlakova, L.E., Adamovich, B.V., Zhukava, H.A., Holeck, K.T., Hetherington, A.L., Jackson, J.R., Balogh, C., Serfőző, Z., Hotaling, C.W., Zhukova, T.V., Mikheyeva, T.M., Kovalevskaya, R.Z., Makarevich, O.A., Kruk, D.V., 2023. Time scales of ecosystem impacts and recovery under individual and serial invasions. Ecosystems 26, 1224-1237.

Kimmerer, W.J., Avent, S.R., Bollens, S.M., Feyrer, F., Grimaldo, L.F., Moyle, P.B., Nobriga, M., Visintainer, T., 2005. Variability in length-weight relationships used to estimate biomass of estuarine fish from survey data. Trans. Am. Fish. Soc. 134, 481-495.

Kimmerer, W.J., Lougee, L., 2015. Bivalve grazing causes substantial mortality to an estuarine copepod population. J. Exp. Mar. Biol. Ecol. 473, 53-63.

Kimmerer, W.J., Rose, K.A., 2018. Individual-based modeling of Delta Smelt population dynamics in the Upper San Francisco Estuary III. Effects of entrainment mortality and changes in prey. Trans. Am. Fish. Soc. 147, 223-243.

Kimmerer, W.J., Thompson, J.K., 2014. Phytoplankton growth balanced by clam and zooplankton grazing and net transport into the low-salinity zone of the San Francisco Estuary. Estuaries Coasts 37, 1202-1218.

Kring, S.A., Figary, S.E., Boyer, G.L., Watson, S.B., Twiss, M.R., 2014. Rapid in situ measures of phytoplankton communities using the bbe FluoroProbe: evaluation of spectral calibration, instrument intercompatibility, and performance range. Can. J. Fish. Aquat. Sci. 71, 1087-1095.

Lantry, B.F., Stewart, D.J., 1993. Ecological energetics of rainbow smelt in the Laurentian Great Lakes - An interlake comparison. Trans. Am. Fish. Soc. 122, 951-976.

Luoma, S.N., Dahm, C.N., Healey, M., Moore, J.N., 2015. Water and the Sacramento-San Joaquin Delta: Complex, chaotic, or simply cantankerous? San Francisco Estuary Watershed Sci. 13.

Mac Nally, R., Thomson, J.R., Kimmerer, W.J., Feyrer, F., Newman, K.B., Sih, A., Bennett, W.A., Brown, L., Fleishman, E., Culberson, S.D., 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecol. Appl. 20, 1417-1430.

Manning, N.F., Bossenbroek, J.M., Mayer, C.M., Bunnell, D.B., Tyson, J.T., Rudstam, L.G., Jackson, J.R., 2014. Modeling turbidity type and intensity effects on the growth and starvation mortality of age-0 yellow perch. Can. J. Fish. Aquat. Sci. 71, 1544-1553.

Maunder, M.N., Deriso, R.B., Waters, C., 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence:

illustrated with application to delta smelt (*Hyposmesus transpacificus*). Can. J. Fish. Aquat. Sci. 68, 1285-1306.

Mayer, C.M., Burlakova, L.E., Eklöv, P., Fitzgerald, D., Karatayev, A.Y., Ludsin, S.A., Millard, S., Mills, E.L., Ostapenya, A.P., Rudstam, L.G., Zhu, B., Zhukova, T.V., 2014. Benthification of freshwater lakes: exotic mussels turning ecosystems upside down. Chapter 36 *in* Nalepa, T.F., Schloesser, D.W. (Eds.), Quagga and zebra mussels: biology, impacts, and control, second edition. CRC Press, Boca Raton, FL, 575-585.

McIntyre, P.B., Flecker, A.S., 2006. Rapid turnover of tissue nitrogen of primary consumers in tropical freshwaters. Oecologia 148, 12-21.

Mei, X., Zhang, X., Kassam, S.S., Rudstam, L., 2016. Will the displacement of zebra mussels by quagga mussels increase water clarity in shallow lakes during summer? Results from a mesocosm experiment. PLoS ONE 11, e0168494.

Merz, J.E., Camp, M.J., Simonis, J.L., Thorpe, W., 2021. A new method for standardizing inland fish community surveys: Characterizing habitat associated with small-bodied fish species, abundance, and size distributions in a highly modified estuary. Frontiers in Environmental Science 9.

Moyle, P.B., Hobbs, J.A., Durand, J.R., 2018. Delta Smelt and water politics in California. Fisheries 43, 42-50.

O'Reilly, C.M., Sharma, S., Gray, D., and 61 coauthors, 2015. Rapid and highly variable warming of lake surface waters around the globe. Geophysical Research Letters 42, DOI: 10.1002/2015GL066235.

Pangle, K.L., Malinich, T.D., Bunnell, D.B., DeVries, D.R., Ludsin, S.A., 2012. Context-dependent planktivory: interacting effects of turbidity and predation risk on adaptive foraging. Ecosphere 3, 114.111.

Perri, K.A., Sullivan, J.M., Boyer, G.L., 2015. Harmful algal blooms in Sodus Bay, Lake Ontario: A comparison of nutrients, marina presence, and cyanobacterial toxins. J. Great Lakes Res. 41, 326-337.

Poslednik, A.M., Evans, T.M., Jackson, J.R., VanDeValk, A.J., Brooking, T.E., Rudstam, L.G., 2023. Round goby (*Neogobius melanostomus*) $\delta^{13}C/\delta^{15}N$ discrimination values and comparisons of diets from gut content and stable isotopes in Oneida Lake. PLoS ONE 18, e0284933.

Rose, K.A., Kimmerer, W.J., Edwards, K.P., Bennett, W.A., 2013a. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: I. Model description and baseline results. Trans. Am. Fish. Soc. 142, 1238-1259.

Rose, K.A., Kimmerer, W.J., Edwards, K.P., Bennett, W.A., 2013b. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: II. Alternative baselines and good versus bad years. Trans. Am. Fish. Soc. 142, 1260-1272.

Rudstam, L.G., Jackson, J.R., Hetherington, A.L., 2016. Concluding remarks: Forecasting the future of Oneida Lake and its fishery in an era of climate change and biological invasions, Chapter 24 *in* Rudstam, L.G., Mills, E.L., Jackson, J.R., D.J.Stewart (Eds.), Oneida Lake: Long-term dynamics of a managed ecosystem and its fishery. American Fisheries Society, Bethesda, NY, 525-540.

Scofield, A.E., Watkins, J.M., Osantowski, E., Rudstam, L.G., 2020. Deep chlorophyll maxima across a productivity gradient: A case study in the Laurentian Great Lakes. Limnol. Oceanogr. 64, 2460–2484.

Shuter, B.J., Ing, K.K., 1997. Factors affecting the production of zooplankton in lakes. Can. J. Fish. Aquat. Sci. 54, 359-377.

Sommer, T., 2020. How to respond? An introduction to current Bay–Delta natural resources management options. San Francisco Estuary and Watershed Science 18 (3) Article 1.

Stockwell, J.D., Johannsson, O.E., 1997. Temperature-dependent allometric models to estimate zooplankton production in temperate freshwater lakes. Can. J. Fish. Aquat. Sci. 54, 2350-2360.

Strayer, D.L., Cole, J.J., Findlay, S.E.G., Fischer, D.T., Gephart, J.A., Malcom, H.M., Pace, M.L., Rosi-Marshall, E.J., 2014. Decadal-scale change in a large-river ecosystem. BioScience 64, 496-510.

U.S. Environmental Protection Agency - Great Lakes National Program Office, 2017. Standard Operating Procedure for zooplankton analysis. LG403 rev 08.

Watkins, J.M., Rudstam, L.G., Holeck, K.T., 2011. Length-weight regressions for zooplankton biomass calculations – A review and a suggestion for standard equations. eCommons Cornell http://hdl.handle.net/1813/24566.

Weidel, B.C., Carpenter, S.R., Kitchell, J.F., Vander Zanden, M.J., 2011. Rates and components of carbon turnover in fish muscle: insights from bioenergetics models and a whole-lake 13C addition. Can. J. Fish. Aquat. Sci. 68, 387-399.

Wellington, C.G., Mayer, C.M., Bossenbroek, J.M., Stroh, N.A., 2010. Effects of turbidity and prey density on the foraging success of age 0 yellow perch *Perca flavescens*. J. Fish Biol. 76, 1729-1741.

June 2024

Independent Structured Decision Making Expert Peer Review of the Delta Smelt Summer-Fall Habitat Monitoring and Science Plan

A report to the Delta Science Program

Prepared by

Dr. Robin Gregory

Decision Science Center, Oregon Research Institute & Institute for Resources, Environment and Sustainability, University of British Columbia

Delta Science Program

DELTA STEWARDSHIP COUNCIL

Table of Contents

Executive Summary

This review examines the Structured Decision Making (SDM) aspects of the Delta Smelt Summer-Fall Habitat Action (SFHA) Monitoring and Science Plans, charged with improving habitat conditions to support growth, survival, and recruitment of the critically endangered Delta Smelt (*Hypomesus transpacificus*). My opinion is that the SDM work is generally done well and the results are communicated effectively. I do, however, have concerns about the ways in which the SDM approach was not used—based on the information I reviewed, potentially helpful SDM and other decision-aiding analyses were not conducted. This includes the following concerns:

- Ambiguities in the definition of objectives, which could impede the development of an adaptive management (AM) approach that will effectively reduce the probability of extinction risk for Delta Smelt.

- The lack of a clear explanation of the framing of the SDM problem, the first step in the PrOACT model —what's in and out of scope and why, who are the legitimate participants, and what is the timeframe for DCG decisions.

- The lack of discussion of a possible need for closer coordination with other federal or state fish and water agencies responsible for considerations that might impact the timing or volume of water available for Delta Smelt. This could lead to the inclusion of a new objective dealing with "enhancing inter-agency coordination."

- A lack of diversity with respect to the selection of DCG members, who appear to have been exclusively drawn from the ranks of resource management agencies—generally ones involved in Delta Smelt recovery efforts over several decades. This increases the possibility that what has been done in the past will continue into the future—the so-called "status quo" bias—and therefore may discourage insightful questions and the development of new alternatives beneficial to the recovery of Delta Smelt. Thus it may be helpful to more fully incorporate the opinions of other experts, drawn from academia and non-governmental organizations (NGOs), in addition to agencies directly involved in the management of Delta Smelt.

- There exists substantial variation in the assessments of experts regarding the identification of key factors underlying the endangered status of Delta Smelt. Many of the results of expert judgment elicitations are presented as averages, even though in cases of high variation among experts the use of averages may mask valuable information.

- Aside from a note regarding temperatures, I did not see evidence for the elicitation of thresholds (e.g., minimum or maximum levels or ranges) for key habitat factors or how feedback on information regarding the relative importance of habitat attributes would influence strategies or AM plans.

- At several points it would have been interesting to obtain explicit judgments of the experts' confidence in their assessments: were those who were willing to provide a response more confident in their knowledge or were they motivated by strategic biases or other considerations?

- I saw no discussion of how to incorporate insights from analyses of the Value of Information (VOI), which evaluates the expected utility of information derived from an AM initiative with respect to reducing key uncertainties affecting Delta Smelt growth and survival. Providing explicit judgments about the VOI gained from various actions could improve the quality of information available to resource managers.

- I am concerned that the current AM approach will not result in significant reductions in uncertainty, particularly in light of the current endangered status of the Delta Smelt population. It would appear that current efforts might more properly be considered as flexibility in the management of Delta Smelt on the basis of monitoring results and annual weather changes.

- An SDM process seeks to create insights for decision making by highlighting uncertainties (with respect to the consequences of actions), tradeoffs (with respect to the achievement of objectives), and priorities (in terms of what is most important to the decision at hand). The reports I reviewed describe modeling results and provide convincing documentation that reducing extinction risks to Delta Smelt is a complex task. However, they do not provide an effective window into the key uncertainties, tradeoffs, or priorities, nor do they sufficiently simplify the management complexities so as to provide resource managers clear insights with respect to decisions regarding key priorities or changes in the status of Delta Smelt recruitment (e.g, is the outlook for Delta Smelt becoming better or worse?).

In my opinion, improvements in the analysis or communication of these aspects of the SDM work could provide additional insights for decisions faced by the Delta

Coordination Group (DCG), thereby increasing the effectiveness, efficiency, and scope of its actions.

Introduction

This review, written by an independent expert in Structured Decision Making (SDM), is submitted in response to the Charge given to the four members of the Delta Smelt Summer-Fall Habitat Action (SFHA) Monitoring and Science Plans Peer Review Panel. The SFHA plan is designed to improve habitat conditions including the overlap of key physical and biological attributes to support growth, survival, and recruitment of the critically endangered Delta Smelt (*Hypomesus transpacificus*), listed in 1998 as threatened under state and federal Endangered Species Acts and redesignated as endangered by California in 2009.

As implemented by the DCG and detailed in the 2023 Action Plan, many of the SDM recommendations are focused on the North Delta Food Subsidy Action (NDFS) during summer and fall. This involves three types of possible actions: redirecting Sacramento River water during summer, redirecting return water down the Yolo Bypass in the fall, and combining these two actions to generate a longer duration increased water flow. No action is anticipated to take place if the Water Year (WY) designation is Dry but actions will occur if the year is Below Normal, Above Normal, or Wet. The May 2023 Addendum states that, with 2023 designated as a Wet year, water was released through daily operations of the Suisun Marsh Salinity Control Gates between mid-August and mid-October, presumably with the intent of extending the period of high Delta Smelt habitat suitability index area.

As one of the two panel members knowledgeable about SDM theory and practice, I focus my review on the five Charge questions and summarize several related findings and recommendations. My status as an independent expert reflects my experience leading and co-leading SDM efforts in both Canada and the United States involving technical experts as well as community resource users, elected officials, and competing resource interest groups. I have not previously worked with members of the DCG Steering Committee nor have I previously worked with members of the Facilitation Team (Lead Jennie Hoffman, support Sally Rudd). I have previously worked with and written papers with other members of Compass Resource Management, although with the exception of Philip Halteman (with whom I work on unrelated projects), I have had no association over the past 5 years.

Key Questions Asked of SDM Panel Members

1. How well do the PrOACT model and SDM approach, as implemented by the DCG, allow for evaluating qualitative versus quantitative information (e.g., expert opinions compared to numerical models) to support the decision?

This first question asks about the evaluation of qualitative (e.g., expert opinions) vs. quantitative (e.g., numerical models) information as part of the SDM. As implemented by the DCG, SDM approaches are based on a well-known decision-aiding model described in the book Smart Choices (Hammond, Keeney, & Raiffa, 1999), with theoretical roots in earlier work by numerous researchers including Ward Edwards, Ralph Keeney, Howard Raiffa, and Detlof von Winterfeldt (von Winterfeldt & Edwards, 1986; Keeney & Raiffa, 1993). The model outlines a 5-step approach to thinking through complex, multidimensional problems subject to uncertainty and, often, controversy. Of note is that these steps—through which knowledgeable participants, aided by a facilitator, identify the Problem, Objectives, Alternatives, Consequences, and Trade-offs—do not include explicit attention to either uncertainty (with respect to consequences of actions) or monitoring and learning, both of which are central to the success of the SFHA. Although, these topics are given specific coverage in other writings by these authors and in recent SDM articles, texts, and edited volumes (e.g., Gregory et al., 2012; Conroy & Peterson 2013).[1]

I do not find the qualitative/quantitative distinction to be particularly helpful in this context, for two reasons: both expert opinions and numerical models reflect the mix of qualitative and quantitative training, experience, and values of those involved (see Slovic, 1997), and—with respect to the Delta Smelt SFHA—the expert opinions typically deal with estimating uncertain quantities (based on expert-judgment elicitations) that generally are expressed using numbers. SDM approaches are typically applied in resource management contexts for which there is substantial uncertainty regarding the consequences of actions (Conroy et al., 2008). As a result, it is not uncommon for scientific experts to be asked to make numeric judgments about the influence of underlying factors or the consequences of actions that reflect their considered opinions and about which there may be controversy. Thus many of the results from both expert opinions and numeric

[1] Keeney, and VonWinterfeldt, in particular, have written extensively about applied approaches for dealing with uncertainty and Raiffa has written about monitoring and learning.

models are expressed in quantitative terms but reflect the underlying qualitative judgments and subjective assumptions of their creators.

I re-interpreted this first question as having two parts. Part 1 is whether SDM practices generally were appropriate and whether the numeric models and expert-judgment elicitations were completed to a high standard. Based on the information I have reviewed, omitting details of the modeling processes (which require fisheries and ecological expertise of other Panel members), my opinion is that the SDM work generally was done well and the results were communicated effectively. This overall positive evaluation underlies the specific comments contained in the remainder of this review letter, which focus on aspects of the SDM work that in my opinion could have been improved and thereby provided additional insights for the decisions faced by DCG members.[2]

The second part of this opening question is whether the expert opinions were elicited and integrated in such a way that they provide clear guidance for the SFHA. Here I do have some concerns. An initial focus of the qualitative (non-modeling) SDM work is the identification of objectives (see Table 1, 2023 SFHA Action Plan). The SDM process identified the ultimate goal of increasing Delta Smelt "recruitment" and six fundamental decision objectives: Delta Smelt growth and survival, food and habitat, contaminant effects, resource (management) costs, effects on other native species, and learning. Sub-objectives are also identified for each fundamental objective apart from resource costs. My concerns refer to (a) ambiguity (a lack of clarity) in the definition of the objectives, which could impede the development of an adaptive management (AM) approach that will effectively reduce the probability of extinction risk for Delta Smelt, and (b) the absence of several possibly important considerations.

With respect to ambiguity—and keeping in mind that I am not a fisheries expert—I understand that "smelt growth and survival" is considered a fundamental objective that contributes to the ultimate concern of smelt recruitment, but I did not see a clear explanation of the link between smelt recruitment and growth and survival. If recruitment implies a wild Delta Smelt population that successfully reproduces and sustains itself, then it seems important to (a) determine whether a self-sustaining

---

[2] I have had no interactions with the SDM facilitators. Thus the SDM facilitators may have thought about some of my suggestions and discarded them for good reasons, which as an external reviewer would not be known to me.

Delta Smelt population is even possible, and (b) develop methods for accurate collection of wild smelt (which at this time seems problematic) and perhaps (c) develop a timetable for decreasing the release of hatchery smelt in the near future–although it does not seem likely that, at any time in the near future, Delta Smelt will be able to avoid extinction without the release of captive-reared fish.

A related example of ambiguity is the effectiveness of learning and the stated need to “improve DCG members’ ability to evaluate risks and make tradeoffs in future years”—this is a very broad statement and hard to operationalize. I looked for but did not find a discussion of key tradeoffs (which relate in part to thresholds for habitat attributes) nor did I see a discussion of when it might be necessary to alter or pivot among summer-fall habitat actions because minimum or maximum levels for key habitat variables have been breached or because of trade-offs, imposed internally or externally, due to conflicts with other water users.

With respect to omitted considerations, the first thing I found missing is a clear explanation of the framing of the SDM problem, the first step in the PrOACT model—including what’s in and out of scope and why, who are the legitimate participants, and what is the timeframe for DCG decisions. The framing of the problem has critical implications for both modeling results and judgments (qualitative and quantitative) on the part of managers. This is because the decision frame effectively bounds the subsequent analyses and recommendations in much the same way that a photographer adjusts the lens of a camera to focus on a portion of a wider scene. Specifically, SDM work relating to actions (A), consequences (C), and tradeoffs (T) —the A, C, and T portions of the PrOACT model—rests on the foundation established by the first two steps: problem framing and the identification of objectives. If the frame is set too broadly, findings may lack precision and relevance; if set too narrowly, key considerations may be excluded.

I also wonder about the benefits of possibly including other objectives that could have an effect on Delta Smelt survival. One example is the listing of “effects to other species” and whether (a) this list is sufficiently comprehensive (are any species of concern not included?) and also (b) whether specific predators or other species—one or two out of the listed set—would be of most concern (and thus most significantly affect water release actions for Delta Smelt) and why. This raises questions (ones that as an external reviewer I cannot answer) about the possible need for closer coordination with other federal or state fish and water agencies responsible for other considerations that impact the timing or volume of water available for Delta Smelt. Therefore a new objective dealing with “enhancing inter-agency coordination,” concerned with non-NDFS actions taken for other species, might be important and assist in the success of the Delta Smelt recovery program (a similar point is made by Peter Moyle in his 2022 California WaterBlog (Moyle, 2022).

It also appears that some considerations identified as important to the achievement of the objectives may not have been modeled or examined in sufficient detail as part of the SFHA process. One example is contaminant effects on smelt growth and survival, a point that also was noted by several members of the DCG in the 2023 Action Plan. Although the SDM process clearly identifies portions of the areas used by Delta Smelt as being relatively higher or lower in contaminant exposure and makes the case this could be a factor influencing smelt survival (either directly or indirectly), it was not clear to me which contaminants are thought to have the most adverse effects on smelt at different life-cycle stages or whether actions can be undertaken to either (a) reduce these specific contaminant concentrations or (b) reduce the exposure of juvenile smelt to the contaminants.

Another concern – underlying the success of the entire Delta Smelt recovery effort – is the inability to locate wild smelt, which suggests that perhaps other factors beyond the four habitat-related considerations may be responsible. There is some discussion in the 2023 Action Plan of various possibilities—the role of predator species, the influence of pesticides and other sources of water contamination, water demands of other fish species as well as ongoing withdrawals for agriculture—and it's acknowledged that the influence of these additional factors is marked by high levels of uncertainty. As a result, it's not obvious that the fundamental objective of "recruitment" makes operational sense; one recent report (Water Education Foundation, 2023) stated that despite the release of something like 60,000 captive-reared smelt, the annual Fall Trawl Survey "has caught fewer and fewer Delta Smelt for two decades and since 2018 it has not caught a single one." If recruitment success is this difficult to measure, then perhaps a fundamental objective like "reduce extinction risk" would prove more amenable to tracking over time.

2. How well does the SDM approach, as implemented by the DCG, integrate participant values in a standardized and transparent way?

The recent work of the DCG has focused on a series of technical issues relating to actions, specifically in the key summer and fall months, that could be undertaken in support of improving the growth, survival, and recruitment of critically endangered Delta Smelt. Numerous considerations provide the context and framing of the SFHA analyses; these include federal and state regulations, issues related to obtaining water permits, the success of earlier programs to reduce the risk of Delta Smelt extinction, and resource (cost and timing) constraints.

Relevant to participant values and problem framing, DCG members appear to have been exclusively drawn from the ranks of resource management agencies—generally ones involved in Delta Smelt recovery efforts over several decades. This increases the possibility that what has been done in the past will continue into the future—the so-called “status quo” bias—and therefore may discourage insightful questions and the development of new alternatives beneficial to the recovery of Delta Smelt. DCG members also are likely to have built-in incentives to support current approaches because they share similar technical backgrounds and because they are likely to have a motivational bias in light of that responsibility—of their agencies or of themselves as individuals —for past initiatives of the Delta Smelt recovery program[3]. As part of Question 5, I suggest some techniques that might help to address this problem (and that, so far as I can tell, were not employed by the SDM facilitators).

On the subject of biases, judgments required of DCG panel members were undoubtedly subject to several other potential cognitive biases—a subject familiar to the SDM facilitators and noted in the January 2021 “SDM for Delta Smelt” Phase 2 Report (Compass Resource Management). However, I did not see a discussion of what was done to diminish the influence of biases (e.g., explicit training in recognizing biases, adoption of debiasing techniques) nor did I see coverage of biases in later documents (2022/2023). To name a few:

- Sunk-cost bias, which encourages the continuation of programs and actions that have been costly or effortful even after their usefulness is questioned;
- Overconfidence, which describes the tendency of many experts to be more confident regarding the accuracy of their opinions than is warranted;
- Prominence effect, which describes the common practice of looking at multi-dimensional problems through a lens heavily weighted in favor of a single objective or concern while largely disregarding other important factors.

The apparent absence of attention to cognitive biases (aka judgmental heuristics) is possibly significant because, although efforts to reduce extinction risks of Delta Smelt over the past 30 years have been impressive from a scientific perspective, it

[3] The 2023 Action Plan (p. 38) states that future expert elicitations for salmonids and sturgeon should consider “including more experts in the respondent group and more workshops with the experts” but this suggestion remains vague and, as noted in the text of this review, perhaps also should be considered with respect to the diversity of participants and with reference to the DCG itself.

appears they have been largely unsuccessful in terms of Delta Smelt recruitment. This is in line with several sources; one review (Water Education Foundation, 2023) concluded in 2023 that the annual midwater trawl survey conducted by California's Department of Fish and Wildlife (CDFW) "… has caught fewer and fewer Delta Smelt most years for two decades, and since 2018 it has not caught a single one" and Moyle et al., 2016 refer to efforts to manage Delta Smelt independently of a broader ecosystem perspective as "equivalent to treating the symptoms without acknowledging the disease."

Table 1 in the 2023 Action Plan includes the somewhat chilling reminder that "there is significant uncertainty about the performance of NDFS alternatives on all objectives." This highlights the importance of understanding participants' opinions relating to actions or their consequences for which there is either agreement or disagreement among experts. Some relevant work has been done; for example, the 2023 SDM Process Document contains some relevant and useful judgments (see Table C-2) with respect to scoring NDFS alternatives for a below-normal (BN) water year. Although it is helpful to see the information tracked in this table, the individual comments of participants are difficult for a reader to pull together in a coherent way—other than re-emphasizing the presence of high levels of uncertainty—and thus it is not clear how this information is intended to be used or to influence the perspective of readers and (more importantly) decisions of DCG members and other policymakers.

Additional evidence for this concern comes from the 2023 Action Plan (AP) which includes a discussion of the expert elicitation contamination workshops. A total of 8 experts were involved, although not everyone felt qualified on all questions (as evidenced on p. 3 that "some did not score juvenile life stages given large uncertainty"). In addition to the information shown it would have been interesting to obtain explicit judgments of the experts' confidence in their assessments: were those who were willing to provide a response more confident in their knowledge or were they motivated by strategic biases or other considerations? What is also striking is that some performance measure scores (for the same alternative) were widely divergent, with ratings 4 points apart on the 5-point scale (e.g., +1 and –2, or +2 and –1). This wide range of responses suggests either very different across-participant opinions or interpretations of the questions asked. Either way, the average scores shown in Figure 10 hide a great deal of potentially useful information and suggest high levels of uncertainty regarding the effects of contaminants and the relative merits, in terms of consequences for Delta Smelt growth and survival, of low-intensity vs. high-intensity flows.

Similar concerns arise from Figure 12 (2023 AP, p. 48) which shows “the four top-level decision objectives” (Delta Smelt, resource costs, learning, and effects to other species) and the (swing) weighted percentages placed on these top-level objectives for a BN water year by 5 of the DCG panel members[4]. The most striking message from this figure—aside from the fact that only 5 of the DCG members participated—is again the wide range of responses, indicative of substantial variation in the relative importance assigned to the achievement of the four objectives. Similarly divergent results (Fig. 12B) were obtained when participants were asked to weigh the contribution of sub-objectives (growth, food, and contaminants) to overall Delta Smelt utility.

Such divergence is not unusual at initial stages of SDM deliberations, as experts tend to have strong opinions. Typically, these disagreements prompt active and focused discussions within the group as to why these differences are found and, ultimately, lead to a coming together of opinions—not a consensus but less divergence. In this case, we are told that discussions occurred but it appears the divergence in opinions persisted. Yet the reader knows neither the specifics of what was done to address these divergences nor, more importantly, the reasons for the stubborn continuation of large divergences in opinions. If the differences were due to variations in participants’ risk tolerance then they relate to values and may be stable. However, if they relate to differences in access to information or in how key terms were interpreted, measured, or defined then there are many things that the facilitators could do to attempt to reduce the variation in opinions prior to moving forward with recommendations regarding water releases or timing.

One implication is that averages will mask valuable information. Another is that further studies may need to be conducted. Lastly, it may be helpful to more fully incorporate the opinions of other experts, drawn from academia and non-governmental organizations (NGOs), in addition to agencies directly involved in the management of Delta Smelt.

[4] It’s not clear from the discussion exactly what “Delta Smelt” means in this context; the sub-objectives are growth and zooplankton biomass so presumably the reference is to Delta Smelt survival?

3. How well does the SDM approach, as implemented by the DCG, effectively and efficiently use the information we have in the context of ongoing uncertainty (e.g., do all the metrics need to be modeled)?

As emphasized in the SDM Action Plan reports from 2022 and 2023, there exists significant uncertainty with respect to many fundamental aspects of the Delta Smelt recovery actions. The intention is to address this uncertainty through an adaptive management approach, introduced by ecologists C. S. Holling (1973), Carl Walters (1986), Lance Gunderson and Holling (2002), and others to address complex issues characterized by uncertainty in the effectiveness of different management approaches. For example, the adaptive management (AM) cycle described in detail for Suisun Marsh (Fig. 7, 2024 Workplan) is designed to test the hypothesis that changes in the timing and extent of flow actions will increase recruitment of Delta Smelt, with both within-year and between-year comparisons intended to provide information on different flow actions.

With respect to the “effective and efficient” use of information on uncertainty, the designation of “suitable habitat” as a sub-objective—based on the “overlap of (suitable) salinity, turbidity, temperature, and hydrodynamics”—raises several red flags. I reviewed the main Habitat Suitability Index (HSI) reference that is provided in the text (Bever et al., 2016) but could not find a clear indication of the relative priority given to each of these four considerations. The SDM sessions examined the HSI by region and sub-region (Figures B-11/12) based on historical turbidity and temperature values for a given water year type. Although Figure 4B (WY 2023, p. 24) shows relative weights for the growth, food, and contaminant sub-objectives, in terms of importance to overall Delta Smelt utility[5], the only analysis I found regarding the relative importance of the different habitat attributes is in the 2023 SFHA monitoring plan (and again these vary widely among participants). However, it was not clear how these scores would be used or translated into specific guidance provided to water managers, who presumably will not always find that the habitat attributes required by Delta Smelt necessarily follow the same trends after a water release. I assume that each of the four HSI factors needs to meet a (minimum or maximum) threshold and that each factor provides benefits to Delta Smelt growth and survival up to some point and that the benefits then level off (or perhaps even become negative). I looked for but did not find graphs showing thresholds and the

---

[5] Why use the undefined term “utility” in this instance rather than “recruitment” or even “growth and survival”?

performance of each of the four factors, perhaps including their likely effect in various sub-regions. Aside from a note regarding temperature thresholds, I also did not see evidence for the elicitation of thresholds (e.g., minimum or maximum levels or ranges) or how feedback on information regarding the relative importance of habitat attributes would influence strategies or AM plans.

On this point, one of the key requirements of a successful adaptive management program is the ability to separate outcomes and obtain relatively clear feedback on the success of different initiatives, which is always difficult when the context for the application of management actions is itself shifting (i.e., including not only what is taking place within the specified management program but also key external factors that could affect outcomes). An earlier paper (Gregory, Ohlson, & Arvai, 2006) identified four criteria that can help to identify contexts where AM techniques (at times paired with a SDM approach) are, and are not, likely to succeed: spatial and temporal scales, dimensions of uncertainty, the evaluation of costs and benefits, and support from stakeholders and other management agencies. Despite the compelling logic for being adaptive, the authors of the paper conclude that external factors beyond the control of the managers in question—weather, competing interests, politics, and funding—often account for the relatively low success rate of key aspects of many AM programs.

How does the Delta Smelt program look when viewed in this lens? The role of external factors appears to be particularly significant in the context of Delta Smelt. For example, hydrology scenarios and six action alternatives are discussed for Wet, Above and Below Normal (AN/BN), and Dry weather years[6]. However, it was reported that the “implementation of the SFHA has not occurred in the last 3 years due to drought conditions” (2023 Action Plan, p. 7) presumably because each of these 3 years was categorized as either dry or critically dry. Nevertheless, Figure 13 on page 49 (for a BN year) shows strong agency support in 2023 for the “double summer Sacramento River and fall Agriculture action” (2023 Action Plan, p. 50).

With modeling results in 2022 and 2023 reported (p. 28) to have been “largely the same,” it’s not clear what information has led to the strong support for this alternative. One concern is that “while assumed to be technically feasible, this

[6] I could not find a description of these four WY types. In particular, the Dry WY is said to be “unlikely to occur”—which implies a wide range of annual probabilities, somewhere between .01 and .49—even though the SFHA Action Plan (p. 18) refers to the 2020 and 2021 WYs as Dry, to 2022 as “critically dry” and 2023 as “dry.” This is not sounding particularly “unlikely.” Adding to my confusion is the fact that the May 15, 2023 SFHA monitoring plan characterizes 2023 (p. 13) as a Wet year.

approach has never been implemented" (p. 27). This is exciting—a new alternative is being proposed, which could demonstrate flexibility in water-flow response—but it is also exemplary of the high levels of uncertainty affecting the predicted benefits of changes to smelt habitat. A second concern is that there is not a visible feedback loop dealing with new learning that would result in such strong support for what seems to be a new and as-yet untried plan. If modeling results are similar, what new information (apart from a new year of weather observations) has been learned to encourage support for and adoption of this new alternative?

Adaptive management (AM) efforts are often characterized as either passive or active (Walters, 1986). Passive AM is basically a live-and-learn approach, in which actions are monitored and programs remain sufficiently flexible so they can be adjusted in the face of new information. In an active AM environment, in contrast, feedback (designed to reduce uncertainty) is usually obtained through explicit experimental trials which last over several years. A comparison of the effects of three water flows (low/medium/high pulse, for example) during the summer/fall seasons, might therefore require a total of 9 years of evidence (3 years data for each of 3 water flows) before clear conclusions can be obtained.

Even with explicit trials, however, the interpretation and implementation of results is rarely straightforward. One reason is the difficulty of maintaining consistent experimental conditions (and often a no-action control finding) so that results can be compared. Politics and changing environmental conditions often create difficulties, and in recent decades climate change has also made the interpretation of results difficult. These problems appear to be severe for Delta Smelt and are made worse by the differences in Water Years. Even if an action taken in an AN year looks promising in terms of smelt growth and survival, it may be another 3–5 years before another AN year occurs. Another reason is the relatively small sample size. Even though a period of 9 years may be required for a relatively straightforward 3x3 comparison of alternative water flows (as in the example above), each group of results nevertheless is based on only 3 years of information and thus the statistical significance of the results is likely to be low. Additionally, future environmental conditions or the competing resource needs of other users and other species may be sufficiently different that external effects change dramatically, for example in terms of contamination levels or the influence of management actions implemented to assist other species and/or interests.

This raises questions for me concerning the viability of a passive AM approach to reduce uncertainty (Lyons et al., 2008), particularly in light of the current endangered status of the Delta Smelt population. It would appear that current efforts might more properly be considered as adaptively managing Delta Smelt on the basis of monitoring results and annual weather changes. This is all well and good, but flexible management in the face of change shows evidence more of common sense than of an effective ongoing adaptive management program; more to the point, flexible management is unlikely to provide a consistent framework for reducing key sources of uncertainty whereas this is a central goal and critical to the success of adaptive management efforts.

4. Is the SDM influence diagram effective for the decision statement? How can it be improved?

An influence diagram (ID) provides a visual picture of the key causal relationships between factors (stressors) important to resource managers, the actions they can take, and the objectives (in this case, outcomes) that matter most. In this sense Figure 5 (p. 21 of 2023 Action Plan), which focused on the overall NDFS process[7], is helpful because it separates means from ends, assists in the definition of reasonable performance measures, highlights information needs (and, in turn, areas where expert judgment elicitations may be required), and helps managers to keep sight of the SFHA's main goals.

That said, Figure 5 is a relatively simple ID in that it is limited to the main actions undertaken by the SFHA and does not include comprehensive coverage of external factors, the importance weights placed on the various means, or the influence of uncertainty. One suggestion is that the connecting arrows in the ID could be shown separately for each individual member of the DCG, with their widths adjusted for the relative importance placed on the contribution of each of the means to the designated ends (in this case, smelt recruitment). Another concern is the apparent hesitation to incorporate insights from analyses of the Value of Information (VOI), which evaluates the expected utility of information derived from an adaptive management (AM) initiative (Keisler et al., 2014) for reducing key uncertainties affecting Delta Smelt growth and survival. Providing explicit judgments about the VOI gained from various actions could improve the quality of information available to resource managers when considering whether the benefits outweigh the cost of a specified AM action (in terms of money or foregone opportunities) – otherwise, they may not fully understand the role of a proposed action or the extent to which

---

[7] Several other influence diagrams are included as part of the 2023 SDM Process Document, including IDs for the Delta Smelt growth PM, the zooplankton availability PM, and the contaminants PM. Similar comments apply to these other IDs as to the more general Figure 5.

it is anticipated to reduce specified uncertainties and, in turn, inform actions taken to enhance Delta Smelt growth and survival.

As a result, and in particular, because the SFHA focuses on reducing uncertainty with respect to the influence of water releases on key habitat variables affecting Delta Smelt growth and survival, the ID by itself does not provide an accurate "decision statement." Nor does it provide a roadmap for how to address key trade-offs or deal with differences of opinion among key decision-makers. Thus, the ID as shown is effective for one step of organizing the decision problem but for it to be "effective for the decision statement" (as per the question) requires combining this information with the results of other SDM (and non-SDM) tools—what is left out of this ID (weights, uncertainty, trade-offs) is important material to be included in the "decision statement" deliberations of the DCG.

5. Are there alternative decision tools that may be complementary to or better suited for the SFHA decision?

The tools currently described as key to the SDM Delta Smelt work all seem appropriate to the SFHA decision. This question thus becomes, not are other tools "better suited" for the SFHA decision but, rather, are there other SDM tools that might complement existing work and either contribute new insights to the DCG or improve its effectiveness and efficiency? Several suggestions are made below, again without knowledge of the extent to which they have been used as part of the ongoing deliberations of the SDM team.

One such tool, used in earlier SDM work (Gregory et al., 2012) and highlighted in the Phase 2 SDM Report (Compass Resource Management, 2021), is a potential complement to expert judgment elicitations of the importance of different factors (e.g., temperature, predation, food quality or quantity) to various hypotheses concerning Delta Smelt survival (e.g., Table 2 shows "Adult to Juvenile Life Stage transition"). It is stated that scientists in 2019/2020 were asked to rate the impact of each factor on Delta Smelt abundance, using a 0–5 scale. The results are highly useful (e.g., Figure 7 shows that recruitment is correlated with cooler water temperatures) but I have two concerns: (a) scientists' confidence in their judgments is not shown and (b) I did not see a strong carry-over from these results to the 2023 Action Plans. On the first point, a simple 4-cell table (see Table 1 below), with importance (High/Low) shown on the y-axis and confidence (High/Low) shown on the x-axis could be used to show the competing hypotheses regarding both the importance of, and scientists' confidence in, factors potentially contributing to successful Delta Smelt growth, survival, and/or recruitment.

Table 1. Characterizing actions based on experts' confidence and judged importance

	Lower Confidence	**Higher Confidence**
Higher Importance	*Higher importance, lower confidence*	*Higher importance, higher confidence*
Lower Importance	*Lower importance, lower confidence*	*Lower importance, higher confidence*

In the face of time or resource constraints, the hypotheses/actions placed in the lower right-hand cell are the first to be dropped (of low importance to Delta Smelt recruitment, with high confidence in this assessment) whereas those in the lower left-hand cell merit further investigation but are not at the top of the research list. The species recovery program is thus able to focus on the top row, with the hypotheses/actions in the upper right-hand cell prioritized for immediate implementation as they are considered to be important and scientists' confidence in their assessment is high. Those in the upper left-hand cell are prioritized for further research and become the focus of adaptive management (AM) efforts to increase the confidence of scientists regarding the contribution of different factors (with subsequent decisions to either emphasize or reduce the role of related hypotheses/actions). This centers both the implementation and research aspects of scientists' attention on those areas they feel to be most important. It saves money in times of limited funding, and it saves time in that deliberations regarding the design of actions to reduce uncertainty are focused on those areas that scientists feel are most likely to yield significant benefits.

The 2023 Action Plan notes that DCG agencies directly ranked each of the 6 NDFS action alternatives from "least to most preferred" and that this "helped assess the degree of confidence the DCG had in the weights…" (p. 48). However, I did not find a summary of these results that would provide direct access to the confidence judgments. What was more surprising is that there is little evidence of how this information was subsequently used to help focus descriptions of specific actions in terms of their intended goal of reducing critical uncertainties, even though the purpose of obtaining experts' confidence judgments is to help focus, and in many cases to simplify, AM efforts. To the extent that uncertainty regarding the effectiveness of actions continues to lead to disagreements among scientists, the inclusion of confidence judgments can help to redefine hypotheses and design new actions, thereby helping to achieve the goal of reducing uncertainty in key areas affecting recruitment of Delta Smelt.

A second technique, designed to open up new ways of thinking and create new management alternatives, is to role play what is essentially a courtroom setting in order to more deeply explore the pros and cons of different hypotheses. The focus could be the role of different habitat factors (e.g., the four components of the HSI), the feasibility of including different objectives or different participants as part of the DCG, or other considerations relating to actions that could directly or indirectly improve recruitment of Delta Smelt. The design of this tool (clearly not specific to an SDM approach) is to randomly assign different questions or different hypotheses to members of the decision making group, in this case presumably the DCG. Each member has 5–10 minutes to argue in favor of a proposal and the other has 5–10 minutes to argue against it. The benefit is that you end up with new voices and ideas—people other than the strongest proponents or opponents need to come up with convincing arguments—and those most confident in a proposal's strengths or weaknesses may need to argue for the opposite point of view, thereby also revealing new insights because they are focusing on weak spots rather than strengths[8]. This courtroom approach may sound presumptuous or even flaky but I have seen it work well in several different contexts where the "actors"—senior scientists and technical experts—surprised themselves with the insights (both for and against an action) that emerged.

Another SDM/Decision Analysis approach that can be useful, particularly with reference to the design and presentation of consequence tables, is the incorporation of certainty equivalents (CE) in the presentation and communication of consequences subject to high levels of uncertainty. Although, formally, the calculation of a CE requires (for each participant) the development of a probability density function and the associated utility function (Keeney & Raiffa, 1993), a practical and more common approach is for the participant to construct their own CE by reviewing the uncertainty range (based on information provided by previous research and other experts) and then selecting a single best estimate of consequences—the "sure thing"—that best represents the uncertainty distribution

[8] In this sense the "science court" process is similar to a "post-mortem" analysis that is increasingly used in government and industry to predict, in advance of agreeing to an initiative, what might become known in the future as to why it went wrong and failed to achieve its goals.

and incorporates their own risk tolerance through upward or downward adjustments (Gregory & Keeney, 2017).

The advantages of using CEs for resource management problems characterized by high levels of uncertainty (Delta Smelt provides an excellent example) include moving away from variations among individuals when interpreting ranges (e.g., low-high estimates of a performance metric), explicitly including risk tolerances (which typically vary across individuals, objectives, and contexts), avoiding participants and decision-makers feeling overwhelmed when examining a complex consequence table, and providing a reminder of the influence of uncertainty on actions to participants and decision-makers. This latter element is particularly important in the context of long-term recovery plans for an endangered species such as Delta Smelt, for two reasons: (a) the significance of uncertainty in the selection of actions undertaken by the DCG may not be fully appreciated by some decision-makers, and (b) the inclusion of risk tolerance adjustments helps to remind all participants that how uncertainty is dealt with is both a factual and a values-based concern (i.e., the same results will be interpreted by some participants as more strongly indicative of the program's success or failure, based in part on their subjective level of risk tolerance). In addition, CEs can facilitate comparisons of the Value Of Information (VOI) across proposed AM initiatives.

Conclusion: Overall Approach to the SFHA (Question 10)

The technical portions of the SDM approach described in the SFHA Action Plans and Monitoring Plans appear to have been carefully done and well documented. I have raised several concerns and provided suggestions for the incorporation of some new analyses that might yield new insights.

My overarching concern with respect to the use of SDM approaches to inform decisions regarding preferred summer-fall habitat actions is that one of the primary benefits of an SDM approach appears to have been largely neglected. In the Delta Smelt reports provided, SDM approaches are principally used to help organize and interpret the large amount of information made available through the modeling results. Modeling is science-based and clearly needed in this context. In contrast, SDM is decision-based and thus requires simplification: when an Objectives by Alternatives consequence matrix grows large it no longer provides an easy path to insights for making better management decisions. An SDM process achieves simplification by highlighting uncertainties (with respect to the consequences of actions), tradeoffs (with respect to the achievement of objectives), and priorities (in terms of what is most important to the decision at hand). These reports describe the modeling results and provide convincing documentation that reducing extinction risks to Delta Smelt is a complex task. However, they do not provide an effective window into the key uncertainties, tradeoffs, or priorities. As a result, there is a lack of clarity regarding the logical next decision steps: (1) what are the key lessons learned thus far from the adaptive management (AM) program, (2) what are the key questions yet to be answered, (3) what needs to be the focus of AM efforts over the next 1–3 years, and (4) in the face of climate change and competing demands for water, how much of a positive impact on Delta Smelt recruitment, realistically (i.e., with moderate to high confidence), can be made over the next 3-5 years?

One suggestion in such circumstances is to take a step back and distinguish what is known from what is not, then reframe the management plan into what becomes, essentially, a two-part recovery approach. The first part would deal with what is well known, with moderate to high confidence, to be essential for the survival of Delta Smelt—the key habitat attributes (including results from the 2019/2020 expert judgment workshops) and their minimum/maximum threshold levels. The task of resource/water managers then becomes to ensure that these conditions are met (e.g., water temperature levels maintained at a sufficiently low level), to the extent possible in Dry years as well as Below/Above Normal and Wet years (a goal that is likely to involve an ongoing captive-rearing program). Meeting this goal might also require added consultation with other water users and perhaps a serious public relations campaign to build up support for a wider scope of actions to be undertaken by the DCG. This enlargement of the current problem frame would bring in new participants, additional values, and would probably lead to the inclusion of new objectives which, in turn, could open the door to new alternatives, new trade-offs among consequences, and new monitoring requirements.

The second part of this reframing would be to identify and deal with the attributes for which there is substantial uncertainty; it would be based on an active AM approach that recognizes that both near-term and long-term results are needed (given the critically endangered status of Delta Smelt). This reframing of the problem might or might not be a good idea but I bring it up here because the SDM work that I reviewed fails to show clear distinctions among habitat, contaminant, or other priorities based on the relative level of uncertainty associated with their importance and scientists' confidence in the program's ability to aid Delta Smelt recruitment and thereby reduce the probability of species extinction.

One final comment relates to the goal of the SFHA, to help endangered Delta Smelt populations recover, to increase recruitment, and to become sustainable. What I did not find in the 2023 Action Plan and SDM Process Documents is a clear statement of the actions needed and their associated benefits in light of the time frame within which success needs to be achieved if Delta Smelt are to avoid extinction, either with the benefits of an active conservation program (e.g. ongoing management and monitoring of populations) or without. Nor did I find a clear statement of what might be possible if the scope for DCG decisions were to be enlarged—a broader framing of the problem to bring in new participants, new objectives, and new alternatives. To what extent would these changes reduce the probability of extinction for Delta Smelt? It is unclear to me because the documents I reviewed largely focused on a scientific agenda for the DCG (an essential component) rather than on a decision making agenda that gives purpose and a sense of urgency to the nearly 30 years since Delta Smelt first were listed as threatened and 15 years since California designated the species as endangered. After reading these materials I really do not know how to gauge the probability that Delta Smelt will be able to avoid extinction or even whether this probability is trending higher or lower– and I would have expected the SDM process to be of more assistance in helping me understand whether all this effort is really getting us anywhere.

References

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

Conroy, M., Barker, R., Dillingham, P., Fletcher, D., Gormley, A., & Westbrooke, I. 2008. Application of decision theory to conservation management: recovery of Hector's dolphin. Wildlife Research 35: 93-102.

Conroy, M. & Peterson, J. 2013. Decision making in natural resource management: a structured, adaptive approach. Wiley-Blackwell, Chichester UK.

Compass Resource Management. 2021. Structured Decision Making for Delta Smelt, Phase 2. Report prepared for Collaborative Science and Adaptive Management Program.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. 2012. Structured decision making: A practical guide to environmental management choices. Wiley-Blackwell Press, Chichester UK.

Gregory, R., Ohlson, D., & Arvai, J. 2006. Deconstructing adaptive management: Criteria for applications to environmental management. Ecological Applications 16(6): 2411–2425.

Gregory, R. & Keeney, R. 2017. A practical approach to address uncertainty in stakeholder deliberations. Risk Analysis 37: 487–501.

Gunderson, L. & Holling, C. S. 2002. Panarchy: Understanding transformation in human and natural systems. Island Press, Washington.

Hammond, J., Keeney, R., & Raiffa, H. 1999. Smart Choices: A Practical Guide to Making Better Decisions. Harvard Business School press, Boston USA.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4: 1–24.

Keeney, R. & Raiffa, H. 1993. Decisions with multiple objectives: Preferences and value tradeoffs. Cambridge University Press, New York.

Keisler, J., Collier, Z., Chu, E., Sinatra, N., & Linkov, I. 2014. Value of information analysis: the state of application. Environmental System Decisions 34: 3–23.

Lyons, J., Runge, M., Laskowski, H., & Kendall, W. 2008. Monitoring in the context of structured decision making and adaptive management. Journal of Wildlife Management 72: 1683-1692.

Moyle, P., Brown, L., Durand, J., & Hobbs, J. 2016. Delta Smelt: Life history and decline of a once-abundant species in the San Francisco Estuary. San Francisco Estuary & Watershed Science, July.

Moyle, P. 2022. The Failed Recovery Plan for the Delta and Delta Smelt. California WaterBlog, May 29.

Slovic, P. 1999. Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. Risk Analysis 19(4): 689-701.

von Winterfeldt, D. & Edwards, W. 1986. Decision Analysis and Behavioral Research. Cambridge University Press, New York.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, New York.

Water Education Foundation. 2023. Delta Smelt (Aquapedia background).

June 2024

Review of the SFHA SDM Process

A report to the Delta Science Program

Prepared by

Dr. Kelly F. Robinson – U.S. Geological Survey, Georgia Cooperative Fish and Wildlife Research Unit, Warnell School of Forestry and Natural Resources, University of Georgia

Delta Science Program

DELTA STEWARDSHIP COUNCIL

Table of Contents

Executive Summary

The structured decision making (SDM) process for evaluating alternatives for the Delta Smelt Summer Fall Habitat Action (SFHA) was developed to improve habitat conditions that will support the growth, survival, and recruitment of Delta Smelt (*Hypomesus transpacificus*). In this framework, the working group identified a suite of actions to be evaluated, based on objectives identified for the system and requirements from the Incidental Take Permit. They developed performance measures for each objective that allow for evaluation of the consequences of implementation of each alternative. Through the development of an influence diagram, the group identified the connections between objectives and actions and used both qualitative and quantitative means to project the outcomes of actions in terms of objectives. Finally, they used a multi-attribute ranking technique to develop weights for the objectives, acknowledging that there will not be an action that best achieves all objectives. Overall, the SDM framework itself is quite sound, and I have provided comments throughout this review that are meant for the working group to consider as they iteratively update this process.

My comments are structured around the charge questions delivered to the reviewers of the SDM process (the 5 questions in the main text of this document). These questions focused on the incorporation of quantitative and qualitative information, integration of participant values, use of information in the face of uncertainty, development of the influence diagram, and potential other tools that could be useful for the SFHA decision. Overall, I felt the main theme that could be developed more fully was a formal evaluation of uncertainties. This system and the SFHA decision both have numerous ecological uncertainties related to the effectiveness of actions, the current ability of the system to sustain Delta Smelt, and future changes that could further affect management actions. The review materials described some of these uncertainties, as well as proposed projects to learn more about the system, in addition to a desire to implement actions in service of learning. However, the current SDM process does not integrate this uncertainty into the consequences and the tradeoffs steps, hindering the ability of the group to identify key uncertainties that could be the focus of adaptive management (e.g., through a value of information analysis). Overall, the team has developed a strong framework for making decisions for the SFHA, but fully incorporating uncertainties

would allow for a transition to an iterative SDM framework that focuses more fully on adaptive management.

Introduction

The working group that prepared the structured decision making (SDM) framework and process for the Delta Smelt Summer Fall Habitat Action (SFHA) created a strong backbone for the decision process. They have clearly put a great deal of effort into framing this process and evaluating the consequences and tradeoffs of potential actions. I have structured the bulk of this report around the five charge questions levied on the SDM process reviewers. In this introduction, I provide an overview of my assessment of the SDM process and some high-level comments.

Uncertainty appears to be a hindrance to identifying an optimal decision each year. One of SDM's key features is the ability to identify decisions that are robust to uncertainty and identify pinch points where uncertainty affects the decision. This can lead to more robust evaluations of tradeoffs and risks. It can also enable the group to devise plans on how to reduce those uncertainties. I would encourage the working group to fully consider how to incorporate uncertainties into the decision process and determine which of these uncertainties should be resolved. This likely would take the form of a more formal adaptive management process, perhaps within the scope of the Adaptive Management Team's (AMT) process, as well as the incorporation of information from laboratory studies and other ongoing research throughout the system. However, the links between the SFHA and Collaborative Science and Adaptive Management Program process are unclear. The documents indicated that there is a potential alignment between these two processes. I would encourage the group to continue to pursue opportunities to reduce uncertainties that are key to identifying an optimal decision.

Another overarching consideration for the team is that, although this decision process has been structured well, it is still unclear whether any of the actions being considered will be able to aid in the recovery of Delta Smelt. The reports document large changes in the ecosystem, and researchers have indicated that actions to recover Delta Smelt will need to overcome these system-wide changes (e.g., Smith and Nobriga 2023; hysteresis as described in Allen and Gunderson 2011). The relatively small changes in growth rate that could be expected under the actions being evaluated highlight this point. Is it possible for the plan to step beyond the actions that are currently being considered and incorporate this ecosystem change more fully? As currently framed, this meticulously crafted SDM process suggests that the actions being evaluated may not enable recovery of this species.

Responses to Charge Questions

Question 1

How well do the PrOACT model and SDM approach, as implemented by the DCG [Delta Coordination Group], allow for evaluating qualitative versus quantitative information (e.g., expert opinions compared to numerical models) to support the decision?

In general, most SDM processes proceed with a necessary mixture of quantitatively predicted consequences from modeling tools, information elicited from experts, and other information that is more qualitative in nature (e.g., satisfaction). I think that the use of both quantitative data and knowledge elicited from experts is important for the SFHA decision process. Below, I provide some ideas and comments that might be useful for the team as they continue to use SDM to make decisions for the SFHA, based on some observations from the materials provided for this review.

In terms of the quantitative predictions, I noted some areas where improvements or changes could be implemented. I am not suggesting that these are imperative for the functioning of the SDM process, but they may be beneficial. First, the team seems to have spent a good deal of time evaluating existing model structures, determining which models might be useful, and considering how best to use these models to predict outcomes in terms of the measurable attributes. In some instances, this is likely a useful approach. For instance, the bioenergetics modeling approach fits with the habitat suitability projections and growth modeling. However, the team could potentially take a step back and consider whether building their own models, specifically to address this decision process, might help to elucidate answers to some of the uncertainties that they are dealing with, and perhaps help them to think more fully about how all of the actions fit together across the landscape. Some of the existing models are quite complex, and while this is a complex system to manage, I wonder if all of the complexity is truly necessary or if some of it could be collapsed into simpler modeling frameworks. In general, developing or using a quantitative prediction model (individual-based, population level, etc.), is preferable to conceptual modeling for projecting effects of actions on performance measures, where possible. Starfield (1997) makes a good argument for building decision-specific models.

Second, some of the modeling efforts blend both quantitative data and conceptual modeling techniques to make predictions about future outcomes under different actions and appear to be leading to projections that are perhaps not biologically plausible. For example, the percent change in zooplankton biomass metric uses a generalized additive modeling approach for the actions that change salinity in the Suisun area, but then a conceptual model was used for the food subsidy actions. The conceptual modeling approach seemed to provide projections of zooplankton biomass that were much greater than what would be expected in the system, calling into question whether this approach is appropriate or useful for discerning among actions. This is a situation in which the team might consider whether there is a modeling approach that they could build from the ground up, or whether expert opinion might in some ways be more accurate than the conceptual model. The goal, stated in the materials provided for this review, is to understand the relative change in zooplankton biomass in response to action, not the absolute biomass. While this seems to be the best approach (e.g., Keith et al. 2011), maybe expert knowledge combined with a decision-specific quantitative model would get the group farther than the use of the copepod-only conceptual model.

For the expert elicitation work, I commend the group and the facilitator for putting together structured approaches for gathering information from the experts for the performance measures. The use of expert knowledge is often necessary for moving decision making forward. I have a few comments on the approach that I hope the team finds useful. First, there are times in which the group used the modified Delphi approach (Kuhnert et al. 2010) to conduct more than one round of elicitation, and I think this can help with ensuring experts are in agreement about the questions being asked and what they are considering when providing their responses. In other instances, only one round of elicitation was performed, which could lead to uncertainty in the experts' answers that result from confusion about the questions being asked. In both cases, there is still a lot of uncertainty among experts in terms of what the outcomes might be. Some of this might stem from linguistic uncertainty (Regan et al. 2002), as described for the contaminants elicitation process in which experts had difficulty separating the effects of actions. However, some of this is probably just because there is a lot of uncertainty in the system. The team has not really dealt with this uncertainty in determining the optimal action for a given year, though, as average scores have been used in the consequence table to describe the achievement of each objective. By only focusing on the average, and not accounting for uncertainty (e.g., through consideration of the confidence intervals around an average outcome), there is no understanding of how uncertainty around an estimate of an outcome might change the decision. I touch on this concern more in my responses to the third charge question. In addition, I wonder if, rather than evaluating some of these objectives as separate entities (e.g., effects of contaminants on a -2 to 2 scale), the team might consider eliciting values that could be incorporated into the projection model for growth. Currently, it seems like the contaminants measure is isolated from the effects that the group is interested in eliciting (see question 4). If this contaminants measure were instead a parameter, it could be used to evaluate the uncertainty in contaminant effects on Delta Smelt growth, and how that uncertainty influences the decision to be made.

Question 2

How well does the SDM approach, as implemented by the DCG, integrate participant values in a standardized and transparent way?

SDM is a value-based approach to decision making (Keeney 1992), and as such, ensuring that participants' values are properly incorporated and weighted is certainly an important part of this decision making process. There are at least two steps in which participant values are incorporated in the SDM process: the objectives setting and the tradeoffs phases. Currently, the fundamental objectives (as described in Figure 3 of the 2023 SDM report) include concerns related to Delta Smelt growth and survival, effects on other species, costs, and learning. These make sense as a suite of objectives related to ecological concerns for the target species (Delta Smelt) and ecosystem, as well as costs for implementation (but please see my comments and questions for charge question 4 regarding the suite of objectives). As I mentioned in my response to question 1, the team might consider whether "contaminant effects" is at the same level as the objective for Delta Smelt growth and survival, as the performance measures are all related to direct or indirect effects of contaminants on Delta Smelt survival, growth, or recruitment. Could this, instead, be incorporated as a model parameter that influences Delta Smelt demographics? Would the contaminants affect other native species as well?

In addition to the Delta Smelt and contaminants question, the Smith and Nobriga (2023) paper discusses economic concerns associated with actions that would be implemented to maintain salinity (e.g., X2, Suisun Marsh Gates). These concerns are not included in the objectives hierarchy for the SFHA. Is this something that can be added, or is this outside of the scope of this decision? Finally, in the 2023 report, the team indicates that there are likely areas where there is duplication (e.g., the way that food is incorporated into the decision process); I would agree with the team's assessment that they refine these objectives and measures and determine how to avoid double counting.

In terms of tradeoffs, the group used a swing weighting approach (von Winterfeldt and Edwards 1986) and the AltaViz tool to formally evaluate the tradeoffs for all participants. Swing weighting is an appropriate method to use for this decision, and I think that the framework for it was set up quite well with the AltaViz tool. I think that the way that the group visualized the outcomes and evaluated them in terms of individual/agency weights is appropriate.

Question 3

How well does the SDM approach, as implemented by the DCG, effectively and efficiently use the information we have in the context of ongoing uncertainty (e.g., do all the metrics need to be modeled)?

Decision making under uncertainty is the norm in natural resources management, and in a complex system like the Bay-Delta, ensuring that uncertainty is accounted for is imperative. One of the benefits of SDM is its ability to allow decision-makers to fully incorporate and evaluate the effects of uncertainty on the decision to be made, and to determine when it might be appropriate and possible to reduce that uncertainty. In the SFHA SDM framework, the working group is dealing with a great deal of uncertainty in structuring the decisions for SFHA plans in the system. However, I do not see where the group is effectively translating that uncertainty to the decision process to fully understand how the decision each year might be influenced by that uncertainty. Below I comment on how the group might consider the effects of uncertainty, including the use of information and models, as well as evaluating the value of information and making the SFHA SDM process more of an adaptive management process.

Conceptual models can be helpful for decision making and at times can elucidate a decision without further analysis. However, for this complex problem, it seems as though some of the conceptual models might be hindering the group's ability to truly predict what is expected under the various actions, how much uncertainty there is in these predictions, and importantly, how that uncertainty ultimately influences the action that is chosen each year. The expert elicitation processes have shown that there is uncertainty among experts in terms of what will happen if certain actions are implemented. That uncertainty seems to be somewhat ignored in the current version of the decision process. Creating confidence intervals for experts' projections, as well as either incorporating stochasticity into the models that are used or running deterministic models with different ranges of parameter values (e.g., something akin to scenario planning [Peterson et al. 2003]), could allow for a sensitivity analysis and an evaluation of the value of information. The team could potentially calculate the consequence table under the average outcomes as well as under scenarios that use the upper and lower bounds of the confidence intervals (similar to downside reporting, Gregory et al. 2012).

Smith and Nobriga (2023) discuss the uncertainties that need to be resolved to better model Delta Smelt bioenergetics, stemming from the use of Rainbow Smelt (*Osmerus mordax*) demographic rates to parameterize the individual-based model. The group might want to consider how to incorporate this uncertainty into the decision framework. There are hypotheses stated in the paper about how Delta Smelt bioenergetics, temperature tolerance, etc. would differ from those of Rainbow Smelt. Would it be possible to conduct model runs of how these rates might differ under these alternative hypotheses? This could generate models and weights that could be formally updated through laboratory experiments and adaptive management.

Overall, the iterative decision making process for the SFHA, along with the uncertainties that have been expressed by the working group and in the published literature, indicate that adaptive management would be an ideal framework for this decision process. The group has been instructed to formally incorporate results from prior years' decisions into the SDM framework each year. It is quite apparent that the group is doing this in structuring the decision process, even in the two years of formal implementation (2022 and 2023 reports). There are marked improvements and clear considerations for how to iteratively refine the decision process. However, each year's decision can also provide a data point for evaluating hypotheses (e.g., about the effects of actions on Delta Smelt growth) and reducing uncertainty. Since this could be a long-term process of learning, if undertaken, the group will want to carefully consider how they structure their learning objectives.

Although the desire to learn is clear from the reports (e.g., group members' desires to implement actions in order to learn) and the objectives hierarchy, there still seems to be a tendency toward trial and error instead of a structured approach to learning. The 2023 SDM framework document indicates that some group members would like to conduct an evaluation of the expected value of perfect information (EVPI). I agree that this process would be helpful and is necessary when considering the implementation of an adaptive management plan (Runge et al. 2011). However, the current setup of the decision process does not formally incorporate uncertainty in the models or consequence table, which means that EVPI cannot be calculated. I would encourage the group to consider how they might be able to include probabilities or hypotheses in the modeling and elicitation approaches they have taken. In addition, they might want to consider if constructed value of information (CVOI), which uses constructed scales as a measure of the value of information (Runge et al. 2023), could be more manageable than a full-on EVPI evaluation. Learning has been formalized as an objective in the SFHA SDM process, and there is clearly a great deal of uncertainty that comes into play when making decisions for water management for this species. Hopefully, my suggestions can help the group consider ways to incorporate uncertainty and learning more fully into the decision process.

Question 4

Is the SDM influence diagram effective for the decision statement? How can it be improved?

The influence diagram appears to contain the major components (e.g., objectives and actions linked through intermediate steps) of what the team describes throughout their decision process. I did find it difficult at times to reconcile the influence diagram (i.e., Figure 1 in the 2023 SDM process document) with the tables that described the objectives and subobjectives (Tables 2 and 3) and the consequence table (Figure 3). The consequence table lists four fundamental objectives (Delta Smelt, resource costs, effects on other native species, and learning). However, Tables 2 and 3 both refer to a different set of objectives as the "decision objectives": Delta Smelt growth and survival, Delta Smelt food and habitat, contaminant effects, resource costs, native species, and learning. Most of these seem to match the blue nodes in the influence diagram. Overall, the hierarchical structure of the consequence table (which, in my opinion, appears to be an appropriate way to structure the objectives) is not evident in the influence diagram or the tables, making the decision framework unclear. I am also curious what a "decision objective" is relative to the four types of objectives described by Keeney (Keeney 2007; fundamental, means, process, and strategic). The decision objectives seem to be a mixture of fundamental and means objectives. The workgroup may want to consider restructuring the influence diagram to reflect the objectives hierarchy more fully.

In addition, the description of the effects of contaminants in the influence diagram does not necessarily align with the structure of the consequence table. The consequence table includes measures of the effects of contaminants on zooplankton quality and abundance, as well as Delta Smelt recruitment. These are not represented explicitly in the influence diagram. In the diagram, there are no arrows linking contaminants to zooplankton, yet there is an implied effect of contaminants on recruitment via the effects on survival and growth of individual fish. If there is an assumption that survival and growth are the variables that influence recruitment, are the effects of contaminants being double counted by measuring the effects on growth, survival, and recruitment? As mentioned above, the group might want to consider how contaminants are included in the decision framework more fully.

I commend the group on their structuring of the influence diagram to fully depict the effects of the actions that might be taken on the objectives that they have described. Hopefully, these comments are useful for improving the way that these objectives are represented.

Question 5

Are there alternative decision tools that may be complementary to or better suited for the SFHA decision?

I think that SDM is an appropriate framework for evaluating this decision, however, the group might want to consider how to more fully incorporate the methods of adaptive management into this decision process. In addition, there are other tools that could be complementary if the group decides that they would like to assess uncertainty more formally in the decision process. Specifically, scenario planning might be useful to consider how large uncertainties (e.g., on the scale of climate change) could affect the decisions being made (Peterson et al. 2003, Miller et al. 2023).

Conclusion

The SDM process to evaluate alternatives for the Delta Smelt SFHA is well constructed, and the iterative updating of this process that occurs on an annual basis provides a means to continuously improve decision making. I commend the full team and facilitator on constructing this SDM framework. My comments focus mostly on the potential to better incorporate uncertainty into the decision process, to consider how to model the effects of the SFHA on the performance measures of interest, and how to bring these two components together (uncertainty and modeling) in the adaptive management framework.

Question 10 in the Charge document for this review requested feedback on the monitoring plan and its ability to reduce uncertainties in the performance measures for the SDM process. The monitoring plan is quite large and still evolving, as some of the actions are still in the conceptual stage. I think that the monitoring plan, as well as the studies that have been or will be implemented (e.g., caging studies to understand food consumption by Delta Smelt), will provide a wealth of information for this process. However, as constructed, I think that the links between the monitoring data collected and the methods used to predict the achievement of objectives, via performance measures, could be improved. If models are built for this decision process and incorporate uncertainty, then the data collected via monitoring can be better used for the reduction of key uncertainties. The team has identified some potential methods for building models in their SFHA Monitoring and Science Plan that they could continue to build on into the future.

Overall, the decision framework for the SFHA decision provides a much-needed structure for this complex problem. However, there are some areas for improvement and for better incorporation of monitoring data. It is unclear if this SFHA SDM framework will lead to increased recruitment of Delta Smelt and subsequent recovery of this species. The monitoring plan can aid in reducing uncertainties, especially if integrated fully into the decision analytic work, but ensuring that actions taken to learn are not causing delays in the implementation of actions to aid recovery of Delta Smelt is critical. Considering an approach to evaluate the value of information (i.e., EVPI or CVOI) could enable the working group to focus on those uncertainties that are most critical to reduce.

References

Allen, C. R., and L. H. Gunderson. 2011. Pathology and failure in the design and implementation of adaptive management. Journal of Environmental Management 92(5):1379–1384.

Gregory, R. S., L. Failing, M. Harstone, G. Long, T. L. McDaniels, and D. Ohlson. 2012. Structured decision making: a practical guide to environmental management choices. Wiley-Blackwell, West Sussex, United Kingdom.

Keeney, R. L. 1992. Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge, MA.

Keeney, R. 2007. Developing objectives and attributes. Pages 104–128 *in* W. Edwards, R. Miles Jr., and D. von Winterfeldt, editors. Advances in decision analysis: from foundations to applications. Cambridge University Press, New York.

Keith, D. A., T. G. Martin, E. McDonald-Madden, and C. Walters. 2011. Uncertainty and adaptive management for biodiversity conservation. Biological Conservation 144(4):1175–1178.

Kuhnert, P. M., T. G. Martin, and S. P. Griffiths. 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecology Letters 13(7):900–14.

Miller, B.W., M. Eaton, A.J. Symstad, G.W. Schuurman, I. Rangwala, W.R. Travis. 2023. Scenario-based decision analysis: integrated scenario planning and structured decision making for resource management under climate change. Biological Conservation 286:110275.

Peterson, G. D., G. S. Cumming, and S. R. Carpenter. 2003. Scenario planning: a tool for conservation in an uncertain world. Conservation Biology 17(2):358–366.

Regan, H. M., M. Colyvan, and M. A. Burgman. 2002. A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications 12(2):618–628.

Runge, M. C., S. J. Converse, and J. E. Lyons. 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biological Conservation 144(4):1214–1223.

Runge, M. C., C. S. Rushing, J. E. Lyons, and M. A. Rubenstein. 2023. A Simplified Method for Value of Information Using Constructed Scales. Decision Analysis 20:220–230.

Smith, W. E., and M. L. Nobriga. 2023. A bioenergetics-based index of habitat suitability: Spatial dynamics of foraging constraints and food limitation for a rare estuarine fish. Transactions of the American Fisheries Society 152(5):650–671.

Starfield, AM. 1997. A Pragmatic Approach to Modeling for Wildlife Management. Journal of Wildlife Management 61 (2): 261–70.

von Winterfeldt, D. and W. Edwards. 1986. *Decision Analysis and Behavioral Research*. Cambridge, United Kingdom: Cambridge University Press.