MEMORANDUM

TO:	Collaborative Adaptive Management Team (CAMT)
FROM:	CAMT Delta Smelt Scoping Team (DSST)
DATE:	February 17, 2023
RE:	CAMT Fall Occupancy Study

EXECUTIVE SUMMARY

A CSAMP-commissioned investigation of the environmental drivers of the quality of fall Delta Smelt habitat was recently published[1]. The study, conducted under the auspices of the CSAMP Delta Smelt Scoping Team (DSST), was intended to address Work Element 3-1-3 of CAMT's 2014 Workplan which identified fall outflow effects on Delta Smelt as a "High Priority" subject for investigation. The investigation evaluated the relative ability of 16 hypothetical conceptual models, developed in concert with the DSST, to predict regional and subregional sub-adult Delta Smelt occupancy as indicated by Fall Midwater Trawl Survey (FMWT Survey) sampling (1980-2015). The investigation's proposed approach was subjected to independent peer review prior to implementation.

The model providing the best fit to FMWT Survey catch data incorporated salinity and water temperature as occupancy covariates; and fish length, sample volume, and water clarity as detection covariates. Occupancy was clearly most responsive to salinity, and detection most responsive to water clarity. The study also found that patterns of occupancy in "wet" and "dry" falls were similar, suggesting Cache Slough and the lower Sacramento River to Suisun Bay represent "core" habitat for Delta Smelt. The three candidate models incorporating an X2 covariate were less predictive of occupancy than the salinity/temperature model. The DSST found these basic study outcomes to be unsurprising, given that salinity and water clarity are known critical features of Delta Smelt habitat. The relatively lower predictive value of X2 is not surprising given that salinity data is collected contemporaneously with catch data, while X2 is a tidally-averaged feature of the estuary which likely has a complex relationship with subregional salinity levels.

The DSST notes that consideration of the investigation's results should include an awareness of the challenges faced by the investigation. First, computational capacity and other factors

[1] Hendrix, A.N., E. Fleishman, , M.W. Zillig, and E.D. Jennings. 2022. Relations between abiotic and biotic environmental variables and occupancy of Delta Smelt (*Hypomesus transpacificus*) in autumn. *Estuaries and Coasts* 2022.

limited the number of candidate models evaluated. The investigation determined the relative predictive capability of the 16 models evaluated, but could not thoroughly explore every permutation of the many covariates that could potentially influence the parameters of the model. Second, adequate data was not always available, in particular for prey density and predation intensity. Thus, prey density was not employed as a covariate in any of the models, and predation intensity values were derived through an expert elicitation process (see Supplementary Resources[2]). In summary, the DSST concludes that the investigation has made positive contributions to understanding fall flow effects on Delta Smelt habitat through the application of new and more sophisticated analytical techniques, including highlighting the importance of evaluating detection. However, the DSST also concludes that the results of the investigation are insufficient by themselves to guide fall flow management. The results of the present investigation in concert with CSAMP's developing Structured Decision Making (SDM) Project and other recently completed studies will collectively inform fall flow management actions. Among the potentially contributing recent studies are the otolith chemistry-based investigations of individual Delta Smelt full-lifecycle habitat use[3].

The DSST has identified potential follow-on scientific efforts to extend the present fall occupancy investigation's results and/or interpretation but is not recommending pursuit of these follow-on efforts before the SDM Project has run its course.

BACKGROUND

The relationship between Delta outflow in the fall (September-December), X2 location, and habitat quality and geographic distribution (occupancy) of pre-spawning Delta Smelt has been the subject of a controversial scientific debate for over three decades. The relationship as presently understood is the basis for management and protection of the species during the fall period. Work Element 3-1-3 of CAMT's 2014 Workplan identifies fall outflow effects on Delta Smelt as a "High Priority" subject for investigation, and CAMT directed the DSST to work with independent investigators to develop a scope of work to address the element. A study proposal was developed by Dr. Erica Fleishman (formerly of UC Davis) and Nobel Hendrix (QEDA Consulting), subjected to peer review through the DSST and by an independent panel formed by the Delta Science Program, and refined and initiated in 2017. During the course of the study until its publication the DSST and the investigators developed and refined the scope. A final

[2] A collection of "Supplementary Resources" associated with the investigation and the memo can be found at https://csamp.baydeltalive.com/camt%20delta%20smelt%20work/delta-smelt-technical-studies.

[3] U.S. Department of Interior, Bureau of Reclamation. 2022 Directed Outflow Project, Report 3. April 2022.

manuscript[4] based on the investigation was published in the journal *Estuaries and Coasts* in August 2022.

This memorandum highlights DSST observations regarding the study, briefly compares the study's findings with other recent research relating to fall flow and other factors influencing Delta Smelt abundance and distribution, and outlines potential areas for future investigation. The DSST currently consists of Shawn Acuña (Metropolitan Water District of Southern California), Ching-Fu Chang and Yuan Liu (Contra Costa Water District), Pat Coulston and Michael Eakin (California Department of Fish and Wildlife), Steve Culberson (IEP Lead Scientist), Scott Hamilton (Coalition for a Sustainable Delta), Chuck Hanson (State Water Contractors), Li-Ming He (U.S. Fish and Wildlife Service), Sam Luoma (NGO representative), and Brian Mahardja (U.S. Bureau of Reclamation). The Department of Water Resources and the Delta Science Program were involved in development of the study, including identification of Candidate Models (see below), but neither are currently represented on the DSST.

There was substantial involvement by the DSST in the performance of the study. Collectively and individually members of the DSST worked with the investigators to identify a suite of conceptual ("candidate") models hypothesized to influence Delta Smelt Fall occupancy, assisted in the assembly of covariate data bases to support the modeling effort, participated in progress report meetings, and reviewed draft reports and the final publication. The investigators have referred to the DSST's involvement in the project as an example of "co-production". The final interpretations and conclusions of the study as published are those of the authors, however, and do not necessarily represent consensus views of the DSST.

INVESTIGATION APPROACH

The investigators sought to evaluate various hypotheses about environmental drivers of the quality of fall Delta Smelt habitat (probability of occupancy) and corresponding Delta Smelt geographic distribution by fitting Bayesian occupancy models, accounting for imperfect detection, to identify the models that best predicted the presence of Delta Smelt in monthly FMWT Survey catch data from 1980 – 2015. Accounting for imperfect detection and understanding the factors affecting detection, were identified as important for improving inferences from FMWT Survey data by an earlier CSAMP-commissioned investigation by Dr. Robert Latour[5]. Generally described below are the basic steps involved in the present investigation's approach.

[4] Hendrix, A.N., E. Fleishman, , M.W. Zillig, and E.D. Jennings. 2022. Relations between abiotic and biotic environmental variables and occupancy of Delta Smelt (*Hypomesus transpacificus*) in autumn. *Estuaries and Coasts* 2022.

[5] Latour, R.J. 2016. Explaining patterns of pelagic fish abundance in the Sacrament-San Joaquin Delta. *Estuaries and Coasts* 39: 233-247.

1) Engagement with DSST members to develop 16 candidate models of occupancy and detection (Table 1), each containing no more than four environmental covariates. Additional models for movement and abundance (Table 2, Supplemental Resources) were also assembled based on the candidate models, but due to budget and time constraints these models were not used.
2) The FMWT Survey design does not directly provide replicate samples as typically used in occupancy modeling. Given this reality the investigators treated Delta Smelt catch from multiple stations within designated regions and subregions as replicates.
3) Adoption of four distinct regions and 15 sub-regions (Figure 1) reflecting the extent of Fall Delta Smelt habitat based on regional divisions per the USFWS, with each region and subregion containing multiple FMWT Survey stations.
4) For the purposes of the modeling 1980 – 2015 FMWT Survey catch data was employed. This span of time was utilized because needed environmental data was not collected prior to 1980, and at least 20 years of data was deemed necessary by the Investigators to robustly support the complex modeling.
5) Derivation (in some cases) and assembly of the 12 covariate data sets by the investigators and DSST.
6) Conduct occupancy modeling to identify the covariates associated with occupancy and detection in each subregion.
7) Estimating the relative strength of the candidate models in accurately predicting regional and subregional Delta Smelt occupancy.

Table 1. Covariate composition of Candidate Models. Models are listed (left to right) in descending order of predictive capability.

	Candidate Models															
Occupancy Covariates	**"9"**	**"15"**	**"3"**	**"12"**	**"16"**	**"14"**	**"13"**	**"6"**	**"2"**	**"10"**	**"4"**	**"7"**	**"1"**	**"11"**	**"5"**	**"8"**
Competitors			X			X										
Competitors x Water Temp.*						X										
Dist. To Lg. Wetlands																X
First Flush (Before/After)														X	X	
Julian Day								X								
OMR														X		
Predation Intensity			X	X	X	X										
Predation x Water Clarity*					X											
Predation x Water Temp.*						X										
Region								X	X							
Salinity	X	X					X			X	X	X				
Subregion							X									
Tidal Current Speed											X		X	X		
Water Clarity			X	X	X		X	X	X	X	X	X	X		X	X
Water Temperature	X	X				X				X			X			
Water Temp. x Salinity*		X														
X2									X					X	X	

Detection Covariates																
Fork Length	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Previous FMWT Index												X				X
Previous STN Index													X			
Sample Volume	X	X	X	X	X	X	X	X	X	X	X			X	X	
Station Depth												X	X			X
Tidal Stage	X	X		X	X	X	X	X		X	X			X	X	
Time of Day			X	X					x							
Water Clarity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

*/ Interaction Covariate

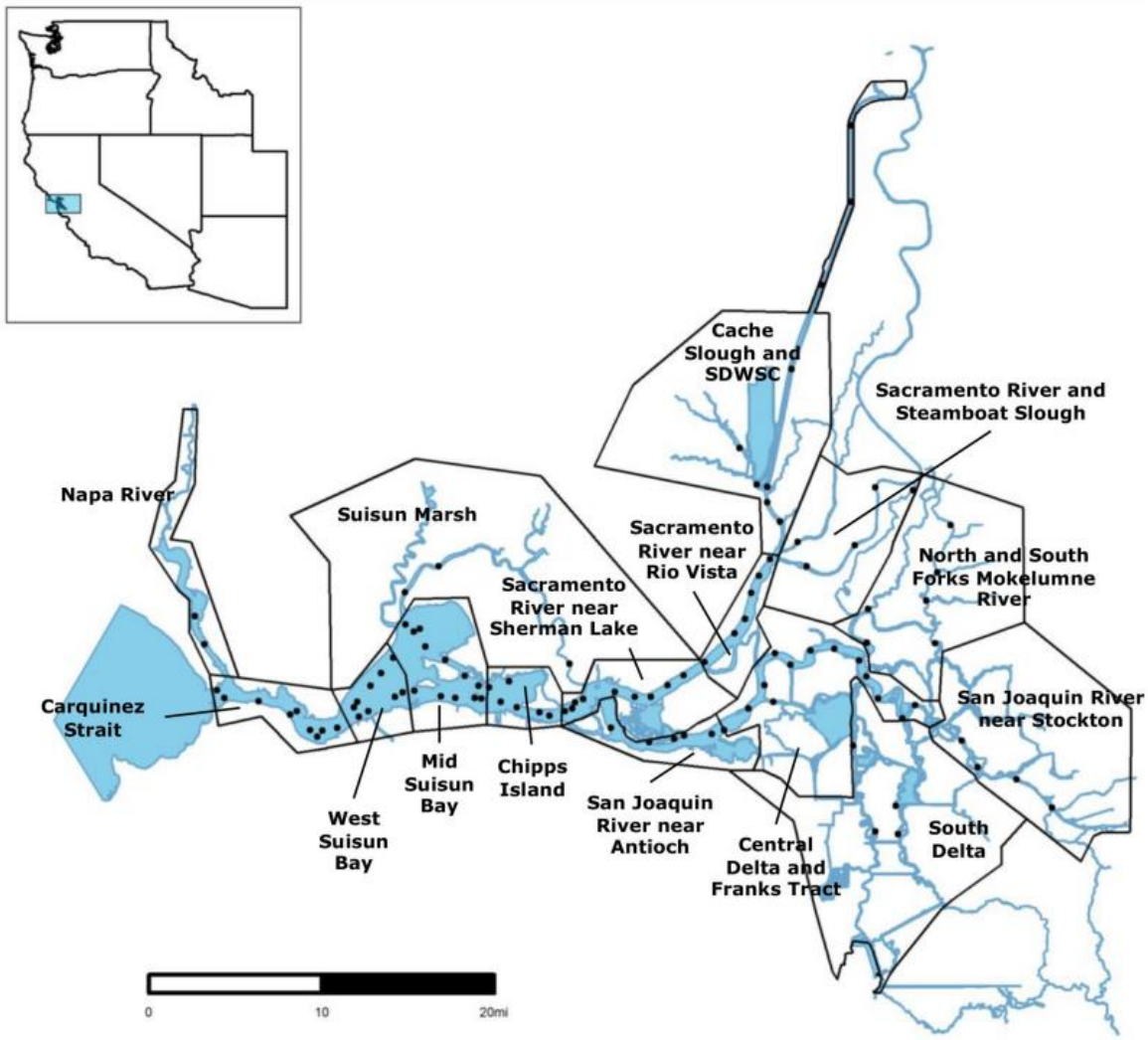

Fig. 1 Location of the upper San Francisco Estuary relative to the western United States (inset) and study area, regions, and subregions. The far west region includes Napa River, Carquinez Strait, and west Suisun Bay; West includes mid Suisun Bay, Suisun Marsh, Chipps Island, Sacramento River near Sherman Lake, and Sacramento River near Rio Vista; north includes Cache Slough and Sacramento Deep Water Ship Channel (SDWSC), Sacramento River and Steamboat Slough, and San Joaquin River near Antioch; and south includes Central Delta and Franks Fract, North and South Forks Mokelumne River; San Joaquin River near Stockton, and South Delta

INVESTIGATION CHALLENGES & LIMITATIONS

The sophisticated modeling and statistical methods used in the investigation come with challenging requirements. Also, characteristics of the methods and data employed can complicate interpretation of the study's results. Some of the challenges and possible limitations associated with the present investigation are listed separately, below, for the "Methods" and "Data", and briefly described.

Methods:

- Computational demands and other factors substantially limited the number of candidate models that could be assessed. Thus, only 16 candidate models were assessed, with a maximum of four covariates each for occupancy and detection.
- Regional and subregional occupancy, not Delta Smelt abundance, density, or recruitment, is the analytical endpoint of this study.
- The study defined "wet" and "dry" years by precipitation in the fall, not by precipitation in the previous Water Year (as has been done in most studies).

Data:

- The design of the FMWT Survey does not directly provide the replicate samples suggested for use in the analytical method employed in this study. To overcome this challenge the investigators treated monthly samples (trawls) from multiple stations within subregions as replicates. There is precedent for this approach in Bay-Delta fisheries science[6,7,8]. The DSST concurs that the study's approach to replication is reasonable, recognizing that the approach introduces some unknown level of imprecision in the study results.
- A potentially important "prey" covariate could not be derived due to a paucity of available data (at the subregional level). A well-conceived and well-populated prey covariate could, itself, be a consequential predictor of Delta Smelt occupancy, or the covariate might influence the method's perception of the importance of other covariates.
- Some covariates (for example, salinity and temperature) are 1) precisely measured, 2) measured contemporaneously with fish samples, and 3) are factors experienced

[6] Mahardja, B., L. Mitchell, M. Beakes, C. Johnston, C. Graham, P. Goertler, D. Barnard, G.Castillo, and B. Matthias. 2021. Leveraging delta smelt monitoring for detecting juvenile Chinook salmon in the San Francisco Estuary. *San Francisco Estuary and Watershed Science* 19.

[7] McKensie, R., B. Mahardja. 2021. Evaluating the role of boat electrofishing in fish monitoring of the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 19(1).

[8] Duarte A. and J.T. Peterson. 2021. Space-for-time is not necessarily a substitution when monitoring the distribution of pelagic fishes in the San Francisco Bay-Delta. *Ecology and Evolution*.

very directly by the fish. In contrast, another of the covariates used, X2 is calculated (not measured), is tidally averaged, and is not directly experienced by the fish. Consideration of the Fall Occupancy Study results should be mindful of the possibility that varying characteristics of the covariate data may influence the perceived relative ability of the covariates to predict occupancy.

The DSST and review panel have concluded that the investigators reasonably addressed the challenges listed above, given available resources and data. However, the DSST also concludes that an awareness of the possible implications of the method and data challenges should accompany consideration of the investigation's findings.

SUMMARY OF FINDINGS

The "Results" and "Discussion" sections of the published paper contain extensive descriptions of the Study's findings. The list below briefly highlights some of the key findings. The DSST has additional insights and commentary regarding the findings, which can be found in succeeding sections of this memo.

- Two of the Candidate Models (CM9 and CM3) performed particularly well in predicting subregional occupancy in comparison with the other 14 CMs. The best performing model, CM9, indicated that occupancy was associated with salinity and water temperature, and detection was associated with Delta Smelt length, sample volume, water clarity, and tidal stage.
- Within CM9 the salinity covariate had the greatest influence in the prediction of occupancy, much greater than water temperature. Occupancy was high at salinities below 5.6 PPS and declined at greater values. Only the highest temperatures, which occur primarily in September are likely to affect occupancy.
- The second-best performing model, CM3, indicated that occupancy was associated with the subregional abundance of Threadfin Shad (a hypothesized competitor), an expert elicited (not measured) index of predation intensity, and water clarity; and detection was associated with Delta Smelt length, sample volume, water clarity, and time of day. Within CM3 occupancy was sensitive to, and positively correlated with, the expert elicited predation intensity index covariate.
- Occupancy prediction was improved by combining ("stacking") combining CMs 9 and 3.
- None of the three CMs incorporating the X2 covariate were strongly predictive of occupancy.
- Patterns of occupancy were similar in wet and dry falls (as defined by fall precipitation), suggesting that Cache Slough and the lower Sacramento River to Suisun Bay may represent "core" habitat for Delta Smelt.

INVESTIGATION RESULTS RELATIVE TO OTHER STUDIES

As noted above, Hendrix et al (2022) found salinity and temperature to be the factors most influencing occupancy in the fall. Since 2016 eight other manuscripts have been published that consider factors affecting delta smelt occupancy and detection at various life stages (Table 3, see Supplemental Resources). Additional factors influencing occupancy that were identified in those studies include: turbidity, flow, prey, velocity, region, tide stage, and water body type. Some of those studies identified a set of factors that were believed to affect detection rather than occupancy. Those factors include: turbidity, tide stage, sampling volume, tow number, depth, fish length, month or season, and hours since sunrise. The present study and the investigation by Bever et al. (2016)[9] both utilized FMWT Survey data to assess occupancy, identified a similar "core" regional habitat for sub-adult Delta Smelt, and found salinity to be a robust predictor of sub-adult Delta Smelt occupancy.

ADDITIONAL DSST OBSERVATIONS

Many of the DSST's observations regarding the investigation and associated published paper are reflected in the above "INVESTIGATION CHALLENGES & LIMITATIONS" section of this memo. Following here are additional, more general observations.

- Subsequent to the initiation of this investigation in 2017 several other studies have been conducted and published which can collectively contribute to development of Delta Smelt-related fall flow (and other) management efforts. CAMT's SDM Project is also expected to contribute.
- Therefore, the results of this study should not be used alone to guide fall outflow management for the purposes Delta Smelt protection.
- The results of the investigation's unique application of sophisticated modelling and statistical methods to the FMWT data generally confirmed, but in some cases conflicted with, our understanding of Delta Smelt fall habitat associations.
- The study results identified lines of inquiry to further our understanding of habitat associations, for example exploring subregional X2/salinity relationships.
- It is unclear what aspects of the X2 and salinity covariates cause the differences in predicting occupancy. Additional model testing could assess these covariates in combination with other important covariates such as September-October water temperature and/or turbidity to better understand the relative performance of X2 and

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

salinity in predicting sub-adult Delta Smelt occupancy as these physical factors are managed in the Delta.

- The present study did not resolve ongoing questions regarding the degree turbidity as a detection factor influences perceptions of turbidity as a Delta Smelt habitat indicator. However, most DSST members still believe that turbidity remains a key component to Delta Smelt habitat and that it can affect catchability, but not to the extent it is the primary reason for why we observed the POD or Delta Smelt decline.

DSST RECOMMENDATIONS

There are many potential follow-on science activities that could aid in the interpretation of the present Fall Occupancy Study and/or address further lines of inquiry suggested by the investigation's results. Examples include:

- Conduct a "Round 2" of candidate model identification and assessment guided by the results of the initial investigation. Round 2 efforts might include: Re-assessment of the initial 16 candidate models using data only from the September-October X2 management period rather than the full four-month (September-December) period of the FMWT Survey, and/or assessing CMs that pair X2 with additional covariates that proved consequential in the initial investigation.
- Conduct an analysis of the sub-regional relationships between X2 and salinity and their relationship with Delta Smelt distribution (and vital rates).
- Integrate the present investigation results with the results of recent studies (e.g., Directed Outflow Project Report 3) of habitat use by individual Delta Smelt throughout their lifecycle.

Although these and many other potential follow-on activities might prove useful in furthering the understanding of factors affecting fall Delta Smelt occupancy, the DSST is not recommending aggressive pursuit of these potential activities at this time. The DSST is recommending that CAMT and the DSST focus on continuing support for the Delta Smelt Structured Decision Making (SDM) Project, and letting the SDM Project run its course before pursuing new or extended activities stemming from the Fall Occupancy Study. There is a concern that follow-on work from the Fall Occupancy could be redundant with, or rendered moot by, the SDM Project.

The SDM Project is a highly-collaborative, robust endeavor using lifecycle models to examine if, and to what extent, a variety of hypothetical management actions improve Delta Smelt habitat and the population. Collectively, the management actions act on the population through many of the Fall Occupancy Study candidate model covariates (e.g., salinity, temperature, and predation). Importantly, the SDM Project will address Delta Smelt prey effects, which the Fall

Occupancy Study was unable to do. The results of the Fall Occupancy Study are potentially useful to the SDM effort, so should be conveyed to the SDM consultants and Technical Working Group.

Finally, consideration should be given to having the DSST engage with the IEP Management Team and study managers to explore issues such as 1) augmenting FMWT Survey and Bay Study with synoptic zooplankton sampling to better assess relationships between predator and prey and 2) conducting limited (2-year, limited # of stations) collection of replicate tows to assess our understanding of survey detection capability. It is possible that studies of this nature are already underway or planned, but deliberate engagement would clarify the status of efforts for both parties' benefit.

SUPPLEMENTAL RESOURCES

Supplements to this memo can be found at https://csamp.baydeltalive.com/camt%20delta%20smelt%20work/delta-smelt-technical-studies. The materials located there include:

- The Hendrix et al. (2022), with its supplements https://csamp.baydeltalive.com/docs/26025
- An Excel file containing the data set used in the investigation https://csamp.baydeltalive.com/docs/26029
- Table 2: A table of abundance and distribution candidate models developed by the DSST, but ultimately not employed in the present study https://csamp.baydeltalive.com/docs/26027
- Table 3: A spreadsheet summarizing various other recent Delta Smelt occupancy investigations https://csamp.baydeltalive.com/docs/26028
- Outflow Abundance Candidate models https://csamp.baydeltalive.com/docs/26026