Delta RMP Steering Committee Teleconference Agenda

Wednesday, September 25, 2019, 3:30 – 4:30

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To dial in by phone: +1.415.594.5500
Conference ID: 238-626-034 #

1	**Introductions and Review Agenda** Introduce SC members, establish quorum, and explain the goals of the meeting. *Quorum requires 8 or more SC members OR 5 or more participant groups.*	3:30 Matthew Heberger
2	**Decision: Funding for mercury monitoring** Proposed mercury monitoring in FY19-20 includes a new component to monitor the effects of wetland restoration projects on mercury in the aquatic food chain. In July 2019, the TAC requested additional information before making a recommendation. Further, the SC asked for: (1) timelines for restoration projects, (2) where the proposed monitoring fits into the project timeline, (3) details on specific monitoring locations, and (4) how the proposed restoration monitoring would benefit the Delta as a whole. Since then, staff scientists have revised and expanded the proposal and added new details. At its September 13, 2019 meeting, the TAC consensus was to recommend that the SC approve the proposed mercury restoration monitoring study. The TAC further recommended that ASC staff add some details to the workplan and QAPP: (1) distance crews can go from target site, (2) how flows and hydrodynamics affect the connectivity between the sites, (3) information about RB2 monitoring at Winter Island, and (4) responses to other comments by Jennie Fuller at the Central Valley Water Board. This decision is timely as field crews wish to begin sampling in the first week of October. **Materials:** ● Revised mercury monitoring proposal ● September 13, 2019 Draft TAC meeting summary **Desired outcome:** ● Decision on whether to fund expanded mercury monitoring of wetland restoration projects.	3:35 Jay Davis

3	**Decision: Release provisional mercury data to Central Valley Water Board staff for use in updating the mercury TMDL** Staff of the Central Valley Regional Water Quality Control Board are currently working on updates to the methylmercury TMDL for the 2020 update to the Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin (Basin Plan). Board staff have requested early access to provisional Delta RMP mercury data, i.e. before it has undergone independent QA review by ASC. Our understanding is that, if changes are made to the data during the QA process, staff will update their calculations, and that the final proposed rule will be based on fully approved data. According to the Charter, the SC must approve all data and reports prior to their release. **Desired outcome:** ● Decision to authorize staff to release provisional data	4:15 Matt Heberger
4	**Wrap Up** ● Review decisions and action items	4:25
	Adjourn	4:30

Delta RMP Mercury Monitoring Proposal for Fiscal Year 2019 - 2020 (Year 4 of Delta RMP Mercury Monitoring)

Summary

Continued monitoring of methylmercury in Delta fish and water is proposed to address the highest priority information needs related to revision and implementation of the Methylmercury TMDL (re-opening of the TMDL is scheduled for 2020). The window for inclusion of new data in the TMDL revision could close as soon as December 2019. Monitoring with the design established in FY17-18 and continued in FY18-19 (Phase 1) is proposed to continue through October 2019. During the second half of the fiscal year (January-June 2020) a transition to a second phase (Phase 2) of monitoring is proposed. Phase 2 would address the critical need for continued monitoring of subregional trends in fish and water, and would add a monitoring element focused on assessing the local and subregional impact of habitat restoration projects on methylmercury impairment.

Three monitoring elements are proposed.

1. **Subregional trends in bass** - Continued annual monitoring of methylmercury in black bass ("black bass" includes largemouth, smallmouth, and spotted bass) at seven stations (distributed among the TMDL subregions) will firmly establish baseline concentrations and interannual variation in support of monitoring of long-term trends as a critical performance measure for the TMDL. The design from Phase 1 will continue unchanged in Phase 2. This design will be re-evaluated after completion of a 10-year period (2016-2025).
2. **Subregional trends in water** - Continued monitoring of methylmercury in water at six stations on a near-monthly basis during the biologically-relevant time period (Mar-Oct) will further solidify the linkage analysis (the quantitative relationship between methylmercury in water and mercury in sport fish) in the TMDL and be valuable in verifying trends and patterns predicted by numerical models of methylmercury transport and cycling being developed for the Delta and Yolo Bypass by the California Department of Water Resources (DWR) and the U.S. Geological Survey (USGS). These models will allow testing of various land and water management scenarios. The design

for water monitoring from Phase 1 will be scaled down from eight stations to six stations.

3. **Restoration monitoring** – In a new element added for Phase 2, annual monitoring methylmercury in black bass and prey fish at new stations (five for black bass and nine for prey fish) located near habitat restoration projects will assess the subregional impact of the projects on impairment. The details of the design for the restoration monitoring (station locations, mix of black bass and prey fish stations) has been determined with input from restoration managers and Delta RMP Mercury Subcommittee members. The San Francisco Bay Regional Water Board has obtained $30,000 for monitoring methylmercury impacts of a restoration project on Winter Island in the West Delta and will coordinate with the Delta RMP.

   The design will include:

- Subregional trends in black bass (7 stations sampled once per year in Aug-Sep);
- Subregional trends in water (8 stations, 4 events in Jul-Oct 2019; 6 stations, 4 events in Mar-Jun 2020);
- An interpretive report on the 3.5 years (August 2016 to October 2019) of monitoring to date that would inform the TMDL revision; and
- Initiation of baseline restoration monitoring in two Delta tidal wetland restoration areas in the Northeast Delta and Northwest Delta, with five added black bass stations (sampled annually beginning in September 2019) and nine added prey fish stations (sampled annually beginning in May-June 2020).

The total amount of funding requested from the Delta RMP to cover one year of work on all of these elements for the FY19-20 budget year is $360,000. The scope of the water monitoring for future years will be re-evaluated based on the analysis in the interpretive report included in this proposal. The prey fish monitoring is proposed to continue for three years with the design presented in this document, with an evaluation based on the first three years of data of whether to reduce the scope for subsequent years. Annual monitoring of bass for subregional trends and restoration is proposed to continue for the next several years, with a re-evaluation of the scope in 2025.

Management Drivers Addressed

Mercury monitoring addresses the Delta Methylmercury TMDL, which establishes goals for cleanup and calls for a variety of control studies and actions.

Management and Assessment Questions Addressed

The management and assessment questions addressed by each of the methylmercury monitoring elements are indicated in Table 1. In addition, the combination of water and fish monitoring addresses a critical data need for management that is not captured in the current set of questions for the Delta RMP: data to strengthen the linkage analysis that is a key component of the technical foundation for the Methylmercury TMDL. The Phase 2 monitoring would also address an additional set of sub-questions specific to understanding and managing the impact of thousands of acres of tidal marsh restoration on mercury impairment.

Data Quality Objectives/Null Hypothesis

The initial and preliminary data quality objective (DQO) for subregional bass trend monitoring is the ability to detect a trend of mercury in fish tissue of 0.040 ppm/yr. This DQO can be refined when additional data are available. The null hypothesis states that there is not a trend. Measurement quality objectives (MQOs) are identical to those used in other mercury studies throughout the state and the country for determinations of impairment and trend detection. These MQOs generally call for indices of accuracy and precision to be within 30% of expected values.

The subregional water and fish monitoring is primarily being collected to solidify understanding of the correlation of fish methylmercury with aqueous unfiltered methylmercury (i.e., the linkage analysis) and to provide essential input data for the models being developed by DWR and USGS. Hypothesis testing relating to patterns in space and time will not be a primary use of the water data.

For prey fish sub-questions 1, 2, and 3 (Table 4), based on data collected for the same target species with the same design in the North Bay Biosentinel (NBB) Project, ANOVAs to detect differences in means across groups of stations will have high power (> 0.99), and pairwise comparisons will have 80% power to detect a difference of 0.023 between stations or time intervals. A preliminary power analysis based on the NBB data indicates that the prey fish design would have a 79% probability of detecting a trend of 0.002 ppm/yr in a 10 year period.

Detailed Proposal: Monitoring to Support Implementation of the Methylmercury TMDL

Background and Motivation

Concentrations of methylmercury in fish from the Delta exceed thresholds for protection of human and wildlife health. The Methylmercury TMDL (Wood et al. 2010) is the driver of actions to control methylmercury in the Delta, establishing water quality goals and directing various discharger groups to conduct monitoring and undertake control studies to evaluate their ability to achieve their allocated load reductions.

The TMDL established three water quality objectives for methylmercury in fish tissue: 0.24 ppm in muscle of large, trophic level four (TL4) fish such as black bass ("black bass" includes largemouth, smallmouth, and spotted bass); 0.08 ppm in muscle of large TL3 fish such as carp; and 0.03 ppm in whole TL2 and TL3 fish less than 50 mm in length. Furthermore, the TMDL established an implementation goal of 0.24 ppm in largemouth bass at a standard size of 350 mm as a means of ensuring that all of the fish tissue objectives are met. Largemouth bass are widely distributed throughout the Delta and are excellent indicators of spatial variation due to their small home ranges. Past data for largemouth bass were a foundation for the development of the TMDL, including the division of the Delta into eight subregions. Monitoring of largemouth bass in these subregions therefore provides the most critical performance measure of progress in addressing methylmercury impairment in the Delta.

The TMDL describes a statistically significant relationship between the annual average concentration of methylmercury in unfiltered water and average mercury in 350 mm largemouth bass when data are aggregated by subregion. This linkage provides a connection, essential for management, between methylmercury inputs from various pathways (e.g., municipal wastewater, municipal stormwater, agricultural drainage, sediment flux in open waters, and wetland restoration projects) and impairment of beneficial uses. Because of this linkage, the TMDL established an implementation goal of 0.06 ng/L of unfiltered aqueous methylmercury. In response to TMDL control study requirements, the Department of Water Resources (DWR) is leading development of numerical methylmercury transport and cycling simulation models for the Delta and Yolo Bypass. Monitoring of aqueous methylmercury is therefore needed to:

1) better quantify the fish-water linkage that is the foundation of the TMDL,
2) evaluate attainment of the TMDL implementation goal,
3) support calculations of mercury and methylmercury loads and mass balances,

4) support development of mercury models for the Delta and Yolo Bypass, and
5) support evaluation of the fish data by providing information on processes and trends.

In FY 2016-2017 the Delta RMP initiated a methylmercury monitoring program for fish and water. Largemouth bass were collected in late summer 2016 (September) from six stations distributed across the subregions. Quarterly sampling of methylmercury and mercury (and ancillary parameters) in water at five stations began in August 2016.

In FY 2017-2018, methylmercury monitoring of fish and water continued. Funding was allocated to sample fish at six stations and water at six stations for eight months. The eight months to be sampled were to be the March-October period used for the linkage analysis in the TMDL. In late 2017, the Mercury Subcommittee decided, based on data needs related to a Regional Board decision to revise the TMDL in 2020, that a more optimal use of the available funds would be to shift to sampling water at eight stations (adding stations in the West Delta and at the export pumps) and to add water sampling in January and February (Table 2). This design would provide information to update the methylmercury mass balance for the Delta by sampling two export stations (in the West Delta and at the pumps) and sampling during high flows in the winter. The FY 2017-2018 plan also included funds for quarterly sediment sampling to support the DWR methylmercury modeling effort, and any future methylmercury modeling.

In FY 2018-2019, the design that was established in the latter part of FY 2017-2018 was continued, with sampling of fish at seven stations in August/September and sampling of water at eight stations monthly during the biologically-relevant period (March-October) plus two high flow months (January and February 2019) to inform the loads assessment (Table 2). Sediment sampling was discontinued due to funding limitations.

The management questions established at the outset of the Delta RMP to guide mercury monitoring included questions related to assessing the impact of wetland restoration (Table 1). Due to the higher immediate priority of monitoring subregional trends in black bass and water driven by information needs related to revising the TMDL in 2019/2020, as well as budget limitations, Delta RMP mercury monitoring has not yet specifically addressed those questions.

The window for inclusion of new data in the TMDL revision is closing in late 2019. A second phase (Phase 2) of monitoring is proposed that would address the critical need for continued monitoring of subregional trends in fish and water, and would add a new monitoring element specifically focused on assessing the local and subregional impact of selected habitat restoration projects on methylmercury impairment.

Large scale restoration of wetlands and other habitats is currently underway as a means of supporting the recovery of declining fish populations and the health of the Delta ecosystem in general. The Delta is the largest estuary on the West Coast. For centuries, the Delta was a dynamic and rich ecosystem of tidal wetlands, riparian forests, and vast seasonal floodplains. But about 98% of the native habitat disappeared after the Gold Rush and ensuing population growth. The spike in human development contributed to a decline in native fish, wildlife, and plants. Multiple important fish species are in decline, including salmon, the endangered Delta Smelt, and a more general phenomenon known as the “Pelagic Organism Decline” that includes several other fish species. In addition to their value as fish habitat, wetlands also provide other benefits including enhancing water quality and opportunities for recreation.

The State of California recognizes the critical need to restore the Delta’s natural habitat and protect water for fish and human uses (http://resources.ca.gov/ecorestore/). In 2015, the California Natural Resources Agency embarked on an initiative – California EcoRestore - to restore 30,000 acres of habitat across the Delta in the next few years. The Department of Water Resources is the lead agency on 28 of 30 EcoRestore projects. California EcoRestore is the primary initiative for restoring wetlands and other habitats in the Delta (Figure 1). Included in the 30,000 acres are 9,000 acres of tidal and sub-tidal habitat (including tidal marsh), 17,500 acres of floodplains, and 3,500 acres of managed wetlands.

While this restoration activity will provide a tremendous net benefit to the Delta, it may have a side-effect of increasing concentrations of mercury in the estuarine food web and exacerbating the existing mercury problem (Davis et al. 2003). Mercury exists in the environment in a variety of forms and has a complex biogeochemical cycle. The most hazardous form, methylmercury, is produced at a relatively high rate in wetlands and newly flooded aquatic habitats, such as floodplains. A variety of mercury sources, largely related to historic mercury and gold mining, is present in the watershed and has created a spatially heterogeneous distribution of mercury in the Bay-Delta Estuary. It is likely that distinct spatial variation on multiple spatial scales exists in net methylmercury production in Bay-Delta tidal wetlands, including variation within each tidal wetland, among tidal wetlands in the same region, and among tidal wetlands in different regions. Understanding this spatial variation and its underlying causes will support efforts to minimize the negative effects of mercury bioaccumulation as a result of restoration activities.

Davis et al. (2003) outlined actions needed to reduce the uncertainty related to the impacts of wetland restoration on mercury in the Estuary food web, including a long-term, multifaceted research effort, long-term monitoring on local and regional scales, and careful evaluation of individual restoration projects with regard to potential increase of food web mercury. Also in 2003, the California Bay-Delta Authority published a “Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration” written by several of the nation’s leading mercury scientists (Wiener et al. 2003). One of the recommendations in this Strategy was “to document the effects of wetland restoration activities on the abundance and distribution of methylmercury by incorporating process-based investigations and analyses of biosentinel species into restoration projects.”

In 2013, the Regional Monitoring Program for San Francisco Bay convened national mercury experts and scientists and managers from the Bay-Delta region for a "Forum on Science to Support Management of Methylmercury in Restored Tidal Marshes" (www.sfei.org/calendar_events/4326). Forum participants agreed on the following points.

- Biosentinel monitoring (e.g., with prey fish or piscivorous fish) should be used to generate hypotheses and process studies should be used to test hypotheses.
- Process studies should be done at a subset of monitored sites.
- A regional approach to monitoring is needed, with some sites selected for detailed investigation.

Consistent with these points, biosentinel monitoring provides a cost-effective means of characterizing patterns of methylmercury impairment in space and time, and identifying areas of particular management or scientific interest. Process studies to determine the causes of observed patterns are more resource-intensive and will therefore need to be done in a more targeted manner. Process studies are not being proposed as part of the Delta RMP Phase 2 monitoring.

In 2012-2014 and 2016-2017, the North Bay Biosentinel Project (Robinson et al. 2018) implemented a biosentinel monitoring program guided by the principles outlined in the Methylmercury Forum. The biosentinel monitoring design outlined in this proposal is based on the experience gained from the North Bay Biosentinel Project.

Proposed Approach for FY 2019-2020

Monitoring with design established in FY17-18 and continued in FY18-19 (Phase 1) is proposed to continue through October 2019. An interpretive report covering the first 3.5 years of monitoring (from August 2016 to October 2019) will be prepared in December 2019 to inform the TMDL deliberations. During the second half of the fiscal year (January-June 2020) a transition to a second phase of monitoring (Phase 2) is proposed. Phase 2 would add a monitoring element focused on assessing the subregional impact of habitat restoration projects on methylmercury impairment.

Three monitoring elements are proposed for the second phase of Delta RMP methylmercury monitoring.

1. **Subregional trends in bass** - Continued annual monitoring of methylmercury in black bass at seven stations will firmly establish baseline concentrations and interannual variation in support of monitoring of long-term trends as a critical performance measure for the TMDL. The design from Phase 1 will continue unchanged in Phase 2. This design will be re-evaluated after establishment of a 10-year time series.
2. **Subregional trends in water** - Continued monitoring of methylmercury in water on a near-monthly basis will further solidify the linkage analysis in the TMDL and be

valuable in verifying trends and patterns predicted by a numerical model of methylmercury transport and cycling being developed for the Delta and Yolo Bypass by DWR - this model will allow testing of various land and water management scenarios. The design for water monitoring from Phase 1 will be scaled down from eight stations to six stations. The need for continuation of this monitoring, including the duration and the level of effort, will be assessed as part the interpretive report on phase 1 of the monitoring.

3. **Restoration monitoring** - In a new element added for Phase 2, annual monitoring of methylmercury in black bass and prey fish at new stations located near habitat restoration projects will assess the subregional impact of the projects on impairment. The details of the design for the restoration monitoring (station locations, mix of bass and prey fish stations) has been determined with input from restoration managers and Delta RMP committee members. The San Francisco Bay Regional Water Board has obtained $30,000 for monitoring methylmercury impacts of a restoration project on Winter Island in the West Delta and will coordinate with the proposed Delta RMP monitoring. This monitoring should begin with a level of effort that is sufficient to detect the potential subregional impact of restoration projects, and could be tapered off over time if the early results indicate a lack of impact.

Applicable Management Decisions and Assessment Questions

The Delta Methylmercury TMDL is the embodiment of management decisions for methylmercury in the Delta, establishing goals for cleanup and calling for a variety of control studies and actions. With providing information to support TMDL implementation in mind, the Mercury Subcommittee carefully considered the assessment questions articulated by the Steering Committee and Technical Advisory Committee for mercury.

The Delta RMP management and assessment questions addressed by each of the methylmercury monitoring elements are indicated in Table 1. In addition, the combination of water and fish monitoring addresses a critical data need for management that is not captured in the current set of questions for the Program: data to strengthen the linkage analysis that is a key component of the technical foundation for the TMDL.

Monitoring of subregional trends in black bass addresses questions relating to Status and Trends, Forecasting, and Effectiveness Tracking. Status and Trends Question 1A is a high priority for managers that relates to the TMDL, and is a primary driver of the sampling design for subregional bass trend monitoring. Annual monitoring of bass mercury is urgently needed to 1) firmly establish a baseline for each Delta subregion and 2) to characterize the degree of interannual variation, which is essential to designing an efficient monitoring program for detection of long-term trends. In addition to addressing status and trends, this monitoring will provide an essential foundation for Forecasting Scenarios (past trends are a starting point for projecting future conditions) and Effectiveness Tracking (evaluating whether water quality is improving at the subregional scale as a result of management actions).

Monitoring of subregional trends in water addresses all of the major categories of Delta RMP management questions (Status and Trends; Sources, Pathways, Loadings, and Processes [SPLP]; Forecasting Scenarios; and Effectiveness Tracking). Data on concentrations of methylmercury in water are valuable as an indicator of Status and Trends as they can be compared to the TMDL implementation goal of 0.06 ng/L of unfiltered aqueous methylmercury. The use of water data to update the mass budget addresses SPLP Question 1A and is a key element of the TMDL. Aqueous methylmercury concentrations are essential input and validation data for the models that DWR and USGS are developing for the Delta that will elucidate the processes affecting methylmercury patterns and allow forecasting and testing of various water management scenarios (DiGiorgio et al. 2016; Windham-Myers et al., 2016). Water concentration data will also be valuable in Effectiveness Tracking, allowing assessment of status relative to the implementation goal and of changes in loading in the context of the overall mass budget for the Delta.

Monitoring of subregional trends in bass and water also provides information on the influence of climate, hydrology, and ecology. For example, the first two years of monitoring (2016 and 2017) have already spanned the end of a prolonged drought and a high flow year, providing an opportunity to examine the impact of extreme variation in flow on methylmercury concentrations in fish and water.

Restoration monitoring addresses questions relating to SPLP, Forecasting Scenarios, and Effectiveness Tracking (Table 1). The basic concern with restoration projects is that they may enhance net methylmercury production within the Delta ecosystem, and represent an internal source that increases as projects proceed (SPLP Question 1B) – restoration monitoring will track whether this occurs or not. Restoration monitoring will yield insights into which types of projects, if any, impact net methylmercury production and food web accumulation (Forecasting Scenarios Question 1) and whether internal loadings change and ambient water quality shows net improvement as a result of restoration projects (Effectiveness Tracking).

Approach

Design Summary: Subregional Trends in Bass

Design	7 fixed stations (Figure 2), black bass only
Key Indicator	Annual average methylmercury in muscle fillet of 350 mm largemouth bass (or similar predator species, i.e., smallmouth bass or spotted bass), derived through analysis of 16 individual bass or other predator species at each station

Parameters	Total mercury*, Total length, Fork length, Weight, Sex, Moisture, Estimated age
Frequency	Annual
Schedule	Sample in August and September
Duration	Monitor through 2025 and then re-evaluate
Co-location	Water MeHg and Hg Other water parameters
Contractors	SFEI (design, data management, reporting), MLML (sample collection, chemical analysis, reporting)
Coordination	DWR, USGS (sampling of flow monitoring stations)
Cost	$61,000

* Total mercury measured as proxy of methylmercury because methylmercury comprises more than 90% of the total mercury in sport fish.

Summary of Results to Date

Results from the first year of DRMP methylmercury monitoring are presented in the Year One Data Report (Davis et al. 2018) and the Year Two Data Report (Davis et al. 2019). The reports provide details on the sample collection and processing, chemical analysis, quality assurance, and the analytical results. Highlights of the results are briefly discussed here.

Results from the first two rounds of DRMP fish monitoring are presented in **Figure 3**, with data from prior fish sampling in or near these stations provided for context. Time series with more than three observations are available for four of the six stations. The existing time series are characterized by a high degree of inconsistency in stations, species, and sampling approach over time, highlighting the need to build a consistent dataset for trend evaluation. The data do suggest a preliminary answer to management question 1A, and a possible effect of the very high flows in 2017. Up through 2016, the data suggested a decline in concentrations at the San Joaquin River at Vernalis over the period of record, while concentrations appeared to be stable at the other three stations. Therefore, the data give a preliminary indication that trends do vary among the Delta subregions (addressing one of the Delta RMP management questions – Table 1). In 2017, concentrations were significantly higher than in 2016 at four of the six stations, most markedly at the Mokelumne River station, suggesting a possible effect of the high flows in that year, again with variation among the subregions in the degree of increase. Additional rounds of consistent sampling are needed to confirm the long-term patterns and the potential influence of hydrology in 2017.

Power to Detect Long-term Trends - Bass Sampling

The power to detect interannual trends in largemouth bass mercury on a per station basis was evaluated using existing data. Even the best existing time series for the Delta have low statistical power to detect trends due to infrequent sampling and varying sampling designs of studies performed over the years (**Figure 3**). One of the goals of the initial phase of Delta RMP fish mercury monitoring is to obtain robust information on interannual variation to support future power analysis. As part of the mercury proposal for FY 2017-2018 we conducted a power analysis on the small amount of information presently on hand. Appendix 2 provides the methods and details on the results. This analysis will be updated after a few years of new data have accumulated.

Power analysis summary

Table 5. Power for trend detection at a single station based on grand mean estimates of observed variance across stations. Pink shading indicates scenarios with greater than 80% power.

		10 Years		20 Years		30 Years	
Trend	N Fish/Yr	Annual	Biennial	Annual	Biennial	Annual	Biennial
0.010 ppm/yr	12	0.11	0.09	0.20	0.15	0.40	0.27
0.020 ppm/yr	12	0.13	0.13	0.44	0.27	0.81	0.60
0.030 ppm/yr	12	0.21	0.17	0.69	0.45	0.99	0.85
0.040 ppm/yr	12	0.29	0.19	0.88	0.61	1.00	0.98
0.010 ppm/yr	16	0.21	0.19	0.33	0.27	0.55	0.44
0.020 ppm/yr	16	0.27	0.24	0.65	0.46	0.93	0.77
0.030 ppm/yr	16	0.36	0.32	0.86	0.64	1.00	0.96
0.040 ppm/yr	16	0.47	0.36	0.97	0.82	1.00	1.00

These preliminary results indicated that increasing the number of fish per station would be effective in increasing power. With 16 fish per station and annual sampling, 80% power would be expected for several of the 20-year scenarios. Beginning with year 2 (FY 2017-2018) the design for fish monitoring was therefore modified to include 16 fish per station. The monitoring results for the San Joaquin at Vernalis suggest that trends of up to 0.040 ppm/yr are possible. The results highlight the importance of initiating consistent time series.

Design Summary: Subregional Trends in Water

Design	8 fixed stations through October 2019; 6 stations after that (dropping the Mallard Island and Mendota Canal stations (**Figure 2**)
Key Indicator	March-October average total (unfiltered) methylmercury at each station
Parameters	Total (unfiltered) methylmercury, filtered methylmercury, unfiltered total mercury, filtered total mercury, total suspended solids (TSS), chlorophyll-a, dissolved organic carbon, volatile suspended solids. Field measurements will include dissolved oxygen, pH, and specific conductance.
Frequency	8 events per year
Schedule	Two 4-month blocks (Jul-Oct; Mar-Jun) of monthly samples
Duration	Monitor through FY 19-20 and then re-evaluate
Co-location	Sport fish sampling Other water parameters
Coordination	DWR, USGS (sampling of flow monitoring stations)
Cost	$187,000

Summary of Results to Date

Results for March-October average total (unfiltered) methylmercury at each station for the first year of sampling are briefly summarized here. Data for the other water parameters are presented in the Year One Data Report (Davis et al. 2018) and the Year Two Data Report (in prep).

Concentration of MeHg in unfiltered water ranged from 0.044 – 0.385 ng L^{-1}. **Figure 4** presents long-term time series of March to October annual averages of unfiltered MeHg concentrations for Delta RMP stations. Sacramento River concentrations have remained constant with good agreement between historic data and current data. Lower Mokelumne results were similar to previously reported values given the large variability of MeHg concentrations for this site. Cache Slough MeHg concentrations were in good agreement with previously reported values. No historic data are available for Little Potato Slough, but MeHg concentrations were consistent with results reported for 2016. Middle River MeHg concentrations were within the range of historic data. San Joaquin River 2017 and 2018 MeHg concentrations were similar to previously reported values with 2017 on the higher end and 2018 on the lower end when compared to historic results. Sacramento River at Mallard 2018 results were in good agreement with previously reported MeHg concentrations. Delta Mendota Canal MeHg concentrations were within the range of previously reported values.

Power Analysis - Water Sampling

Not applicable. The primary objectives of the water sampling are to strengthen the linkage analysis and support model development. The water monitoring is not intended as a primary tool for long-term trend monitoring.

Design Summary: Restoration Monitoring

Design	5 new black bass fixed stations and 9 new prey fish fixed stations in two areas – Northeast Delta and Northwest Delta (Figures 5 and 6)
Key Indicator	Bass: Annual average methylmercury in muscle fillet of 350 mm largemouth bass (or similar predator species, i.e., smallmouth bass or spotted bass), derived through analysis of 16 individuals at each station Prey fish: Annual average methylmercury in whole fish, based on 6 composites of 10 individuals of the indicator species at each station
Parameters	Total mercury, Total length, Fork length, Weight, Sex, Moisture, Estimated age*
Frequency	Annual
Schedule	Bass: sample in August-September Prey fish: sample in April-June
Duration	Monitor through 2023 and then re-evaluate
Co-Location	None
Contractors	SFEI (design, data management, reporting), MLML (sample collection, chemical analysis, reporting)
Coordination	Coordinated with Region 2 monitoring in the West Delta ($30K over 2 years in funds from Region 2)
Cost	$78,000 total for the year for monitoring the Northeast Delta and Northwest Delta (all from Delta RMP)

* for bass only

Restoration monitoring will focus on two areas in the Delta where restoration activity is concentrated (Table 3, Figures 1, 4, 5). In each of these areas, bass stations and prey fish stations are strategically located. The details of the design for the restoration monitoring (station locations, mix of bass and prey fish stations) have been determined with input from restoration managers and Delta RMP committee members. The bass station locations have been selected to detect the potential aggregate impact of restoration projects at the subregional scale. Prey fish station locations have been selected to a) link specific restoration projects to the trends that are observed in the bass, and b) track trends in reference tidal wetlands to aid in the interpretation of the prey fish data from the project-specific stations. Table 3 provides a summary of the rationale for each station. The time series obtained for the bass and prey fish at these stations will be compared to each other, to the subregional bass trend stations, and to historic data (Table 3) to evaluate whether restoration causes a subregional increase in methylmercury in fish.

The proposed design represents a practical regional approach to monitoring the impact of restoration on mercury in the Delta in a cost-effective manner. The Northeast and Northwest Delta areas selected for monitoring have the greatest concentration of tidal marsh restoration in the Delta (Figure 1). The West Delta, where San Francisco Bay Regional Water Board (Region 2) funds will support limited monitoring, is another area where restoration activity is focused. Monitoring with a consistent design across these top priority areas, and with a tie-in to the existing network of black bass monitoring stations will go a long way toward providing a regional assessment with the limited funds available, and understanding how representative the subregional trend stations are.

The sooner these restoration monitoring time series are initiated, the more valuable they will be for detecting the impacts of restoration projects. Some of the restoration projects have not yet been implemented, and some have been implemented recently (Table 3). Available project fact sheets are compiled in Appendix 1.

The five black bass stations added for restoration monitoring will extend the existing design for monitoring subregional trends in bass, with intensified monitoring in the two areas where restoration activity is focused. The design considerations for this work are the same as those that have applied for the subregional bass monitoring for the past three years, including the power analysis presented for that element above.

The prey fish monitoring will answer different questions than the bass monitoring, and have a different design and statistical framework. The elements of the design are presented in Table 4, following the seven-element structure recommended by USEPA (2006). Element 1, the problem statement, was presented above in “Background and Motivation.” Element 4, study boundaries, are common to all of the questions and are described in the text below. Element 7, the plan for obtaining the data, was outlined in the "Design Summary: Restoration Monitoring" also presented above.

Prey fish have a smaller home range than black bass and can be sampled within restoration projects. They can therefore be used as indicators of methylmercury accumulation and impairment within specific projects, similar reference wetlands, and also on small spatial scales around the restoration areas. They are therefore useful indicators for tracking whether restoration projects are associated with a local increase in fish mercury within the projects relative to other areas or to historic data.

Prey fish species also integrate food web mercury concentrations over shorter time spans than bass. The small size classes to be collected are mostly young-of-the-year, and thus are integrating over several months, in contrast to bass whose tissues reflect exposure primarily from the most recent six months prior to sampling, but also to some extent exposure from previous years (Greenfield et al unpublished). Prey fish therefore are highly responsive temporal indicators, well-suited to detecting near-term changes in biotic exposure after restoration is initiated.

Prey fish are therefore well-suited as indicators to answer the questions listed in Table 4, In summary, the prey fish biosentinel monitoring will provide a means of screening to inform managers of problem areas and areas with low concentrations, the magnitude of any problems, and whether any problem levels are associated with increases at a subregional scale and persist over time.

The biosentinel monitoring will not, and is not aiming to, identify the *causes* of any high or low concentrations observed. More focused process studies would be needed to do that. The biosentinel monitoring will be very helpful, however, in determining where to conduct process studies (i.e., generating hypotheses, as discussed in the Methylmercury Forum).

The prey fish sampling will be conducted in a manner that is consistent with past monitoring (Slotton et al. 2002, 2007) to allow comparisons to concentrations observed historically. Species and size ranges used in the past will also be used in this study.

The primary target species will be Mississippi silverside (*Menidia audens*) (http://calfish.ucdavis.edu/species/?uid=92&ds=698) with a target size range of 45-75 mm. Mississippi silverside is the species that has been sampled most extensively in the Delta in the past, and has also been sampled extensively in the Bay (Greenfield et al. 2013a, b). This size range was used by Slotton et al. (2007) and again by Slotton in the North Bay Biosentinel Project

(Robinson et al. 2018). To economize on the costs of mercury analysis, composites of fish will be analyzed, following the approach used in the North Bay Biosentinel Project. Six composites will be prepared across 5 mm increments between 45 and 75 mm. Linear regression of the concentrations obtained will be used to estimate a station mean adjusted for a length of 60 mm.

Young-of-the-year (YOY) largemouth bass (*Micropterus salmoides*) will be an important secondary target species, as it was in Slotton et al. (2007). In particular, this species was more abundant than silverside in the Northeast Delta area around the McCormick-Williamson Tract. YOY largemouth have more recently been sampled extensively in lakes and reservoirs across the state as part of fish mercury monitoring by the Surface Water Ambient Monitoring Program (SWAMP). We will target YOY largemouth in the 50-110 mm range, preparing six composites in 10 mm increments across this range. Linear regression of the concentrations obtained will be used to estimate a station mean adjusted for a length of 85 mm (as used by Slotton et al. [2007]).

Prey fish will be collected in the spring and early summer (May-July), coinciding with the breeding and fledging season for piscivorous birds. One of the additional benefits of prey fish sampling is its value in characterizing mercury exposure in piscivorous wildlife, and evaluating impairment relative to the 0.05 ppm statewide objective for mercury in prey fish for any species between 50-150 mm in length. Sampling during this time of year is also better logistically in terms of collection permits and avoiding impacts on fall salmon runs.

Prey fish stations at restoration project sites were chosen to include major tidal restoration projects in the Northwest and Northeast Delta. Stations were selected with input from DWR and others. Restoration project sites included areas that had recently (within the past 10 years) been restored to tidal action, and for which tidal marsh was the expected restoration endpoint. These sites differ in their age, vegetation, channelization, and position in the Delta, and therefore represent a range of conditions that might influence mercury dynamics.

The concept of reference stations in the Delta is tricky because there are few old, unrestored marshes in the Delta, and most are small in size. In addition, conditions in the Delta are highly variable and dynamic, making it difficult to pair sites in restoration/control way. Rather than assigning specific reference sites to pair with specific restoration projects, we added "reference" sites in marshes that were more than 10 years old (often the result of accidental restoration as the result of unplanned breaches). These reference stations will help us to sample across the range of conditions in the Delta to get a more complete picture of ambient mercury levels in prey fish in these Northwest and Northeast Delta areas.

The Region 2 Water Board has obtained $30,000 for monitoring methylmercury impacts of a restoration project on Winter Island in the West Delta and is interested in coordinating and fitting in with the proposed Delta RMP monitoring. The Region 2 funds will allow for limited monitoring in the West Delta using a similar design in and around the Winter Island project. Prey fish monitoring using the same design described above will be conducted. The funds will allow for sampling of three stations in both 2020 and 2021. Station selection will be made by Region 2 in consultation with the Mercury Subcommittee.

Other biosentinel restoration monitoring projects in the region have shown that restoration in some instances does not lead to methylmercury increases (e.g., Robinson et al. 2018). If prey fish stations are yielding results that indicate a lack of change from baseline conditions, they can be phased out. In 2024, the program should evaluate the results from the first three years of monitoring and determine whether monitoring can be scaled back.

Power Analysis – Restoration Monitoring

The power of the proposed design to detect differences between stations, differences between new and historic data within a station, differences between years for new data, and long-term temporal trends were evaluated using recent data generated by Slotton for the North Bay Biosentinel (NBB) Project. The design in this proposal for Mississippi silverside is the same design used in the NBB Project: estimation of length-adjusted means for Mississippi silverside based on analysis of six composite samples across the 45-75 mm size range. One of the goals of the initial phase of Delta RMP prey fish mercury monitoring is to obtain robust information on interannual variation to support future power analysis. This power analysis will be updated after three years of new data have accumulated.

The specifications and results of the power analysis are presented in Table 4. For prey fish sub-questions 1, 2, and 3, the same basic statistical tests will be used to detect differences in mean concentrations among stations in space and time: ANOVA to detect overall differences among groups of stations, and t-tests to detect differences in pairwise comparisons of stations. Based on the NBB data, these ANOVAs will have high power (> 0.99) to detect differences among groups of station means. The pairwise comparisons will have 80% power to detect a difference of 23 ppb between stations or time intervals.

Some prey fish stations may be selected for long-term monitoring. For example, if elevated concentrations are observed at a project, it will be valuable to track whether the elevated concentrations persist or decline over time. Power for trend detection at a single prey fish station was estimated based on data obtained for silverside in the NBB project using the same sampling design, and is summarized below in Table 5. The analysis indicates 79% power to detect a trend of 2 ppb/yr in a 10 yr timeframe. This analysis will be updated with data for the stations of interest after three years of monitoring.

Table 5. Power for trend detection at a single station based on grand mean estimates of observed variance across stations. Pink shading indicates scenarios with greater than 80% power.

SCENARIO 1 - MEAN			10 Years		20 Years		30 Years	
Site Variance	Trend	N Comps/Yr	Annual	Biennial	Annual	Biennial	Annual	Biennial
Grand Mean	2 ppb/yr	6	0.79	0.72	0.86	0.81	0.90	0.85
Grand Mean	5 ppb/yr	6	0.80	0.73	0.87	0.83	0.90	0.86
Grand Mean	10 ppb/yr	6	0.81	0.73	0.88	0.83	0.90	0.86

Data Quality

The measurement quality objectives (MQOs) for measurements of methylmercury and mercury in fish and water are documented in the QAPP for the Delta RMP Yee et al. (2019). These MQOs are the same as MQOs used in mercury studies throughout California, with statewide fish monitoring by the SWAMP as a prominent example. The MQOs generally call for indices of accuracy and precision to be within 30% of expected values. Data of this quality are routinely used for determinations of impairment and trend detection throughout the state and the country. The variance attributable to the analytical process is one of the contributors to the overall variance observed in the data. This variance is therefore accounted for in the power estimates provided in the previous sections.

Reporting and Deliverables

With three years of monitoring completed, and an opportunity to inform the revision of the TMDL, the fall of 2019 will be an opportune time to prepare an interpretive report that provides a more thorough assessment of the dataset generated by this program and a comparison to data from other studies. This report will be drafted by December 2019 so the findings can be considered in the process of TMDL revision.

Deliverable	Due Date
Draft Interpretive Report on Years 1-3	December 2019
Final Interpretive Report on Years 1-3	March 2020
Draft Data Report on Year 4 (FY 19-20)	December 2020
Final Data Report on Year 4 (FY 19-20)	March 2021

Budget

	19/20
Core Bass (7 sites from 18/19 on)	61
Water (6 sites, 8 events after Jan 20)	186
Sediment	
Oversight, Coord., Data Mgt, Reporting	60
Restoration	78
Total	385
MLML In-Kind	25
Delta RMP	360

Multi-Year Plan Budget

Proposed Multi-Year Plan With Restoration (no West Delta)	**16/17**	**17/18**	**18/19**	**19/20**	**20/21**	**21/22**	**22/23**
Core Bass (7 sites from 18/19 on)	45	52	61	61	63	65	67
Water (6 sites, 8 events after Jan 20)	65	153	259	186	164	169	174
Sediment		29					
Oversight, Coord., Data Mgt, Reporting	18	25	35	60	35	35	35
Restoration				78	78	78	78
Total	128	259	355	385	340	347	354
Region 2 In-Kind							
MLML In-Kind	21	25	30	25	25	25	25
Delta RMP	107	234	325	360	315	322	329

Table 1. Delta RMP mercury management and assessment questions addressed by each mercury monitoring element. Questions highlighted in yellow were identified by the Steering Committee as the highest priority for initial studies.

Type	Core Management Questions	Assessment Questions	Sub-Questions	Subregional Trends in Bass	Subregional Trends in Water	Restoration Monitoring
Status and Trends	Is there a problem or are there signs of a problem? a. Is water quality currently, or trending towards, adversely affecting beneficial uses of the Delta? b. Which constituents may be impairing beneficial uses in subregions of the Delta? c. Are trends similar or different across different subregions of the Delta?	1. What are the status and trends in ambient concentrations of total mercury and methylmercury (MeHg) in fish, water, and sediment, particularly in subareas likely to be affected by major sources or new sources (e.g., large-scale restoration projects)?	A. Are trends over time in MeHg in sport fish similar or different among Delta subareas?	X		
			B. Are trends over time in MeHg in water similar or different among Delta subareas?		X	
Sources, Pathways, Loadings, and Processes	Which sources and processes are most important to understand and quantify? a. Which sources, pathways, loadings, and processes (e.g., transformations, bioaccumulation) contribute most to identified problems? b. What is the magnitude of each source and/or pathway (e.g., municipal wastewater, atmospheric deposition)? c. What are the magnitudes of internal sources (e.g., benthic flux) and sinks in the Delta?	1. Which sources, pathways, and processes contribute most to observed levels of MeHg in fish?	A. What are the loads from tributaries to the Delta (measured at the point where tributaries cross the boundary of the legal Delta)?		X	
			B. How do internal sources and processes influence MeHg levels in fish in the Delta?	X	X	X
			C. How do currently uncontrollable sources (e.g., atmospheric deposition, both as direct deposition to Delta surface waters and as a contribution to nonpoint runoff) influence MeHg levels in fish in the Delta?			
Forecasting Scenarios	a. How do ambient water quality conditions respond to different management scenarios? b. What constituent loads can the Delta assimilate without impairment of beneficial uses? c. What is the likelihood that the Delta will be water quality-impaired in the future?	1. What will be the effects of in-progress and planned source controls, restoration projects, and water management changes on ambient methylmercury concentrations in fish in the Delta?		X	X	X
Effectiveness Tracking	a. Are water quality conditions improving as a result of management actions such that beneficial uses will be met? b. Are loadings changing as a result of management actions?	[none]		X	X	X

Table 2. Sampling schedule for Delta RMP mercury monitoring. The March-October period used for the linkage analysis in the TMDL is indicated with gray shading. Bold indicates the components that are new or modified in Phase 2.

Year →	2016						2017												2018												2019												2020					
Fiscal Yr →	FY 16/17												FY17/18												FY18/19												FY19/20											
Month →	7	8	9	10	**11**	**12**	**1**	**2**	3	4	5	6	7	8	9	10	**11**	**12**	**1**	**2**	3	4	5	6	7	8	9	10	**11**	**12**	**1**	**2**	3	4	5	6	7	8	9	10	**11**	**12**	**1**	**2**	3	4	5	6
Monitoring element (# of sites sampled)																																																
Bass - Core		6												6												7													7									
Bass - Restoration																																							**5**									
Prey fish																																															**9**	
Water		5			**5**			**5**		5						6			**8**	**8**	8	8	8	8	8	8	8	8			**8**	**8**	8	8	8	8	8	8	8	8					**6**	**6**	**6**	**6**
Sediment																6			**6**			6		6																								

gray shading = March-October period used for the linkage analysis in the TMDL

bold = proposed wetland restoration monitoring component

Table 3. Information on the restoration monitoring stations.

Station Type	Map Label	Name	Type	Restoration Timing (Breach)	Rationale for Station Location	Nearby Historic Prey Fish Station(s) (Slotton et al. 2007)	Past Data - Fall (ppb)	Past Data - Seasonal (ppb)
Prey Fish	1	Barker Slough	Restoration	~2014	Site suggested by DWR as an alternative restoration project since Prospect Island restoration is not yet complete.	Unnamed station (page 51)	Silverside 40 (2005)	
Prey Fish	2	Lindsey Slough	Restoration	2014	Site farther up Lindsey Slough, near wetlands not associated with restoration project.			
Prey Fish	3	Lookout Slough	Possible Future Site	~2023	Large restoration project.			
Prey Fish	4	Liberty Island	Reference		Wetlands established after unplanned breach in 1998. Treating this as "reference marsh" because it was not a recent, planned restoration.	NDLIN (Liberty Island North Marsh) - deep within marsh	Silverside 40, 60 (2005, 2006)	
Prey Fish	5	Wildlands Mitigation	Restoration	2011	Has dendritic channel network as part of wetland design to an extent not seen in neighboring reference wetlands. This channel structure might affect Hg levels in fish via either effects of flooding on Hg cycling or effects on fish foraging patterns.	NDLHC (Little Holland Tract Central)	Silverside 45, 55 (2005, 2006)	
Prey Fish	6	"Stairstep" marsh	Reference		Wetlands established after unplanned breach of Little Holland Tract in 1982. Treating this as "reference marsh" because it was not a recent, planned restoration.	NDLHC (Little Holland Tract Central)	Silverside 45, 55 (2005, 2006)	
Prey Fish	7	Yolo Flyway Farms	Restoration	2020	New restoration. Farther up the fluvial-tidal gradient than nearby sites.			
Prey Fish	8	Prospect Island	Possible Future Site	~2022	Upcoming EcoRestore project.	NDPRSL (Prospect Slough) NDPRSL (Prospect Slough) MINSL (Miners Slough)	Silverside 50, 80 (2005, 2006) YOY LMB 40 (2005) YOY LMB 45 (2005)	NDPRSL Silverside 50, 90, **120**, 60, 60, 80 10/05, 02/06, **05/06**, 07/06, 09/06, 11/06
Prey Fish	9	Delta Meadows	Reference		One of the few large areas wetlands in the region, and a well studied site in terms of fish monitoring.			
Prey Fish	10	McCormack Williamson Tract	Possible Future Site	2021	Upcoming EcoRestore project.	Slough/McW Tract) - base of McW Tract)	YOY LMB 80, 130 (2005, 2006)	
Prey Fish	11	Westerveldt Restoration	Restoration	2011	Older restoration site. Site suggested by DWR as an alternative restoration project since Grizzly Slough restoration is not yet complete.	COS (Cosumne River) - adjacent to seasonal floodplain	Silverside 160, 180 (2005, 2006) YOY LMB 240, 545 (2005, 2006)	COS Silverside 160, 160, **NA**, 870, 180, **NA** 10/05, 02/06, **05/06**, 07/06, 09/06, 11/06 YOY LMB 240, **NA**, 750, 620, 550 11/05, **05/06**, 07/06, 09/06, 11/06"
Prey Fish	12	Cougar Wetland	Restoration	2019	Recent restoration site. Site suggested by DWR as an alternative restoration project since Grizzly Slough restoration is not yet complete.	COS (Cosumne River) - adjacent to seasonal floodplain	Silverside 160, 180 (2005, 2006) YOY LMB 240, 545 (2005, 2006)	
Prey Fish	13	Grizzly Slough	Possible Future Site	2021	Upcoming EcoRestore project.			
Bass	A	Lindsey Slough	New		Near Barker Slough restoration and Lindsey Slough wetlands.			
Bass	B	Lookout Slough	New		Near Lookout Slough, an opportunity to sample regional Hg pre-breach.			
Bass	C	Cache Slough at Liberty Island Mouth (510A	Existing					
Bass	D	Yolo Flyway Farms/ Lower Yolo Ranch	New		New (2020) restoration project nearby.			
Bass	E	McCormack Williamson Tract	New		Near McCormack Williamson Tract, an opportunity to sample regional Hg pre-breach.			
Bass	F	Lower Mokelumne River 6 (544ADVLM6)	Existing					
Bass	G	Grizzly Slough/ Westervelt / Cougar	New		Near Westervelt, Cougar, and (future) Grizzly Slough restoration sites.			

Table 4. Management sub-questions, statistical framework, and power for restoration monitoring with prey fish.

2. Specific questions to answer	3. Data inputs	5(a) Analytic approach	5(b) Decision rule	6. Data Quality Objectives	6. Power analysis
Question 1: Do habitat restoration projects have a local increase in fish mercury relative to other areas? (Are mercury concentrations in prey fish higher at stations in habitat restoration projects than in other stations sampled contemporaneously?)	Prey fish mercury concentrations in restoration stations and at reference stations (six replicate composite samples [10 fish per composite] spanning 5 mm increments from 45-70 mm)	ANOVA to analyze the differences in mean concentrations across all stations t-test for pairwise comparisons of mean concentrations between stations	H0: There are no differences in mean prey fish mercury concentration among stations HA: There are differences in mean prey fish mercury concentration among stations	ANOVA: Effect size not specified t-test for pairwise comparisons: Effect size of 23 ppb Tolerable limits: Type 1 error (alpha) of <0.05 (95% statistical significance) and a Type 2 error (beta) of <0.2 (80% statistical power).	Based on silverside data from the North Bay Biosentinel project. ANOVA: Power to detect a difference among stations: >0.99 t-test for pairwise comparisons: Power=0.80
Question 2: Do habitat restoration projects have a local increase in fish mercury relative to historic data from the local area? (Are mercury concentrations in prey fish higher at stations in habitat restoration projects than in other stations from the local area sampled historically?)	Prey fish mercury concentrations in restoration stations (six replicate composite samples [10 fish per composite] spanning 5 mm increments from 45-70 mm) and historic prey fish mercury concentrations	ANOVA to analyze the differences in mean concentrations across years t-test for pairwise comparisons of mean concentrations between years	H0: There are no differences in mean prey fish mercury concentration among years HA: There are differences in mean prey fish mercury concentration among years	ANOVA: Effect size not specified t-test for pairwise comparisons: Effect size of 23 ppb Tolerable limits: Type 1 error (alpha) of <0.05 (95% statistical significance) and a Type 2 error (beta) of <0.2 (80% statistical power).	Based on silverside data from the North Bay Biosentinel project. ANOVA: Power to detect a difference among years: 0.99 t-test for pairwise comparisons: Power=0.80

Table 4. (continued) Management sub-questions, statistical framework, and power for restoration monitoring with prey fish.

2. Specific questions to answer	3. Data inputs	5(a) Analytic approach	5(b) Decision rule	6. Data Quality Objectives	6. Power analysis
Question 3.1: Do prey fish mercury concentrations at habitat restoration projects increase in the initial period after restoration? (Do mercury concentrations in prey fish increase over time at stations in habitat restoration projects in the first five years after restoration?)	Prey fish mercury concentrations in restoration stations (six replicate composite samples [10 fish per composite] spanning 5 mm increments from 45-70 mm), repeated annual sampling	ANOVA to analyze the differences in mean concentrations across years t-test for pairwise comparisons of mean concentrations between years	H0: There are no differences in mean prey fish mercury concentration among years HA: There are differences in mean prey fish mercury concentration among years	ANOVA: Effect size not specified t-test for pairwise comparisons: Effect size of 23 ppb Tolerable limits: Type 1 error (alpha) of <0.05 (95% statistical significance) and a Type 2 error (beta) of <0.2 (80% statistical power).	Based on silverside data from the North Bay Biosentinel project. ANOVA: Power to detect a difference among years: 0.99 t-test for pairwise comparisons: Power=0.80
Question 3.2: Do prey fish mercury concentrations at habitat restoration projects increase over the longer-term after restoration? (Do mercury concentrations in prey fish increase over time at stations in habitat restoration projects 10-20 years after restoration?)	Prey fish mercury concentrations in restoration stations (six replicate composite samples [10 fish per composite] spanning 5 mm increments from 45-70 mm), repeated sampling over the years	Linear regression	H0: There is no change over time (slope of regression line not significantly different from zero) HA: There is a change over time (slope of regression line is significantly different from zero)	Effect size (trend) of 2 ppb/yr over 10 years Tolerable limits: Type 1 error (alpha) of <0.05 (95% statistical significance) and a Type 2 error (beta) of <0.2 (80% statistical power).	Based on silverside data from the North Bay Biosentinel project. Linear regression of length-adjusted station means: Power=0.79

Figure 1. California EcoRestore projects.

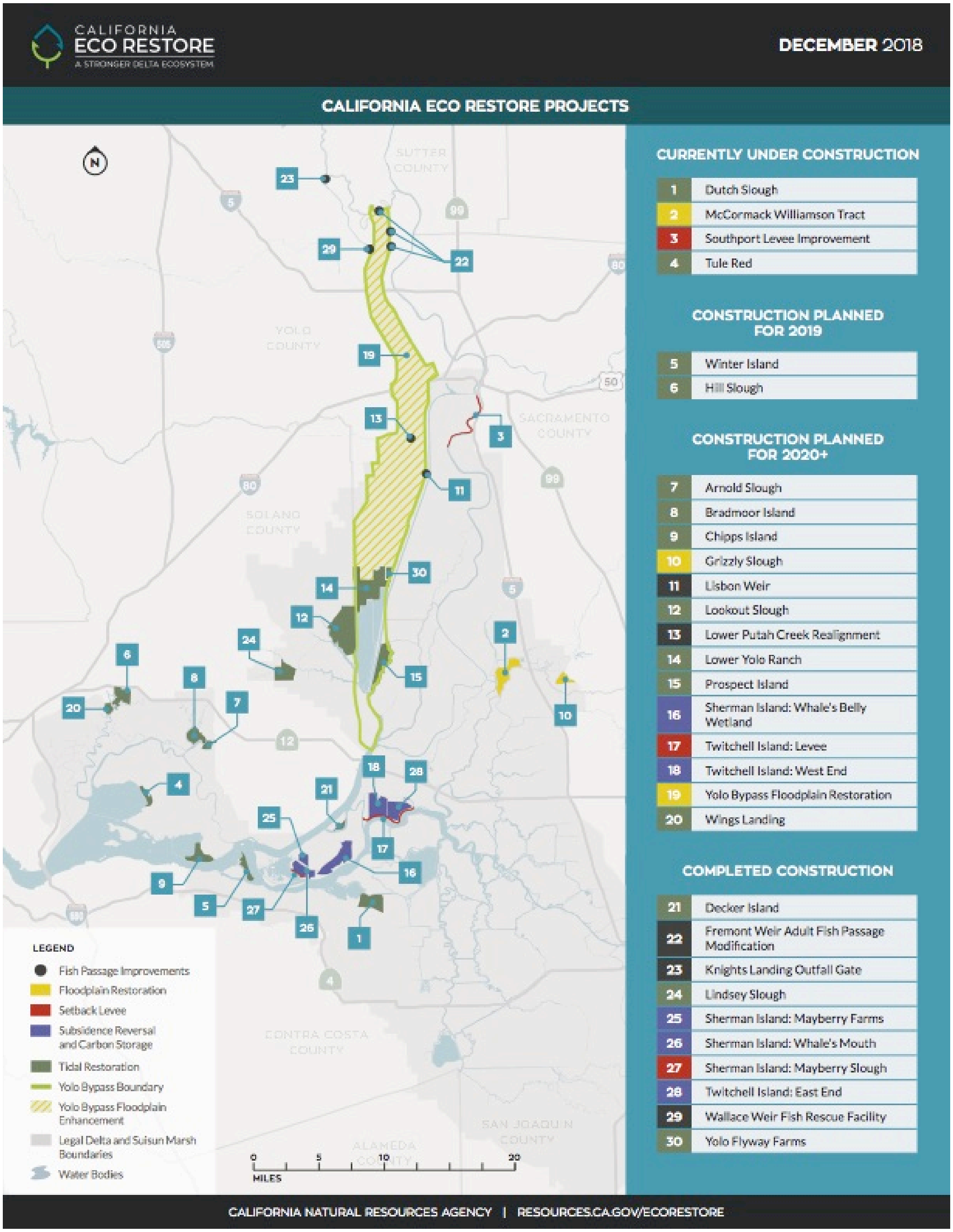


Figure 2. Planned subregional bass and water sampling stations for methylmercury in FY19-20.

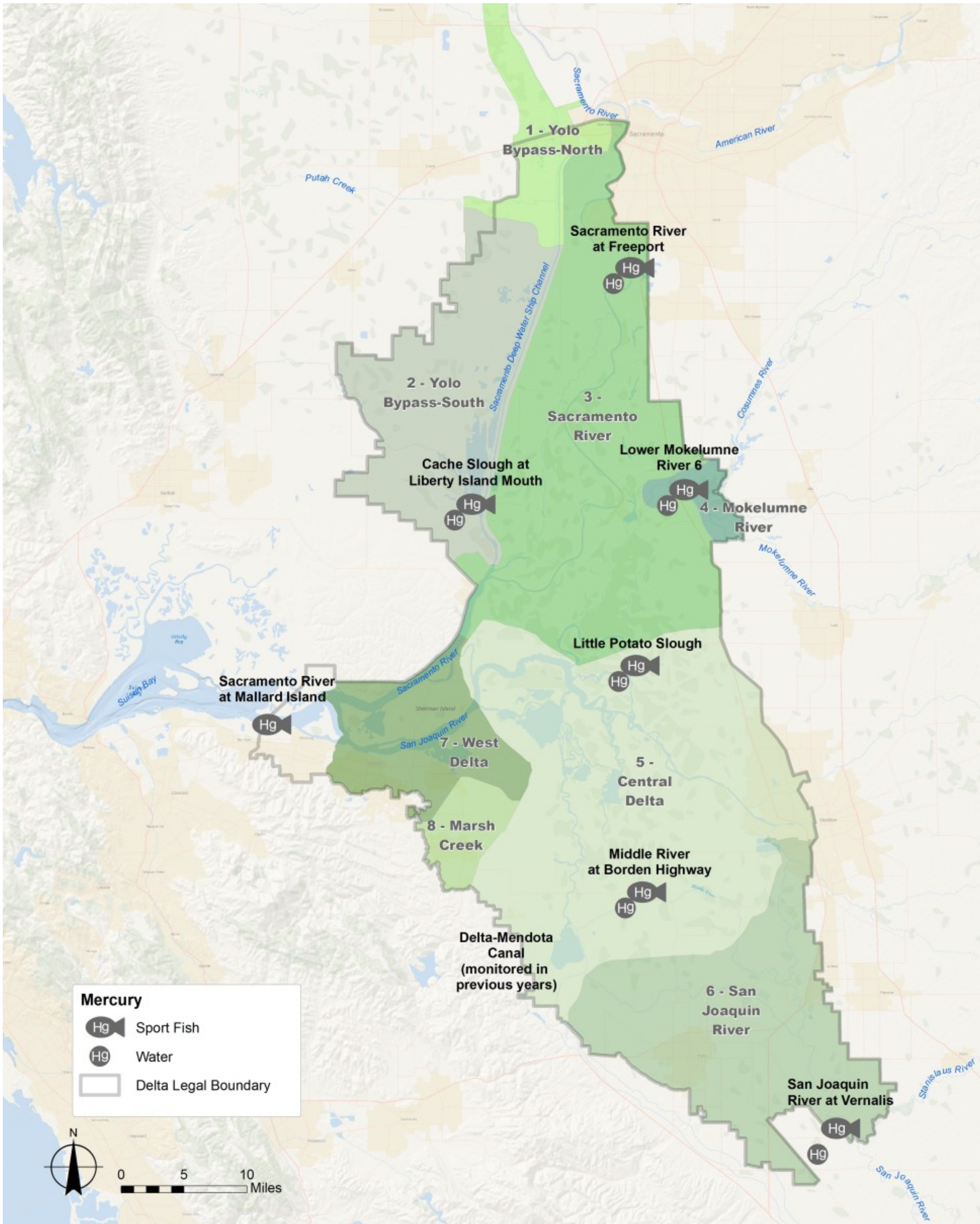


Figure 3. Long-term time series of mean mercury (ppm wet weight) in black bass for Delta RMP stations and nearby stations sampled historically. Details on following page.

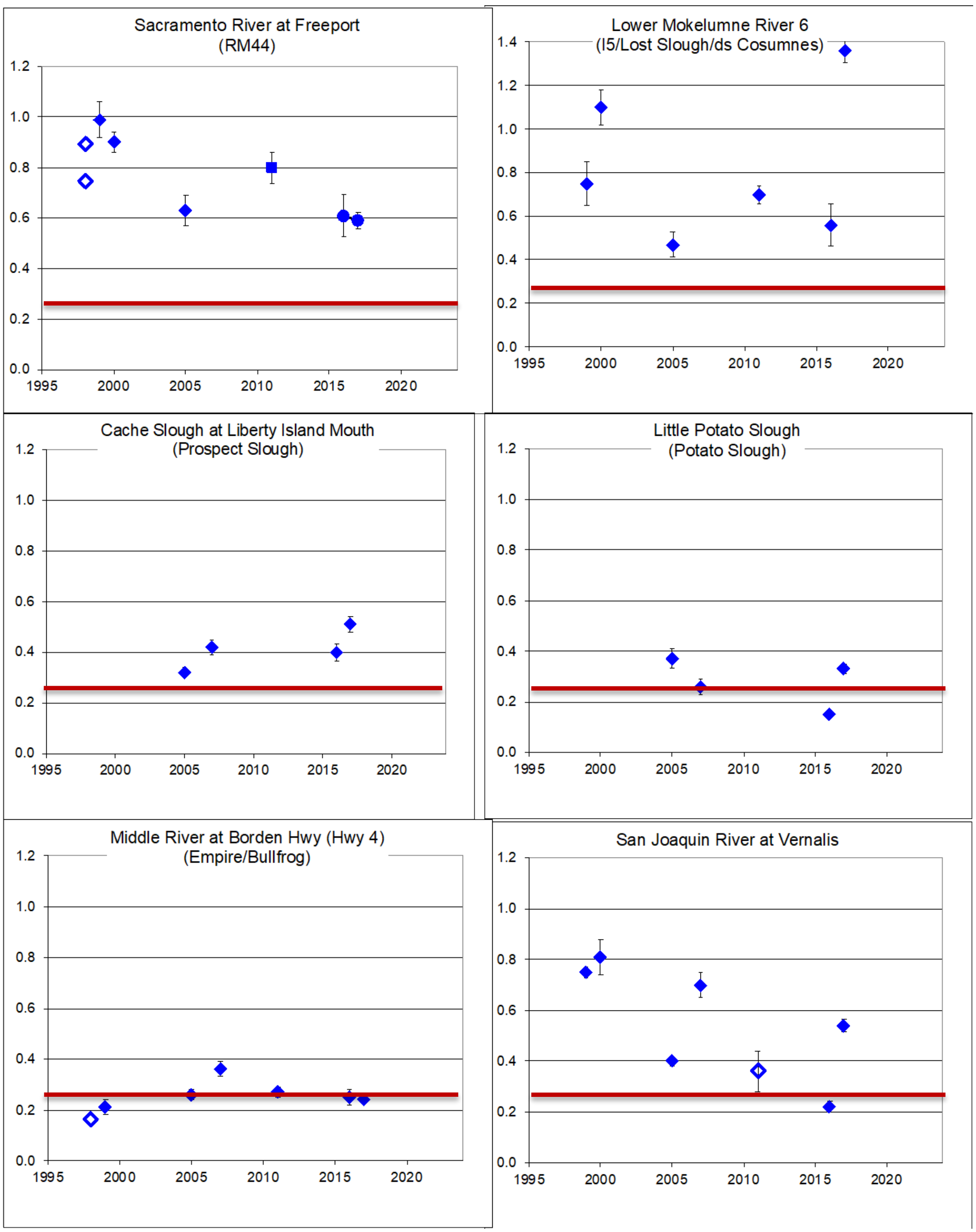


Figure 3 Details

Points generally show 350 mm length-adjusted means (exceptions to this noted in plot details below) and error bars indicate two times the standard error. Filled symbols indicate 350 mm length-adjusted means, hollow symbols indicate individual composite samples or arithmetic means when the station did not have a significant length:mercury correlation. Diamonds indicate largemouth bass; squares are spotted bass; circles are smallmouth bass. Data sources: Delta RMP - 2016; the Surface Water Ambient Monitoring Program (Davis et al. 2013) - 2011; the Fish Mercury Project (Melwani et al. 2009) - 2005-2007; the CALFED Mercury Project (Davis et al. 2003) - 1999-2000; the Delta Fish Study (Davis et al. 2000) - 1998; and the Sacramento River Watershed Program (2002) - 1998. Red lines show the TMDL goal of 0.24 ppm.

Sacramento River at Freeport
Stations - Freeport: 2016; RM44: All other years
Statistics - Individual composite results: 1998; 350 mm length adjusted mean: all other years

Lower Mokelumne River 6
Stations - Lower Mokelumne River 6: 2016; Mokelumne River near I-5: 2011; Lost Slough: 2005; Mokelumne River downstream of the Cosumnes River: 1999, 2000

Cache Slough at Liberty Island Mouth
Stations - Cache Slough at Liberty Island Mouth: 2016; Prospect Slough: 2005, 2007

Little Potato Slough
Stations - Little Potato Slough: 2016; Potato Slough (aka San Joaquin River at Potato Slough): 2005, 2007

Middle River at Borden Hwy (Hwy 4)
Stations - Middle River at Borden Hwy (Hwy 4): 2016; Middle River near Empire Cut: 2011; Middle River at Bullfrog: 1998, 1999, 2007; Middle River at HWY 4: 2005
Statistics - Individual composite result: 1998; 350 mm length adjusted mean: all other years

San Joaquin River at Vernalis
Stations - Same station all years

Figure 4. **Annual mean aqueous unfiltered methylmercury concentration at each Delta RMP monitoring station sampled from October 2017 through June 2018. Plots based on March-October data.**

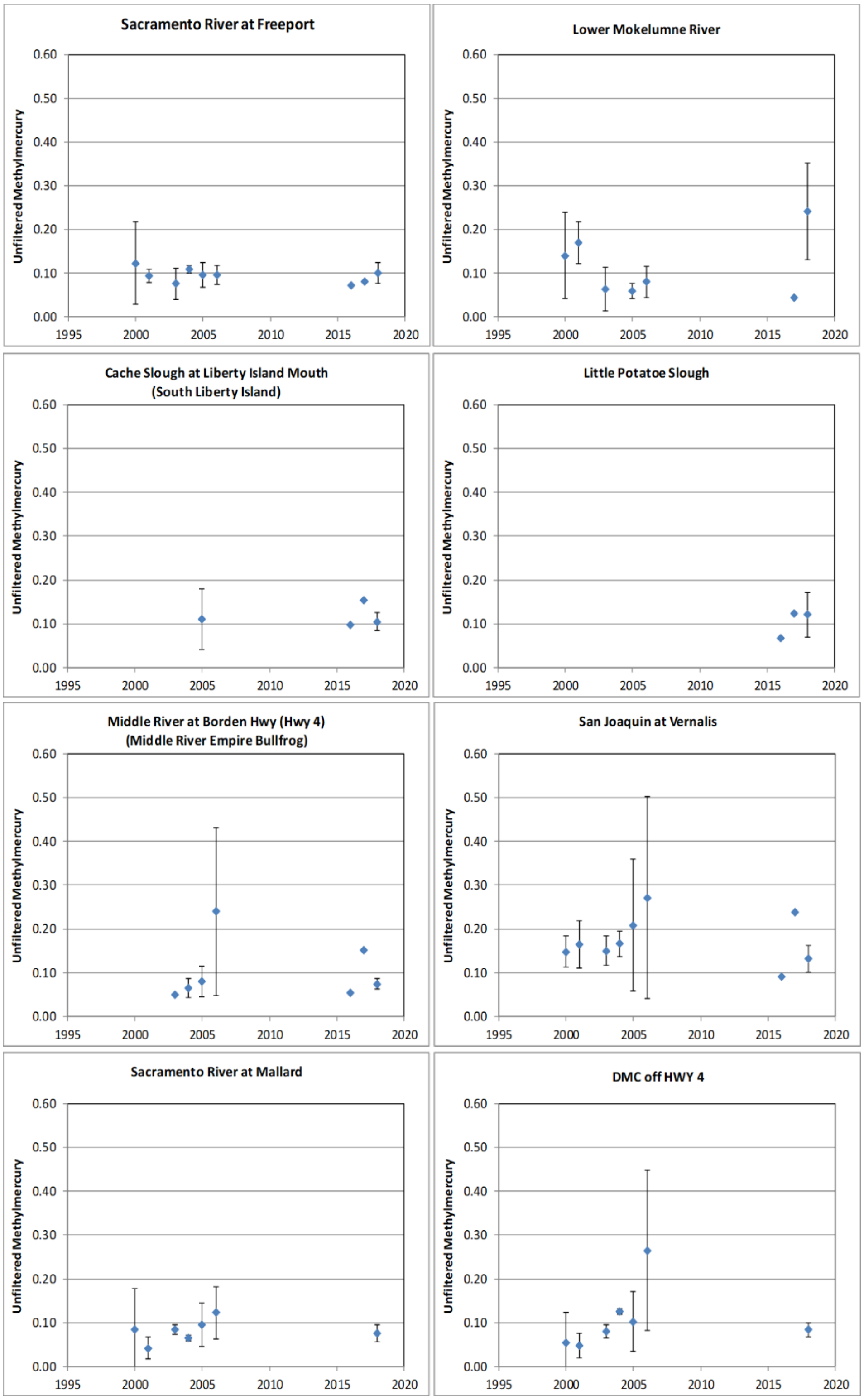


Figure 5. Design for Restoration Monitoring in the Northwest Delta.

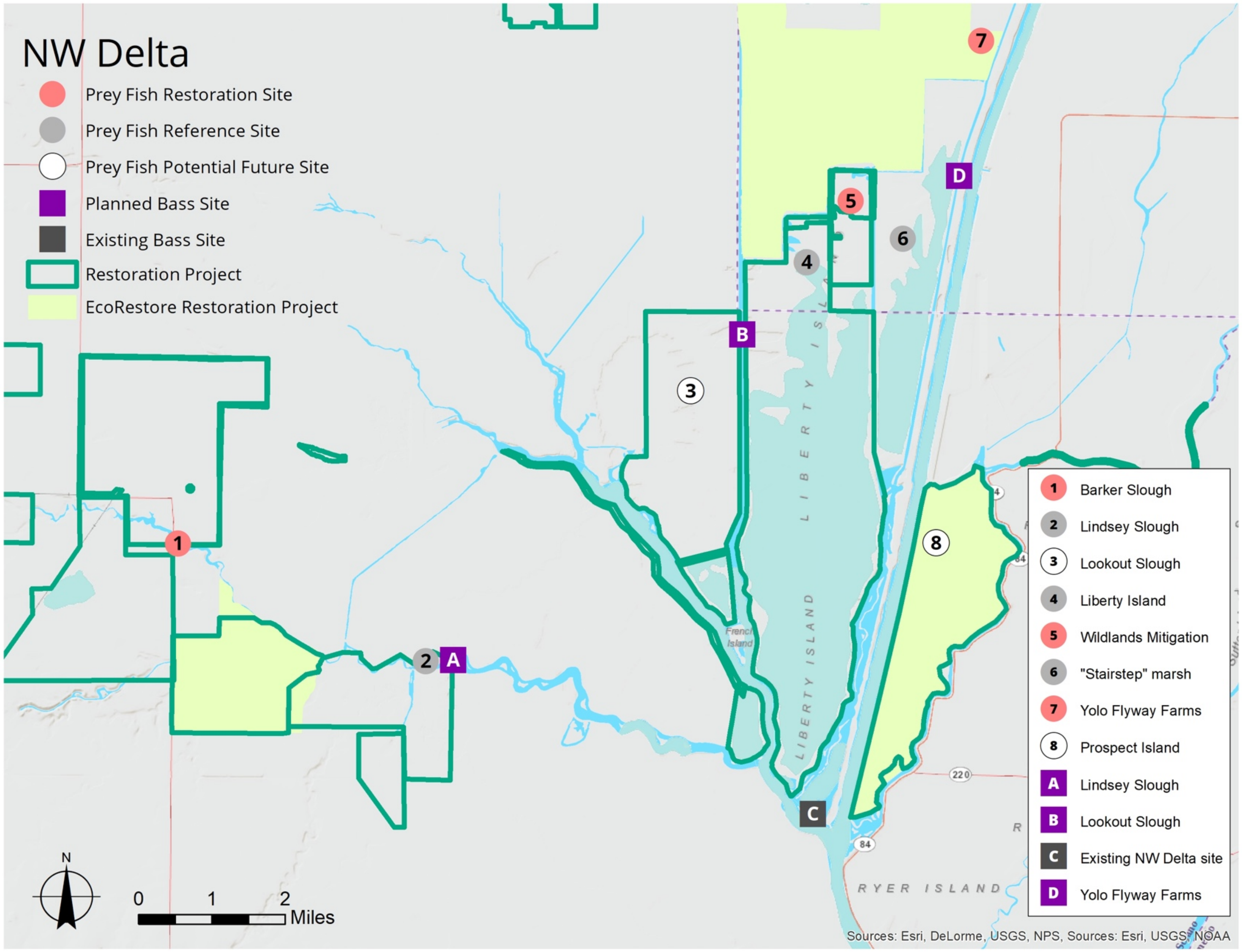
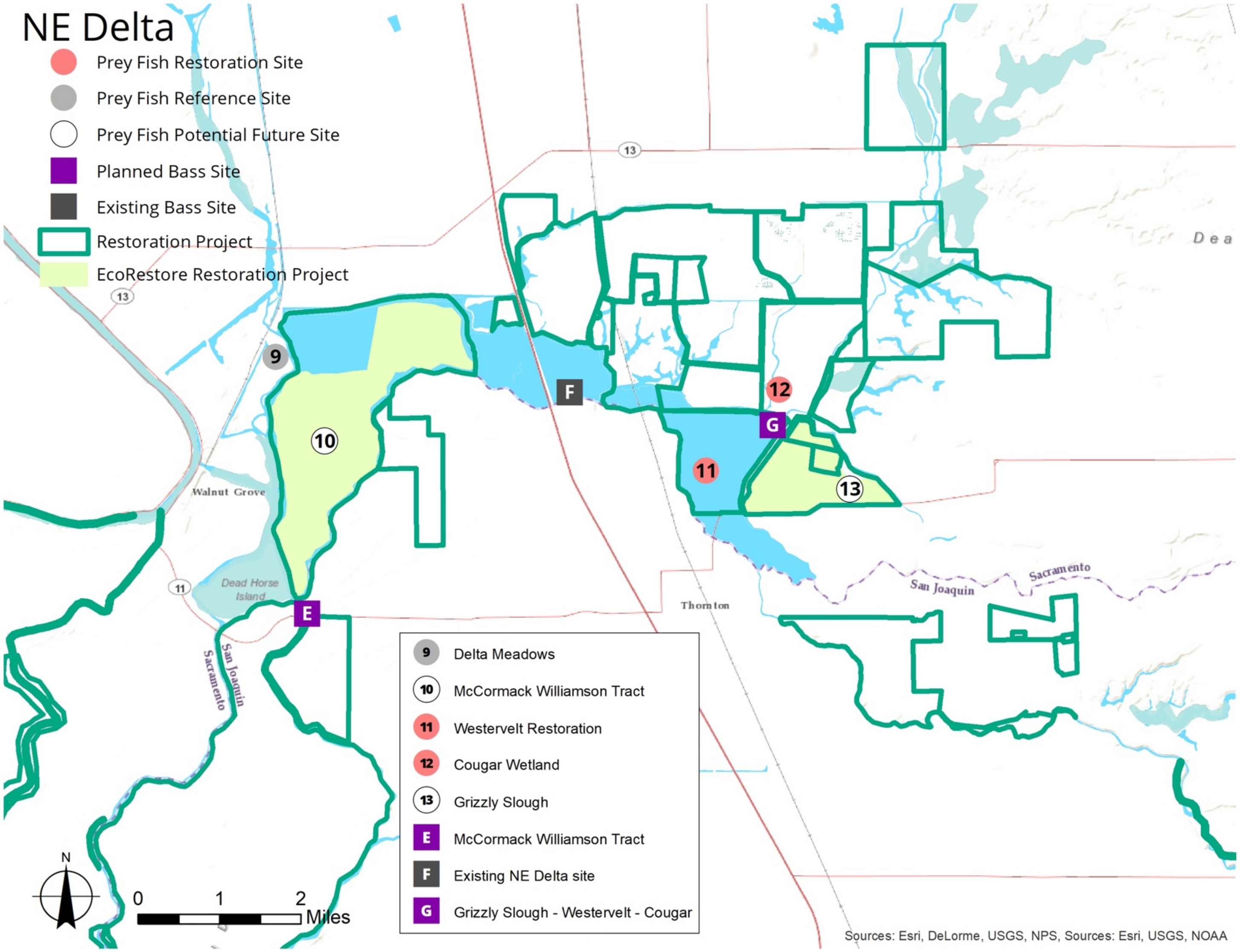


Figure 6. *Design for Restoration Monitoring in the Northeast Delta.*



References

Davis, J.A., J.N. Collins, D. Yee, S. Schwarzbach, and S.N. Luoma. 2003. Issues in San Francisco Estuary tidal wetlands restoration: Potential for increased mercury accumulation in the Estuary food web. San Francisco Estuary and Watershed Science 1: issue 1, article 4.

Davis, J.A., Heim, W.A., Bonnema, A., Jakl, B., and Yee, D. 2018. Mercury and Methylmercury in Fish and Water from the Sacramento-San Joaquin Delta: August 2016 – April 2017. Delta Regional Monitoring Program.

Davis, J.A., Heim, W.A., Bonnema, A., Jakl, B., and Yee, D. 2019. Mercury and Methylmercury in Fish and Water from the Sacramento-San Joaquin Delta: Year Two (August 2017 – June 2018). Delta Regional Monitoring Program.

DiGiorgio, Carol, Helen Amos, Jamie Anderson, Maninder Bahia, Cody Beals, Don Beals, David Bosworth, et al. "Creation of Mercury Models for the Delta and Yolo Bypass: Linking Modeling and Delta Regulatory Decisions." Sacramento, California, 2016. http://scienceconf2016.deltacouncil.ca.gov/content/creation-mercury-models-delta-and-yolo-bypass-linking-modeling-and-delta-regulatory

Greenfield, B.K., Melwani, A.R., Allen, R.M., Slotton, D.G., Ayers, S.M., Harrold, K.H., Ridolfi, K., Jahn, A., Grenier, J.L. and Sandheinrich, M.B., 2013. Seasonal and annual trends in forage fish mercury concentrations, San Francisco Bay. Science of the Total Environment, 444, pp.591-601.

Greenfield, B.K., Slotton, D.G. and Harrold, K.H., 2013. Predictors of mercury spatial patterns in San Francisco Bay forage fish. Environmental toxicology and chemistry, 32(12), pp.2728-2737.

Greenfield, B.K., Lent, M., Slotton, D.G., Ayers, S.M. Unpublished. Modeling mercury bioaccumulation in largemouth bass in the Sacramento-San Joaquin Delta and tributaries. San Francisco Estuary Institute.

Robinson, A., Richey, A., Slotton, D., Collins, J., and Davis, J.A. 2018. North Bay Mercury Biosentinel Project 2016-2017. Contribution #868. San Francisco Estuary Institute and the Aquatic Science Center. Richmond, CA. https://www.sfei.org/documents/north-bay-mercury-biosentinel-project

Slotton D.G., et al. 2002. The Effects of Wetland Restoration on the Production and Bioaccumulation of Methylmercury in the Sacramento-San Joaquin Delta, California: Draft Final Report. UC Davis.

Slotton, D.G., S.M. Ayers, R.D. Weyand. 2007. CBDA Biosentinel Mercury Monitoring Program: Second Year Draft Data Report. UC Davis.

Wiener, J.G., Gilmour, C.C. and Krabbenhoft, D.P., 2003. *Mercury strategy for the bay-delta ecosystem: a unifying framework for science, adaptive management, and ecological restoration*. California Bay-Delta Authority.

Windham-Myers, L. L. Lucas, J.A. Fleck, A.R. Stewart, R.C. Martyr, and M. Marvin-DiPasquale. 2016. The Delta doughnut: A persistent pattern for methylmercury metrics. Bay-Delta Science Conference, November 15-17, 2016. http://scienceconf2016.deltacouncil.ca.gov/content/delta-doughnut-persistent-pattern-methylmercury-metrics

Wood, Michelle L., Chris G. Foe, Janis Cooke, and Stephen J. Louie. "Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury: Staff Report." Sacramento, California: Central Valley Regional Water Quality Control Board, 2010. http://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/delta_hg/april_2010_hg_tmdl_hearing/apr2010_tmdl_staffrpt_final.pdf.

USEPA. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process. United States Environmental Protection Agency. EPA/240/B-06/001.

Yee, D., John Ross, Amy Franz, Thomas Jabusch, Jay Davis, Michael Weaver, Matthew Heberger, Lisa Thompson, and Tim Mussen. 2019. Delta Regional Monitoring Program Quality Assurance Project Plan for Fiscal Year 2019–2020 Monitoring. Delta Regional Monitoring Program.

Appendix 1. Restoration Project Fact Sheets

CALIFORNIA
ECO RESTORE

Lindsey Slough Tidal Marsh Restoration

Project Description: The Lindsey Slough Restoration Project restored habitat function and connectivity to Delta wetlands and waterways that had been degraded by the construction of dikes and culverts 100 years earlier. The project consisted of (1) excavation and debris removal to enlarge an existing north embankment breach on Calhoun Cut at a northern arm of Lindsey Slough; (2) breaching of the south embankment of Calhoun Cut; (3) excavation of a one mile long channel at the historic southern arm of Lindsey Slough; (4) lowering of an existing earthen causeway on the historic channel; and (5) beneficial reuse of sediment excavated from the channel to create low habitat berms within the marsh and raise the remnant marsh site to a more mature marshplain form.

Restoration Targets: This project restored habitat function and connectivity to 159 acres of freshwater emergent wetlands and 69 acres of alkali wetlands, and recreated and reconnected a one-mile tidal channel.

Location and Landowner: This project is located on the northwest fringe of the historical Sacramento-San Joaquin Delta, just west of the confluence of Lindsey Slough, Barker Slough, and Calhoun Cut within the Cache Slough tidal drainage on the California Department of Fish and Wildlife's Calhoun Cut Ecological Reserve in Solano County (site map attached).

Funding: Design and Construction: $376,195 from Prop 84 (drought funds)
Planning (and land acquisition): $959, 195 (Ecosystem Restoration Program)

Permitting: Completed

Estimated Timeline: Completed.

Known Obstacles to Implementation: This project was completed in 2014.

Project Proponent: California Department of Fish and Wildlife
Greg Martinelli: Greg.Martinelli@wildlife.ca.gov, (707) 944-5570
Sarah Estrella: Sarah.Estrella@wildlife.ca.gov, (209) 234-3677

LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

Cache Slough Complex

TIDAL HABITAT AND FLOOD IMPROVEMENT

The Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (Project) is located in the Cache Slough region, one of the key areas in the Sacramento-San Joaquin Delta (Delta) with elevations favorable for maintaining tidal habitats for the endangered Delta smelt. The proposed Project would restore approximately 3,000 acres of tidal wetland, creating habitat that is beneficial to native fish and wildlife. Lookout Slough is adjacent to additional tidal habitat restoration efforts being implemented by the Department of Water Resources (DWR), including Yolo Flyway Farms and Lower Yolo Ranch, to create a contiguous tidal wetland restoration complex spanning 16,000 acres in the Cache Slough region. Once completed, the proposed Project would be the Delta's largest single tidal habitat restoration project to date.

In addition to the restoration of important tidal wetland habitat, the proposed multi-benefits of this Project will meet objectives of the Central Valley Flood Protection Plan to reduce flood risk. The proposed Project includes construction of a new setback levee along the west and north edges of the site to allow for breaching the existing Yolo Bypass West Levee along Shag Slough. The new setback levee will provide 100-year flood protection with additional height for climate change and sea level rise resiliency. Breaching and degrading the existing levees will restore historical tidal influence on the site, providing food web and other benefits to Delta smelt and increasing seasonal floodplain rearing habitat for salmonids.

This effort is being implemented by DWR through a partnership with Ecosystem Investment Partners (EIP) and Reclamation District 2098. Partnering with EIP and leveraging their unique expertise in planning, permitting and constructing large-scale restoration projects will allow DWR to implement this effort in a timely manner. The project is expected to be complete by 2022.

The Project is intended to partially fulfill DWR's 8,000-acre tidal habitat restoration obligations pursuant to the 2008 U.S. Fish and Wildlife Service (USFWS) Delta Smelt Biological Opinion (BiOp) and is consistent with the 2009 National Marine Fisheries Service (NMFS) Salmonid BiOp for long-term coordinated operations of the State Water Project and the federal Central Valley Project.

RESTORATION GOALS / TARGET

1. Create and maintain diverse intertidal and subtidal habitat to support native species and improved food productivity within the Project area.
2. Design and implement the Project to support viable populations of special status aquatic and terrestrial species.
3. Provide additional flood storage and conveyance within the Yolo Bypass to reduce the chance of catastrophic flooding and protect existing nearby infrastructure (e.g. agriculture, power and human habitation).

LOCATION AND LANDOWNER

Lookout Slough is located in the Cache Slough region at the lower end of the Yolo Bypass in Solano County. EIP is the current owner of the Lookout Slough site and will complete necessary permitting and construction efforts. Upon completion, DWR will maintain the project site and partner with the California Department of Fish and Wildlife for long-term monitoring.

FUNDING

Funding for this Project is provided through two separate sources based on specific benefits. The habitat restoration objectives of the project will be funded by the State Water Project and State Water Contractors ($97,000,000), and the flood protection objectives will be funded by Proposition 1 – for multi-benefit and systemwide flood improvements ($21,865,000). The estimated total cost of the project is approximately $118,865,000.

TIMELINE

This Project is proposed to be completed by 2022

- California Environmental Quality Act (CEQA) Notice of Preparation – Spring 2019
- Draft Environmental Impact Report (EIR) Released for Public Review and Comment – Summer 2019
- Final EIR Certified – Fall 2019
- If Approved, Begin Construction - Spring 2020
- End Construction – Fall 2021

PERMITTING

- CEQA/National Environmental Policy Act
- National Historic Preservation Act – Section 106
- USFWS Endangered Species Act - Section 7
- NMFS Endangered Species Act - Section 7
- US Army Corps of Engineers - Section 404 and Section 408
- Central Valley Regional Water Quality Board - Section 401
- California Department of Fish and Wildlife - Streambed Alteration Agreement and California Endangered Species Act Incidental Take Permit
- Central Valley Flood Protection Board – Encroachment Permit
- Delta Stewardship Council - Delta Plan Consistency Determination
- County permits and authorizations

PROJECT PROPONENT

Department of Water Resources
Division of Environmental Services
Fish Restoration Program
Heather Green
Heather.Green@water.ca.gov

Department of Water Resources
Division of Flood Management
Kyle Bickler, PE, GE
Kyle.Bickler@water.ca.gov

CALIFORNIA
ECO RESTORE
A STRONGER DELTA ECOSYSTEM.

YOLO FLYWAY FARMS TIDAL HABITAT RESTORATION PROJECT

Cache Slough Complex

TIDAL WETLAND

The Yolo Flyway Farms Tidal Habitat Restoration Project (Project) is a joint effort by the California Department of Water Resources (DWR) and Reynier Fund, LLC. to restore seasonal wetland and cattle grazing land to sub-tidal, intertidal and seasonal wetlands to benefit native fish species. The 359-acre Project involves restoring and enhancing approximately 300 acres of tidal freshwater wetlands, and an additional 30 acres of seasonal wetlands, at the southern end of the Yolo Bypass in the northwestern Sacramento/San Joaquin River Delta (Delta). The proposed Project seeks to partially restore historical ecological functions in the current, highly altered regional landscape. DWR and Reynier Fund, LLC. are restoring this project to help meet the 2008 U.S. Fish and Wildlife Service (USFWS) Delta Smelt OCAP Biological Opinion's requirement to restore 8,000 acres of tidal wetlands in the Delta. The Project will also contribute to restoration requirements of the 2009 National Marine Fisheries Service (NMFS) OCAP BiOp.

The project design seeks to maximize residency time and food web production by capturing and slowly draining water through the excavation of two breaches along the Yolo Bypass Toe Drain and interior channels to connect and enhance existing wetlands on site. The project plans to accommodate sea level rise through the enhancement of transitional uplands. The project's restoration activities will restore tidal action to benefit native fish species.

The completed restoration project will be conveyed to DWR in fee title.

RESTORATION GOAL / TARGET

The primary goals of the Project are to (1) improve habitat conditions for Delta smelt by enhancing regional food web productivity; (2) improve habitat conditions for salmonids by providing rearing habitats for out-migrating juveniles and migratory habitats for adults; (3) support a range of other aquatic and wetland-dependent species; (4) provide habitat for establishment of native plant communities; (5) minimize potential for colonization by aquatic weeds, and; (6) preserve existing topographic variability to allow for habitat succession and resilience against future climate change.

LOCATION AND LANDOWNER

The Yolo Flyway Farms Tidal Habitat Restoration Project is located in the northern Delta in southern Yolo County, at the southern end of the Yolo Bypass floodway immediately adjacent to the Yolo Bypass Toe Drain. The site is currently owned and managed by Reynier Fund, LLC.

FUNDING

Fully funded by the State Water Project for all phases of the effort.

PERMITS NECESSARY

- Central Valley Regional Water Quality Control Board: Section 401 and Waste Discharge Report
- State Lands Commission: Notice of Proposed Use of State Lands

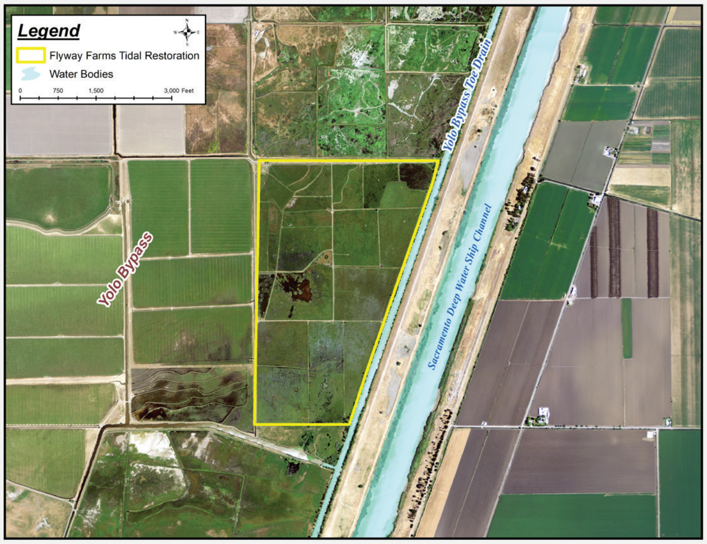
- National Historic Preservation Act: Section 106
- California Department of Fish and Wildlife: Streambed Alteration Agreement Section 1600; Incidental Take Permit
- U.S. Army Corps of Engineers: Nationwide 27 (404 permit)
- USFWS Endangered Species Act: Section 7
- NMFS Endangered Species Act: Section 7
- Delta Stewardship Council: Delta Plan Consistency Determination
- Yolo County approvals and permits

ESTIMATED TIMELINE

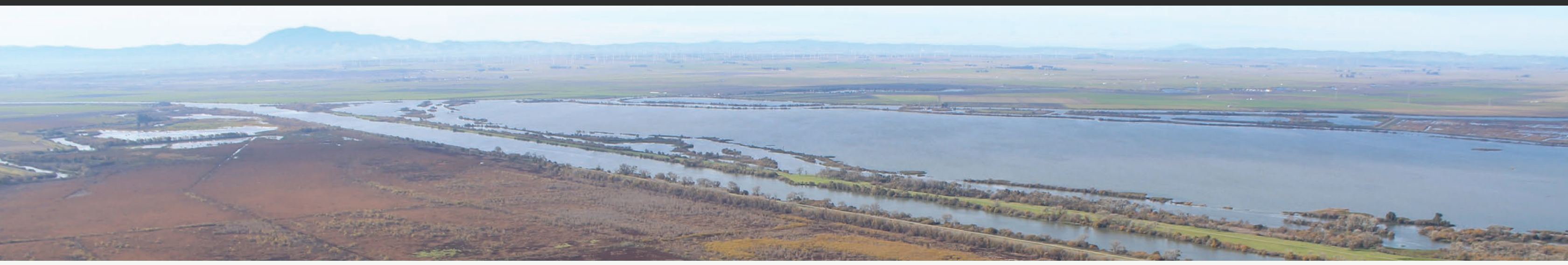
- Permitting: August 2017 through 2018
- Construction Complete: 2018
- Monitoring: 2017 through 2029
- Ongoing Adaptive Management and Maintenance: 2019+

PROJECT PROPONENT

Department of Water Resources
Division of Environmental Services
Fish Restoration Program
Bonnie Irving
Program Manager
bonnie.irving@water.ca.gov
(916) 376-9748



CALIFORNIA
ECO RESTORE
A STRONGER DELTA ECOSYSTEM.



PROSPECT ISLAND TIDAL HABITAT RESTORATION PROJECT

Solano County

TIDAL WETLAND & SUB-TIDAL HABITAT

Historically, the Prospect Island site was tidal marshland, with Prospect Slough to the west and north, and Miner Slough to the east and south. Levees were constructed during the late 19th century to convert the land for agricultural uses. Prospect Island is part of the Yolo Bypass floodplain; however construction of the Deep Water Ship Channel (DWSC) in the 1960s isolated Prospect Island from the main reach of the Bypass.

The proposed project would restore tidal action to the interior of Prospect Island, partially fulfilling the 8,000-acre tidal habitat restoration obligations contained within the Reasonable and Prudent Alternative (RPA) 4 of the U.S. Fish and Wildlife Service (USFWS) Delta Smelt Biological Opinion for long-term coordinated operations of the State Water Project (SWP) and the federal Central Valley Project (CVP). Because restoration of tidal habitat would provide access for salmonid rearing at Prospect Island, the project would also be consistent with RPA 1.6.1 of the 2009 National Marine Fisheries Service (NMFS) Salmonid Biological Opinion for SWP/CVP. The project would result in a suite of overarching long-term ecosystem benefits, including enhancement of primary productivity and food availability for fisheries in the Sacramento-San Joaquin Delta (Delta); an increase in the quantity and quality of salmonid rearing habitat and habitat for other listed species; enhancement of water quality, recreation and carbon sequestration in tidal marshes; promotion of habitat resiliency; and promotion of habitat conditions that support native species. Current design of the project includes breaching the external Miner Slough levee and removing a portion of the internal cross levee to open the site to daily tidal inundation. The Department of Water Resources (DWR) is the California Environmental Quality Act (CEQA) Lead Agency for this project.

RESTORATION GOALS / TARGET

- Between 1,000 and 1,500 acres of tidal and sub-tidal restoration
- Specific project objectives:
  - Enhance productivity and food availability for Delta Smelt and other native fishes
  - Increase salmonid rearing habitat
  - Increase habitats to support other listed species
  - Provide ecosystem benefits including water quality enhancement, recreation, and carbon sequestration
  - Promote future habitat resiliency to threats such as land use conversions, climate change, sea level rise, and invasive species
  - Avoid establishment or spread of exotic invasive species

LOCATION AND LANDOWNER

Prospect Island is a 1,600-acre property located in southeast Solano County, in the northwestern part of the Delta. The site is bound on the east by Miner Slough, on the west by the DWSC, on the south by the confluence of the DWSC and Miner Slough, and on the north by an east-west levee that runs from Arrowhead Harbor Marina to the DWSC. It is located just east of the naturally restored 4,500-acre Liberty Island.

Both the northern, 1,300-acre portion and the southern, 300-acre portion of Prospect Island are owned by DWR.

FUNDING

Fully funded by the SWP Contractors for all phases of the effort

ESTIMATED TIMELINE

- CEQA (final): Mid-2017
- Permitting completed: Late 2017
- Construction design completed: Late 2017

- Site preparation: Early 2018
- Begin construction: Mid-2018
- Construction complete: 2020

PERMITTING

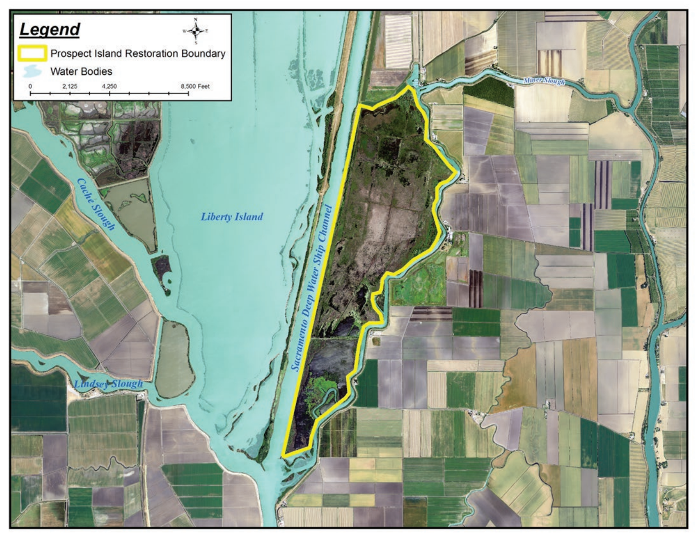
- US Army Corps of Engineers:
  - Clean Water Act (CWA) Section 404/River Harbors Act Section 10
- NMFS:
  - Endangered Species Act Section 7
- USFWS:
  - Endangered Species Act Section 7
- CA Department of Fish and Wildlife:
  - Section 1602 Lake or Streambed Alteration Agreement
  - Incidental Take Permit 2081
- California State Historic Preservation Office:
  - Letter of concurrence with USACE via the National Historic Preservation Act Section 106
- Central Valley Flood Protection Board:
  - Title 23 CCR Division Encroachment Permit
- Central Valley Regional Water Quality Control Board:
  - CWA Section 401 Water Quality Certification
  - Section 402 National Pollution Discharge Elimination System
  - Porter Cologne Water Quality Control Act Waste Discharge Requirement
- California State Lands Commission (CSLC):
  - State Lands Lease Amendment CSLC approval
- Solano County:
  - DWR would apply for all legally applicable local permits from Solano County

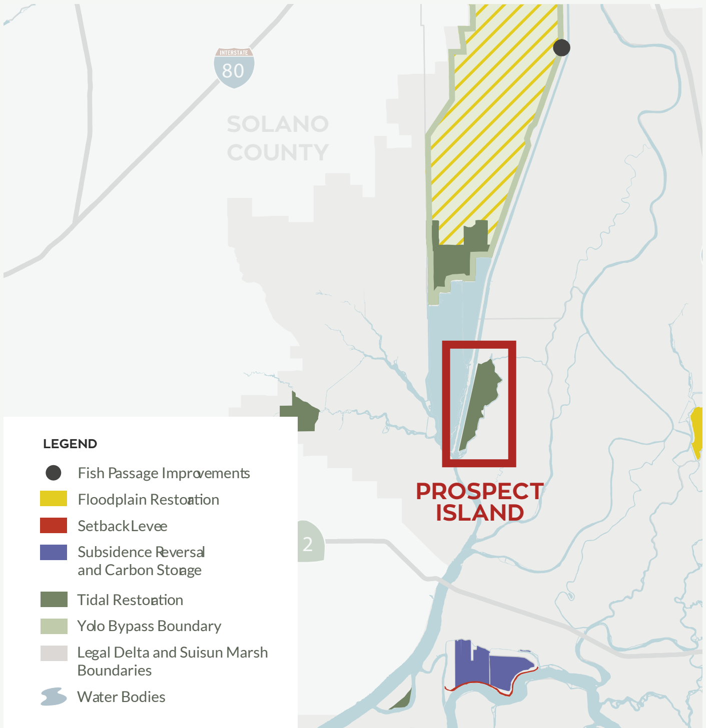
PROJECT PROPONENT

- Department of Water Resources
  Division of Environmental Services, Fish Restoration Program
  Dan Riordan, Chief
  dan.riordan@water.ca.gov
  (916) 376-9738

ADDITIONAL INFORMATION

- DWR website:
  http://www.water.ca.gov/environmentalservices/frpa_prospect_restoration.cfm





CALIFORNIA ECO RESTORE
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MCCORMACK-WILLIAMSON TRACT RESTORATION PROJECT

Sacramento County, CA

TIDAL MARSH / FLOODPLAIN

The McCormack-Williamson Tract (MWT) island in Sacramento County offers opportunities for restoration of critical tidal freshwater marsh and floodplain habitat. Restoration of MWT is included as part of the Department of Water Resources' (DWR) North Delta Flood Control and Ecosystem Restoration Project ("North Delta FCERP"). The North Delta FCERP will implement flood control improvements principally on and around MWT, Dead Horse Island, and Grizzly Slough in a manner that benefits aquatic and terrestrial habitats, species, and ecological processes. DWR certified the Environmental Impact Report for the North Delta FCERP in 2010, which proposed developing flood control and restoration (Alternative 1A) on MWT with the following goals:

- Provide flood control improvements to reduce damage from overflows caused by insufficient channel capacities and levee failures in the project study area.
- Benefit native species by re-establishing natural ecological functions and habitats.
- Contribute to scientific understanding of ecological restoration.
- Enhance public recreation opportunities in a manner that does not compromise flood protection infrastructure or operations, compromise habitat integrity, or disturb wildlife.

Flood flows and high water conditions in the area downstream of the confluence threaten levees, bridges and roadways. The MWT and Grizzly Slough properties are proposed for restoration to reduce flooding and provide aquatic and floodplain habitats along the downstream portion of the Cosumnes Preserve along the Cosumnes and Mokelumne Rivers. The project at MWT is intended to allow the passing of flood flows through the Tract, in a way that minimizes flood impacts to the system because MWT's levees are already lower than surrounding neighbor's levees and flooding has occurred on the island historically.

Currently two projects are proposed for MWT:

- The levee re-sloping and tower levee, known as "Project A"
- The levee breach, weir and restoration, known as "Project B"

These projects combine flood surge reduction measures with the construction of habitat friendly levees and a breach on MWT to provide benefits to ecosystem processes and species by recreating tidal marsh, subtidal and floodplain/riparian habitats.

RESTORATION GOALS / TARGET

The restoration projects on MWT are focused on floodplain restoration and flood control, and creation of tidal marsh habitat.

Approximate acreage goals:

- Upland Floodplain: 71 acres
- Riparian: 103 acres

- Tidal Marsh: 908 acres
- Subtidal: 407 acres
- Total: 1,489 acres

LOCATION AND LANDOWNER

MWT is a North Delta island located immediately downstream of the confluence of the Cosumnes and Mokelumne Rivers, just northeast of the Delta Cross Channel. The 1,600-acre "island" in Sacramento County is owned by The Nature Conservancy (TNC), which was purchased through a CALFED grant in 1999.

FUNDING

- Property Acquisition:
  - CALFED Ecosystem Restoration Program (ERP) $5.4M
- Development for Project A and B:
  - Department of Water Resources
  - Proposition 50
  - CALFED ERP
- Design/construction:
  - Project A: Proposition 1E $6M
  - Project B: TBD
- Ongoing maintenance and monitoring: TBD
  - Planning - a grant from the California Department of Fish and Wildlife (CDFW) will be used to fund TNC to develop of a monitoring plan for the site.

TIMELINE

Planning and Permitting 2011-2017.

- Project A: Levee re-sloping and tower levee implementation - 2017-2018
- Project B: Breach, weir and restoration implementation - 2018-2019

PERMITTING

- CEQA: North Delta FCERP EIR completed in 2010 for MWT and Grizzly Slough projects
  - Project A: Addendum completed in 2015
  - Project B: TBD
- Section 404 Permit Application/Wetland Delineation Verification
  - Project A: Application submitted December 2015
  - Project B: Wetland delineation complete
- Sacramento County Grading Permit
  - Project A: Completed and submitted in 2016
  - Project B: Formulating
- Clean Water Act, 401 Water Quality Certification
  - Project A: Completed and submitted in 2016
  - Project B: Formulating
- Federal Endangered Species Act
  - Project A: Biological Assessment submitted in 2016; currently in formal consultation
  - Project B: Formulating
- State Historic Preservation Office, Section 106 Consultation/Cultural Resources
  - Project A: Report complete and submitted
  - Project B: Formulating
- Section 401 Water Quality Certification
  - Project A: Not applicable (N/A)
  - Project B: Formulating
- Streambed Alteration Agreement/Section 1602 or 1605
  - Project A: N/A
  - Project B: Formulating
- California Endangered Species Act, Section 2081 Incidental Take Permit
  - Project A: N/A
  - Project B: Formulating
- Central Valley Flood Protection Board Encroachment Permit
  - Project A: N/A
  - Project B: Formulating
- California State Lands Commission Lease Agreement
  - Project A: N/A
  - Project B: Formulating

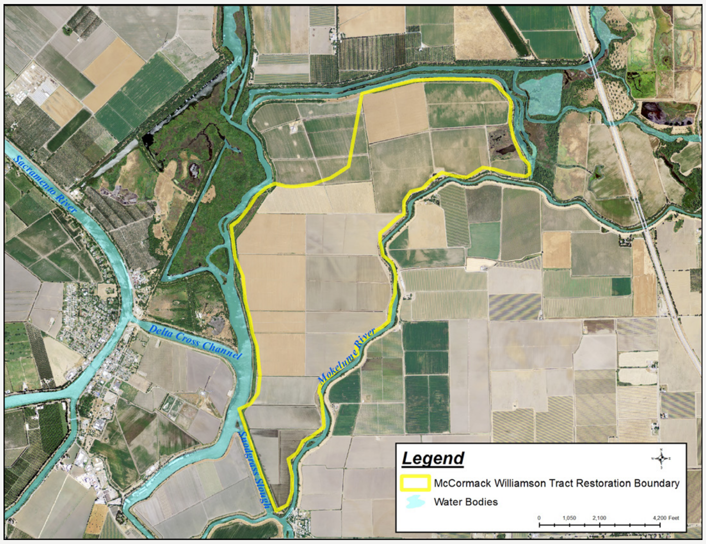
PROJECT PROPONENT

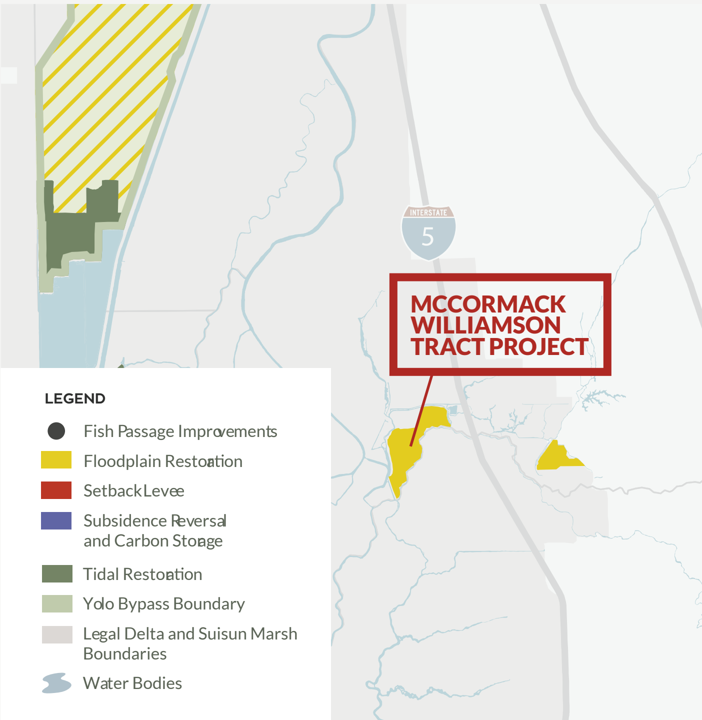
- Anitra Pawley, PH.D.
  Program Manager
  Delta Levees Office, Division of Flood Management
  Department of Water Resources
  3310 El Camino Ave Suite 145
  Sacramento, CA 95821
  (916) 480-5359
  anitra.pawley@water.ca.gov

- Judah Grossman
  Project Director
  The Nature Conservancy
  555 Capital Mall
  Sacramento, CA. 95831
  (916) 642-8053
  jgrossman@tnc.org

MORE INFORMATION

North Delta Flood Control and Ecosystem Restoration Project Final EIR: http://www.water.ca.gov/floodsafe/fessro/levees/north_delta/docs/





CALIFORNIA
ECO RESTORE

Grizzly Slough Floodplain Project

Project Description: DWR's North Delta Flood Control and Ecosystem Restoration Project ("NDFCERP") includes restoration of the Grizzly Slough Floodplain. The NDFCERP will implement flood control improvements principally on and around MWT, Dead Horse Island, and Grizzly Slough in a manner that benefits aquatic and terrestrial habitats, species, and ecological processes. The NDFCERP EIR, approved and certified in November 2010 by DWR, proposed developing a flood control and restoration project (Alternative 1A) on GS with the following goals:

- Provide flood control improvements to reduce damage from overflows caused by insufficient channel capacities and levee failures in the Project study area.
- Benefit native species by re-establishing natural ecological functions and habitats,
- Contribute to scientific understanding of ecological restoration, and
- Enhance public recreation opportunities in a manner that does not compromise flood protection infrastructure or operations, compromise habitat integrity, or disturb wildlife.

The Grizzly Slough Floodplain Restoration Project (GS Project), is one of two main elements of the North Delta Flood Control and Ecosystem Restoration Project that consists of flood management and habitat improvements where the Mokelumne River, Cosumnes River, Dry Creek and Morrison Creeks converge. Flood flows and high water conditions in this area threaten levees, bridges and roadways. The North Delta project will reduce flooding and provide contiguous aquatic and floodplain habitat along the downstream portion of the Cosumnes Preserve by modifying levees on Grizzly Slough. Benefits to ecosystem processes, fish and wildlife, will be achieved by recreating floodplain seasonal wetlands and riparian habitat on the Grizzly Slough property (Figure 3).

Type of Project: Floodplain/riparian restoration.

Restoration Targets:

Upland Floodplain/Riparian		400 acres
Total =		**~400 acres**

Location and Landowner: The Project is located 1.5 miles northeast of Thornton in southern Sacramento County (Figure 2). Owner: Department of Water Resources

Funding: Development: DWR Proposition E, Delta Levees
Design/construction: DWR Proposition E, Delta Levees
Ongoing maintenance and monitoring: To be determined.

Permitting:

Permits	Status
Section 404 Permit Application/Wetland Delineation Verification	Formulating
Section 401 Water Quality Certification	Formulating
Federal Endangered Species Act (ESA) Coordination: NEPA Compliance	Formulating
Section 106 Consultation/Cultural Resources	Formulating
Section 404(b)(1) Water Quality Analysis:	Formulating
Streambed Alteration Agreement/Section 1602 or 1605 Streambed Alteration Agreement	Formulating
Section 2081 Incidental Take Permit/State Endangered Species Act (SESA)	Formulating
Central Valley Regional Water Quality Control Board (CVRWQCB) Encroachment Permit	Formulating
California State Lands Commission Lease Agreement	Formulating

CEQA/NEPA compliance status**:** CEQA, North Delta EIR 2010

Estimated Timeline: CEQA, North Delta EIR 2010

Planning and Permitting 2015-2017

Implementation 2017-2018

Project Proponent:

Anitra Pawley, PH.D.
Program Manager
Department of Water Resources/FESSRO
North Delta Program
P.O. Box 942836
Sacramento, CA. 95831
anitra.pawley@water.ca.gov
(916) 651-7014

David P. Lounsbury, PE
Project Engineer (Representing RD 348)
Wagner & Bonsignore, Consulting Civil Engineers
2151 River Plaza Drive, Suite 100
Sacramento, CA 95833
dlounsbury@wbecorp.com
(916) 441-6850

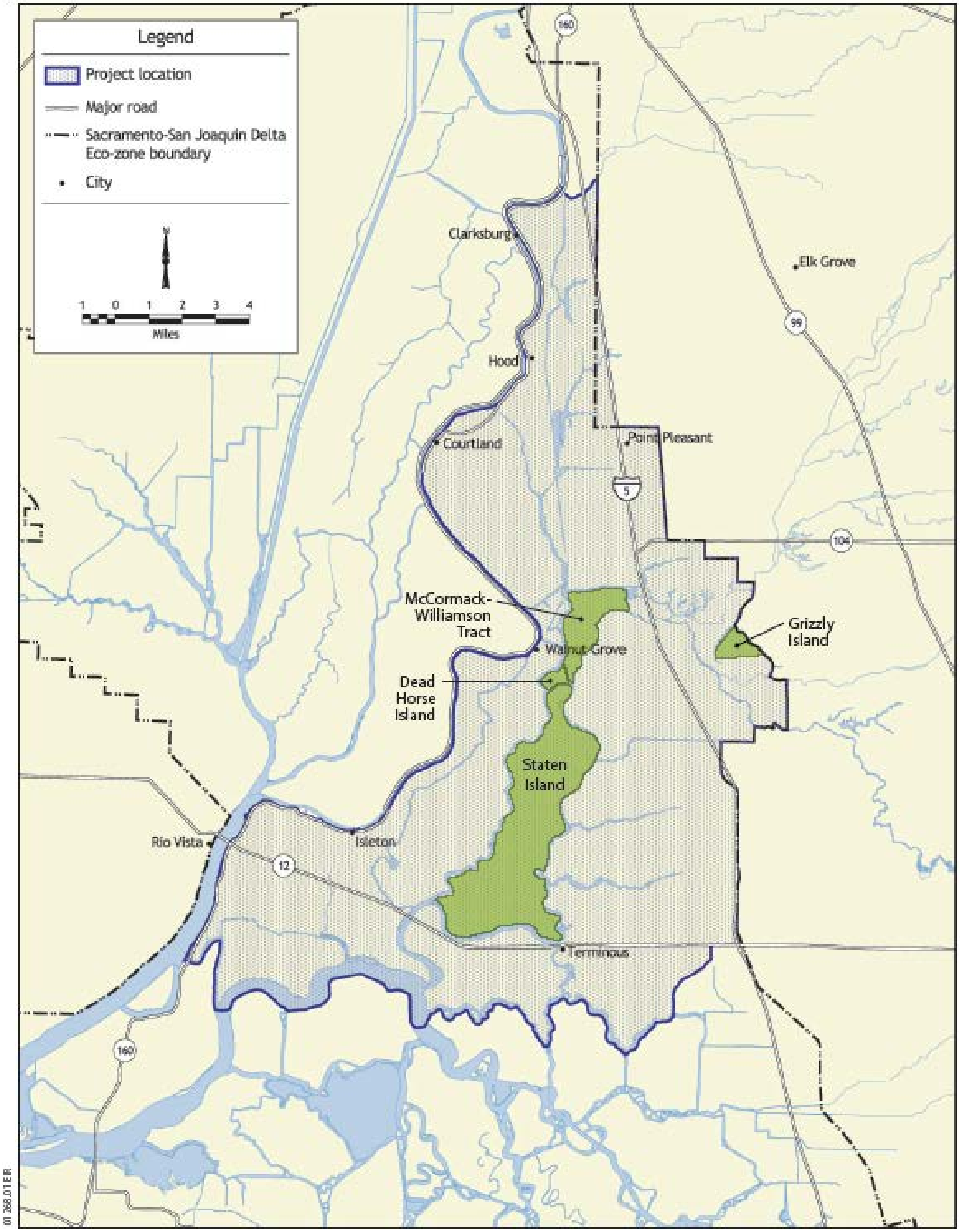


Figure 1 - Project Area of the North Delta Flood Control and Ecosystem Restoration Project

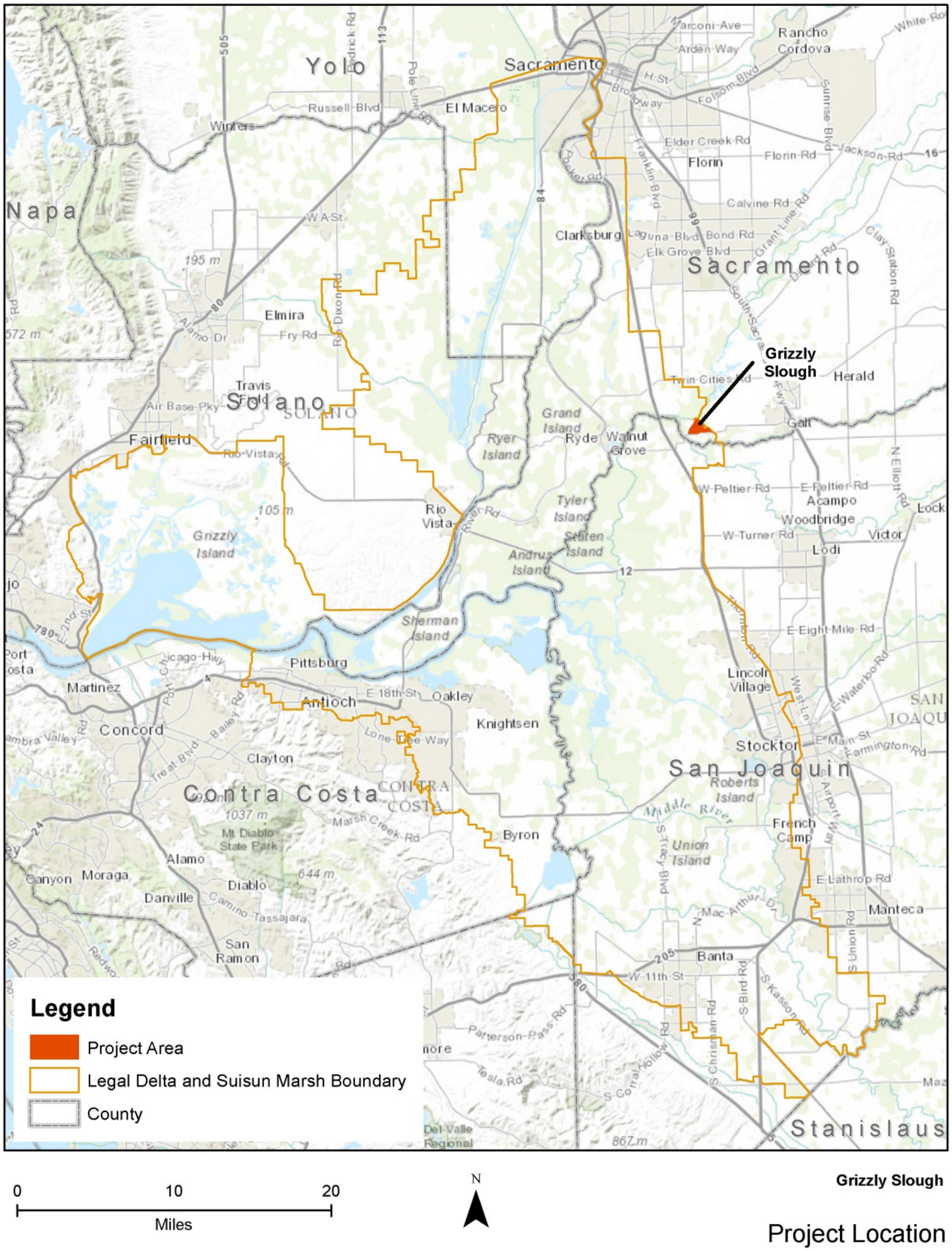


Figure 2: Grizzly Slough Floodplain Project Location.

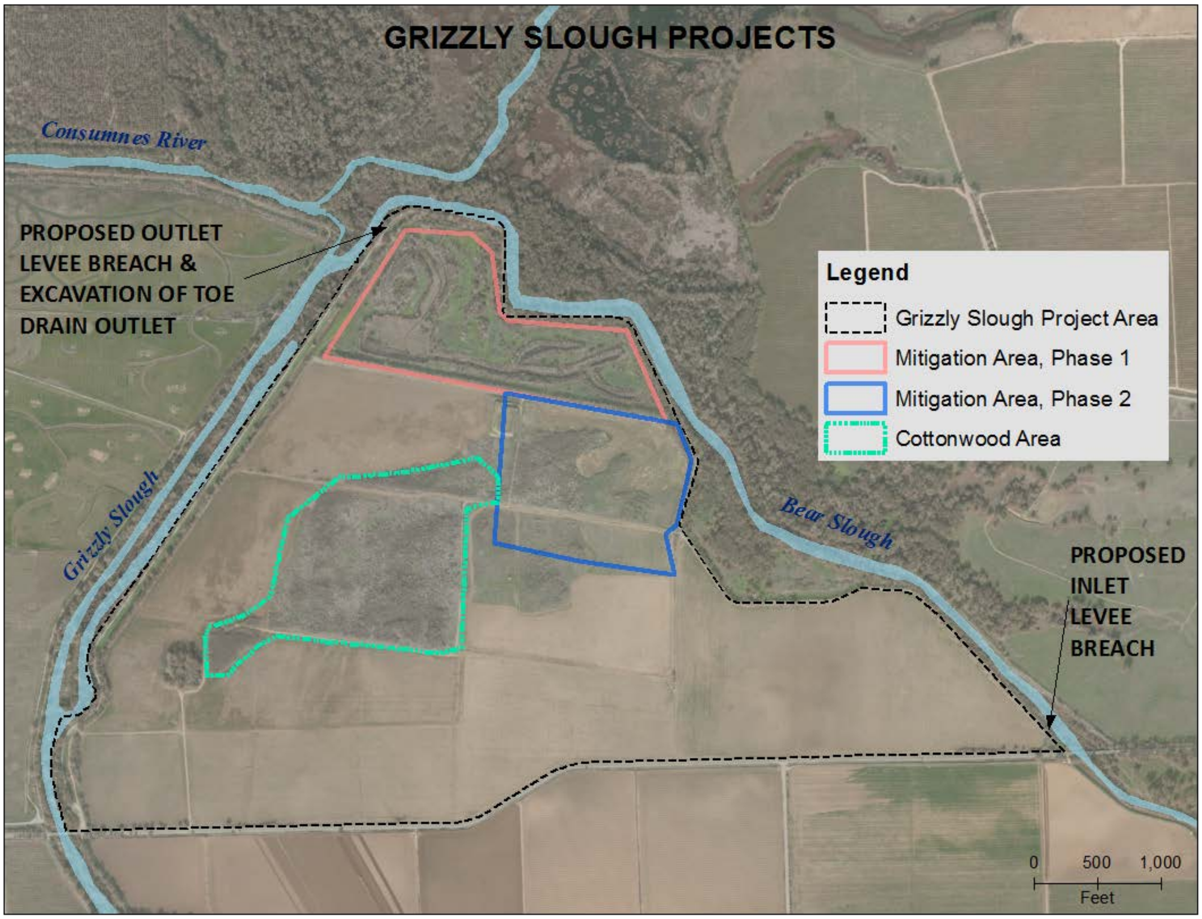


Figure 3 – Proposed Project Plan for the North Delta, Grizzly Slough Floodplain Project.

Appendix 1. Restoration Project Fact Sheets

1. Lindsey Slough Tidal Marsh Restoration
2. Lookout Slough Tidal Habitat Restoration and Flood Improvement Project
3. Yolo Flyway Farms Tidal Habitat Restoration Project
4. Prospect Island Tidal Habitat Restoration Project
5. Mccormack-Williamson Tract Restoration Project
6. Grizzly Slough Floodplain Project

CALIFORNIA
ECO RESTORE

Lindsey Slough Tidal Marsh Restoration

Project Description: The Lindsey Slough Restoration Project restored habitat function and connectivity to Delta wetlands and waterways that had been degraded by the construction of dikes and culverts 100 years earlier. The project consisted of (1) excavation and debris removal to enlarge an existing north embankment breach on Calhoun Cut at a northern arm of Lindsey Slough; (2) breaching of the south embankment of Calhoun Cut; (3) excavation of a one mile long channel at the historic southern arm of Lindsey Slough; (4) lowering of an existing earthen causeway on the historic channel; and (5) beneficial reuse of sediment excavated from the channel to create low habitat berms within the marsh and raise the remnant marsh site to a more mature marshplain form.

Restoration Targets: This project restored habitat function and connectivity to 159 acres of freshwater emergent wetlands and 69 acres of alkali wetlands, and recreated and reconnected a one-mile tidal channel.

Location and Landowner: This project is located on the northwest fringe of the historical Sacramento-San Joaquin Delta, just west of the confluence of Lindsey Slough, Barker Slough, and Calhoun Cut within the Cache Slough tidal drainage on the California Department of Fish and Wildlife's Calhoun Cut Ecological Reserve in Solano County (site map attached).

Funding: Design and Construction: $376,195 from Prop 84 (drought funds)
Planning (and land acquisition): $959, 195 (Ecosystem Restoration Program)

Permitting: Completed

Estimated Timeline: Completed.

Known Obstacles to Implementation: This project was completed in 2014.

Project Proponent: California Department of Fish and Wildlife
Greg Martinelli: Greg.Martinelli@wildlife.ca.gov, (707) 944-5570
Sarah Estrella: Sarah.Estrella@wildlife.ca.gov, (209) 234-3677

LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

Cache Slough Complex

TIDAL HABITAT AND FLOOD IMPROVEMENT

The Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (Project) is located in the Cache Slough region, one of the key areas in the Sacramento-San Joaquin Delta (Delta) with elevations favorable for maintaining tidal habitats for the endangered Delta smelt. The proposed Project would restore approximately 3,000 acres of tidal wetland, creating habitat that is beneficial to native fish and wildlife. Lookout Slough is adjacent to additional tidal habitat restoration efforts being implemented by the Department of Water Resources (DWR), including Yolo Flyway Farms and Lower Yolo Ranch, to create a contiguous tidal wetland restoration complex spanning 16,000 acres in the Cache Slough region. Once completed, the proposed Project would be the Delta's largest single tidal habitat restoration project to date.

In addition to the restoration of important tidal wetland habitat, the proposed multi-benefits of this Project will meet objectives of the Central Valley Flood Protection Plan to reduce flood risk. The proposed Project includes construction of a new setback levee along the west and north edges of the site to allow for breaching the existing Yolo Bypass West Levee along Shag Slough. The new setback levee will provide 100-year flood protection with additional height for climate change and sea level rise resiliency. Breaching and degrading the existing levees will restore historical tidal influence on the site, providing food web and other benefits to Delta smelt and increasing seasonal floodplain rearing habitat for salmonids.

This effort is being implemented by DWR through a partnership with Ecosystem Investment Partners (EIP) and Reclamation District 2098. Partnering with EIP and leveraging their unique expertise in planning, permitting and constructing large-scale restoration projects will allow DWR to implement this effort in a timely manner. The project is expected to be complete by 2022.

The Project is intended to partially fulfill DWR's 8,000-acre tidal habitat restoration obligations pursuant to the 2008 U.S. Fish and Wildlife Service (USFWS) Delta Smelt Biological Opinion (BiOp) and is consistent with the 2009 National Marine Fisheries Service (NMFS) Salmonid BiOp for long-term coordinated operations of the State Water Project and the federal Central Valley Project.

RESTORATION GOALS / TARGET

1. Create and maintain diverse intertidal and subtidal habitat to support native species and improved food productivity within the Project area.
2. Design and implement the Project to support viable populations of special status aquatic and terrestrial species.
3. Provide additional flood storage and conveyance within the Yolo Bypass to reduce the chance of catastrophic flooding and protect existing nearby infrastructure (e.g. agriculture, power and human habitation).

LOCATION AND LANDOWNER

Lookout Slough is located in the Cache Slough region at the lower end of the Yolo Bypass in Solano County. EIP is the current owner of the Lookout Slough site and will complete necessary permitting and construction efforts. Upon completion, DWR will maintain the project site and partner with the California Department of Fish and Wildlife for long-term monitoring.

FUNDING

Funding for this Project is provided through two separate sources based on specific benefits. The habitat restoration objectives of the project will be funded by the State Water Project and State Water Contractors ($97,000,000), and the flood protection objectives will be funded by Proposition 1 – for multi-benefit and systemwide flood improvements ($21,865,000). The estimated total cost of the project is approximately $118,865,000.

TIMELINE

This Project is proposed to be completed by 2022

- California Environmental Quality Act (CEQA) Notice of Preparation – Spring 2019
- Draft Environmental Impact Report (EIR) Released for Public Review and Comment – Summer 2019
- Final EIR Certified – Fall 2019
- If Approved, Begin Construction - Spring 2020
- End Construction – Fall 2021

PERMITTING

- CEQA/National Environmental Policy Act
- National Historic Preservation Act – Section 106
- USFWS Endangered Species Act - Section 7
- NMFS Endangered Species Act - Section 7
- US Army Corps of Engineers - Section 404 and Section 408
- Central Valley Regional Water Quality Board - Section 401
- California Department of Fish and Wildlife - Streambed Alteration Agreement and California Endangered Species Act Incidental Take Permit
- Central Valley Flood Protection Board – Encroachment Permit
- Delta Stewardship Council - Delta Plan Consistency Determination
- County permits and authorizations

PROJECT PROPONENT

Department of Water Resources
Division of Environmental Services
Fish Restoration Program
Heather Green
Heather.Green@water.ca.gov

Department of Water Resources
Division of Flood Management
Kyle Bickler, PE, GE
Kyle.Bickler@water.ca.gov

CALIFORNIA ECO RESTORE
A STRONGER DELTA ECOSYSTEM.

YOLO FLYWAY FARMS TIDAL HABITAT RESTORATION PROJECT

Cache Slough Complex

TIDAL WETLAND

The Yolo Flyway Farms Tidal Habitat Restoration Project (Project) is a joint effort by the California Department of Water Resources (DWR) and Reynier Fund, LLC. to restore seasonal wetland and cattle grazing land to sub-tidal, intertidal and seasonal wetlands to benefit native fish species. The 359-acre Project involves restoring and enhancing approximately 300 acres of tidal freshwater wetlands, and an additional 30 acres of seasonal wetlands, at the southern end of the Yolo Bypass in the northwestern Sacramento/San Joaquin River Delta (Delta). The proposed Project seeks to partially restore historical ecological functions in the current, highly altered regional landscape. DWR and Reynier Fund, LLC. are restoring this project to help meet the 2008 U.S. Fish and Wildlife Service (USFWS) Delta Smelt OCAP Biological Opinion's requirement to restore 8,000 acres of tidal wetlands in the Delta. The Project will also contribute to restoration requirements of the 2009 National Marine Fisheries Service (NMFS) OCAP BiOp.

The project design seeks to maximize residency time and food web production by capturing and slowly draining water through the excavation of two breaches along the Yolo Bypass Toe Drain and interior channels to connect and enhance existing wetlands on site. The project plans to accommodate sea level rise through the enhancement of transitional uplands. The project's restoration activities will restore tidal action to benefit native fish species.

The completed restoration project will be conveyed to DWR in fee title.

RESTORATION GOAL / TARGET

The primary goals of the Project are to (1) improve habitat conditions for Delta smelt by enhancing regional food web productivity; (2) improve habitat conditions for salmonids by providing rearing habitats for out-migrating juveniles and migratory habitats for adults; (3) support a range of other aquatic and wetland-dependent species; (4) provide habitat for establishment of native plant communities; (5) minimize potential for colonization by aquatic weeds, and; (6) preserve existing topographic variability to allow for habitat succession and resilience against future climate change.

LOCATION AND LANDOWNER

The Yolo Flyway Farms Tidal Habitat Restoration Project is located in the northern Delta in southern Yolo County, at the southern end of the Yolo Bypass floodway immediately adjacent to the Yolo Bypass Toe Drain. The site is currently owned and managed by Reynier Fund, LLC.

FUNDING

Fully funded by the State Water Project for all phases of the effort.

PERMITS NECESSARY

- Central Valley Regional Water Quality Control Board: Section 401 and Waste Discharge Report
- State Lands Commission: Notice of Proposed Use of State Lands

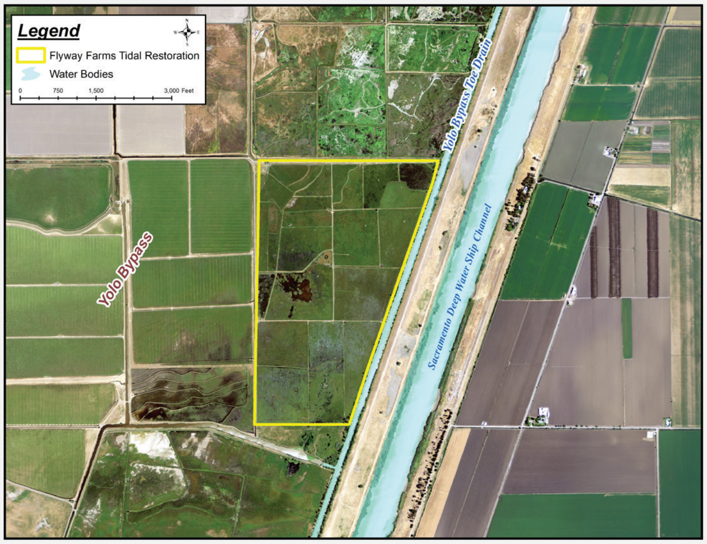
- National Historic Preservation Act: Section 106
- California Department of Fish and Wildlife: Streambed Alteration Agreement Section 1600; Incidental Take Permit
- U.S. Army Corps of Engineers: Nationwide 27 (404 permit)
- USFWS Endangered Species Act: Section 7
- NMFS Endangered Species Act: Section 7
- Delta Stewardship Council: Delta Plan Consistency Determination
- Yolo County approvals and permits

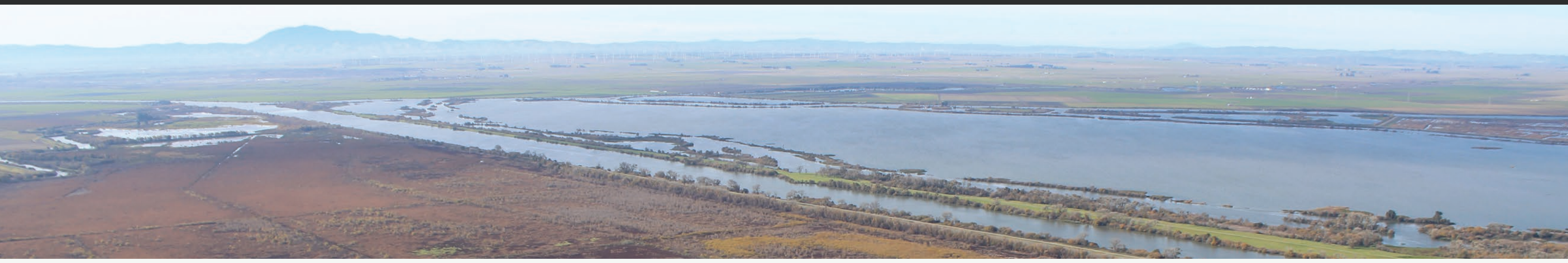
ESTIMATED TIMELINE

- Permitting: August 2017 through 2018
- Construction Complete: 2018
- Monitoring: 2017 through 2029
- Ongoing Adaptive Management and Maintenance: 2019+

PROJECT PROPONENT

Department of Water Resources
Division of Environmental Services
Fish Restoration Program
Bonnie Irving
Program Manager
bonnie.irving@water.ca.gov
(916) 376-9748





PROSPECT ISLAND TIDAL HABITAT RESTORATION PROJECT

Solano County

TIDAL WETLAND & SUB-TIDAL HABITAT

Historically, the Prospect Island site was tidal marshland, with Prospect Slough to the west and north, and Miner Slough to the east and south. Levees were constructed during the late 19th century to convert the land for agricultural uses. Prospect Island is part of the Yolo Bypass floodplain; however construction of the Deep Water Ship Channel (DWSC) in the 1960s isolated Prospect Island from the main reach of the Bypass.

The proposed project would restore tidal action to the interior of Prospect Island, partially fulfilling the 8,000-acre tidal habitat restoration obligations contained within the Reasonable and Prudent Alternative (RPA) 4 of the U.S. Fish and Wildlife Service (USFWS) Delta Smelt Biological Opinion for long-term coordinated operations of the State Water Project (SWP) and the federal Central Valley Project (CVP). Because restoration of tidal habitat would provide access for salmonid rearing at Prospect Island, the project would also be consistent with RPA 1.6.1 of the 2009 National Marine Fisheries Service (NMFS) Salmonid Biological Opinion for SWP/CVP. The project would result in a suite of overarching long-term ecosystem benefits, including enhancement of primary productivity and food availability for fisheries in the Sacramento-San Joaquin Delta (Delta); an increase in the quantity and quality of salmonid rearing habitat and habitat for other listed species; enhancement of water quality, recreation and carbon sequestration in tidal marshes; promotion of habitat resiliency; and promotion of habitat conditions that support native species. Current design of the project includes breaching the external Miner Slough levee and removing a portion of the internal cross levee to open the site to daily tidal inundation. The Department of Water Resources (DWR) is the California Environmental Quality Act (CEQA) Lead Agency for this project.

RESTORATION GOALS / TARGET

- Between 1,000 and 1,500 acres of tidal and sub-tidal restoration
- Specific project objectives:
  - Enhance productivity and food availability for Delta Smelt and other native fishes
  - Increase salmonid rearing habitat
  - Increase habitats to support other listed species
  - Provide ecosystem benefits including water quality enhancement, recreation, and carbon sequestration
  - Promote future habitat resiliency to threats such as land use conversions, climate change, sea level rise, and invasive species
  - Avoid establishment or spread of exotic invasive species

LOCATION AND LANDOWNER

Prospect Island is a 1,600-acre property located in southeast Solano County, in the northwestern part of the Delta. The site is bound on the east by Miner Slough, on the west by the DWSC, on the south by the confluence of the DWSC and Miner Slough, and on the north by an east-west levee that runs from Arrowhead Harbor Marina to the DWSC. It is located just east of the naturally restored 4,500-acre Liberty Island.

Both the northern, 1,300-acre portion and the southern, 300-acre portion of Prospect Island are owned by DWR.

FUNDING

Fully funded by the SWP Contractors for all phases of the effort

ESTIMATED TIMELINE

- CEQA (final): Mid-2017
- Permitting completed: Late 2017
- Construction design completed: Late 2017

- Site preparation: Early 2018
- Begin construction: Mid-2018
- Construction complete: 2020

PERMITTING

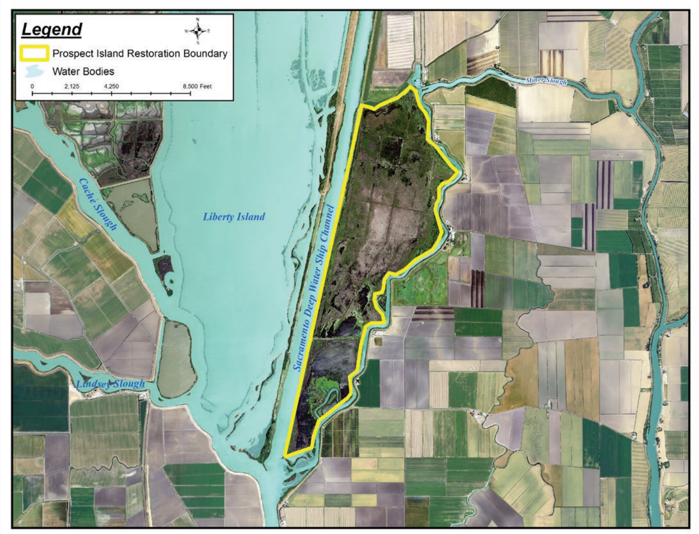
- US Army Corps of Engineers:
  - Clean Water Act (CWA) Section 404/River Harbors Act Section 10
- NMFS:
  - Endangered Species Act Section 7
- USFWS:
  - Endangered Species Act Section 7
- CA Department of Fish and Wildlife:
  - Section 1602 Lake or Streambed Alteration Agreement
  - Incidental Take Permit 2081
- California State Historic Preservation Office:
  - Letter of concurrence with USACE via the National Historic Preservation Act Section 106
- Central Valley Flood Protection Board:
  - Title 23 CCR Division Encroachment Permit
- Central Valley Regional Water Quality Control Board:
  - CWA Section 401 Water Quality Certification
  - Section 402 National Pollution Discharge Elimination System
  - Porter Cologne Water Quality Control Act Waste Discharge Requirement
- California State Lands Commission (CSLC):
  - State Lands Lease Amendment CSLC approval
- Solano County:
  - DWR would apply for all legally applicable local permits from Solano County

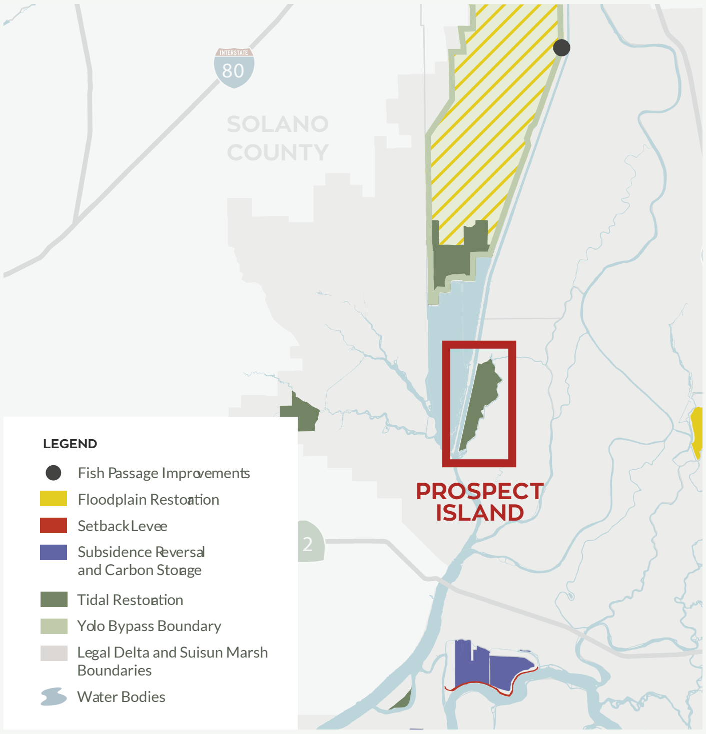
PROJECT PROPONENT

- Department of Water Resources
  Division of Environmental Services, Fish Restoration Program
  Dan Riordan, Chief
  dan.riordan@water.ca.gov
  (916) 376-9738

ADDITIONAL INFORMATION

- DWR website:
  http://www.water.ca.gov/environmentalservices/frpa_prospect_restoration.cfm





MCCORMACK-WILLIAMSON TRACT RESTORATION PROJECT

Sacramento County, CA

TIDAL MARSH / FLOODPLAIN

The McCormack-Williamson Tract (MWT) island in Sacramento County offers opportunities for restoration of critical tidal freshwater marsh and floodplain habitat. Restoration of MWT is included as part of the Department of Water Resources' (DWR) North Delta Flood Control and Ecosystem Restoration Project ("North Delta FCERP"). The North Delta FCERP will implement flood control improvements principally on and around MWT, Dead Horse Island, and Grizzly Slough in a manner that benefits aquatic and terrestrial habitats, species, and ecological processes. DWR certified the Environmental Impact Report for the North Delta FCERP in 2010, which proposed developing flood control and restoration (Alternative 1A) on MWT with the following goals:

- Provide flood control improvements to reduce damage from overflows caused by insufficient channel capacities and levee failures in the project study area.
- Benefit native species by re-establishing natural ecological functions and habitats.
- Contribute to scientific understanding of ecological restoration.
- Enhance public recreation opportunities in a manner that does not compromise flood protection infrastructure or operations, compromise habitat integrity, or disturb wildlife.

Flood flows and high water conditions in the area downstream of the confluence threaten levees, bridges and roadways. The MWT and Grizzly Slough properties are proposed for restoration to reduce flooding and provide aquatic and floodplain habitats along the downstream portion of the Cosumnes Preserve along the Cosumnes and Mokelumne Rivers. The project at MWT is intended to allow the passing of flood flows through the Tract, in a way that minimizes flood impacts to the system because MWT's levees are already lower than surrounding neighbor's levees and flooding has occurred on the island historically.

Currently two projects are proposed for MWT:

- The levee re-sloping and tower levee, known as "Project A"
- The levee breach, weir and restoration, known as "Project B"

These projects combine flood surge reduction measures with the construction of habitat friendly levees and a breach on MWT to provide benefits to ecosystem processes and species by recreating tidal marsh, subtidal and floodplain/riparian habitats.

RESTORATION GOALS / TARGET

The restoration projects on MWT are focused on floodplain restoration and flood control, and creation of tidal marsh habitat.

Approximate acreage goals:

- Upland Floodplain: 71 acres
- Riparian: 103 acres

- Tidal Marsh: 908 acres
- Subtidal: 407 acres
- Total: 1,489 acres

LOCATION AND LANDOWNER

MWT is a North Delta island located immediately downstream of the confluence of the Cosumnes and Mokelumne Rivers, just northeast of the Delta Cross Channel. The 1,600-acre "island" in Sacramento County is owned by The Nature Conservancy (TNC), which was purchased through a CALFED grant in 1999.

FUNDING

- Property Acquisition:
  - CALFED Ecosystem Restoration Program (ERP) $5.4M
- Development for Project A and B:
  - Department of Water Resources
  - Proposition 50
  - CALFED ERP
- Design/construction:
  - Project A: Proposition 1E $6M
  - Project B: TBD
- Ongoing maintenance and monitoring: TBD
  - Planning - a grant from the California Department of Fish and Wildlife (CDFW) will be used to fund TNC to develop of a monitoring plan for the site.

TIMELINE

Planning and Permitting 2011-2017.

- Project A: Levee re-sloping and tower levee implementation - 2017-2018
- Project B: Breach, weir and restoration implementation - 2018-2019

PERMITTING

- CEQA: North Delta FCERP EIR completed in 2010 for MWT and Grizzly Slough projects
  - Project A: Addendum completed in 2015
  - Project B: TBD
- Section 404 Permit Application/Wetland Delineation Verification
  - Project A: Application submitted December 2015
  - Project B: Wetland delineation complete
- Sacramento County Grading Permit
  - Project A: Completed and submitted in 2016
  - Project B: Formulating
- Clean Water Act, 401 Water Quality Certification
  - Project A: Completed and submitted in 2016
  - Project B: Formulating
- Federal Endangered Species Act
  - Project A: Biological Assessment submitted in 2016; currently in formal consultation
  - Project B: Formulating
- State Historic Preservation Office, Section 106 Consultation/Cultural Resources
  - Project A: Report complete and submitted
  - Project B: Formulating
- Section 401 Water Quality Certification
  - Project A: Not applicable (N/A)
  - Project B: Formulating
- Streambed Alteration Agreement/Section 1602 or 1605
  - Project A: N/A
  - Project B: Formulating
- California Endangered Species Act, Section 2081 Incidental Take Permit
  - Project A: N/A
  - Project B: Formulating
- Central Valley Flood Protection Board Encroachment Permit
  - Project A: N/A
  - Project B: Formulating
- California State Lands Commission Lease Agreement
  - Project A: N/A
  - Project B: Formulating

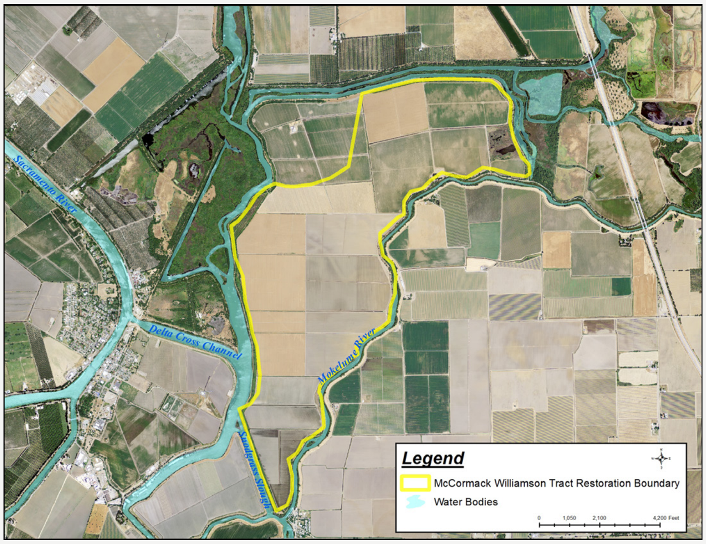
PROJECT PROPONENT

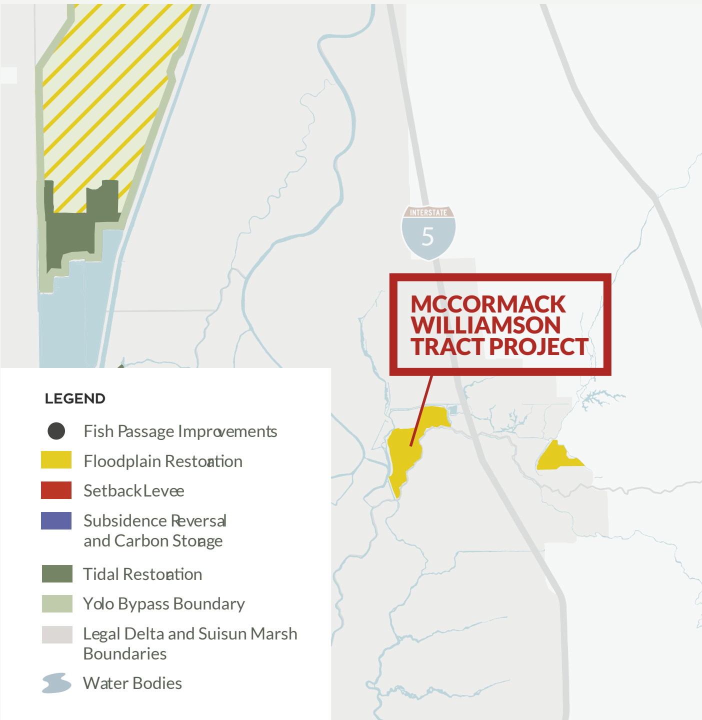
- Anitra Pawley, PH.D.
  Program Manager
  Delta Levees Office, Division of Flood Management
  Department of Water Resources
  3310 El Camino Ave Suite 145
  Sacramento, CA 95821
  (916) 480-5359
  anitra.pawley@water.ca.gov

- Judah Grossman
  Project Director
  The Nature Conservancy
  555 Capital Mall
  Sacramento, CA. 95831
  (916) 642-8053
  jgrossman@tnc.org

MORE INFORMATION

North Delta Flood Control and Ecosystem Restoration Project Final EIR: http://www.water.ca.gov/floodsafe/fessro/levees/north_delta/docs/





CALIFORNIA ECO RESTORE

Grizzly Slough Floodplain Project

Project Description: DWR's North Delta Flood Control and Ecosystem Restoration Project ("NDFCERP") includes restoration of the Grizzly Slough Floodplain. The NDFCERP will implement flood control improvements principally on and around MWT, Dead Horse Island, and Grizzly Slough in a manner that benefits aquatic and terrestrial habitats, species, and ecological processes. The NDFCERP EIR, approved and certified in November 2010 by DWR, proposed developing a flood control and restoration project (Alternative 1A) on GS with the following goals:

- Provide flood control improvements to reduce damage from overflows caused by insufficient channel capacities and levee failures in the Project study area.
- Benefit native species by re-establishing natural ecological functions and habitats,
- Contribute to scientific understanding of ecological restoration, and
- Enhance public recreation opportunities in a manner that does not compromise flood protection infrastructure or operations, compromise habitat integrity, or disturb wildlife.

The Grizzly Slough Floodplain Restoration Project (GS Project), is one of two main elements of the North Delta Flood Control and Ecosystem Restoration Project that consists of flood management and habitat improvements where the Mokelumne River, Cosumnes River, Dry Creek and Morrison Creeks converge. Flood flows and high water conditions in this area threaten levees, bridges and roadways. The North Delta project will reduce flooding and provide contiguous aquatic and floodplain habitat along the downstream portion of the Cosumnes Preserve by modifying levees on Grizzly Slough. Benefits to ecosystem processes, fish and wildlife, will be achieved by recreating floodplain seasonal wetlands and riparian habitat on the Grizzly Slough property (Figure 3).

Type of Project: Floodplain/riparian restoration.

Restoration Targets:

Upland Floodplain/Riparian		400 acres
Total =		**~400 acres**

Location and Landowner: The Project is located 1.5 miles northeast of Thornton in southern Sacramento County (Figure 2). Owner: Department of Water Resources

Funding: Development: DWR Proposition E, Delta Levees
Design/construction: DWR Proposition E, Delta Levees
Ongoing maintenance and monitoring: To be determined.

Permitting:

Permits	Status
Section 404 Permit Application/Wetland Delineation Verification	Formulating
Section 401 Water Quality Certification	Formulating
Federal Endangered Species Act (ESA) Coordination: NEPA Compliance	Formulating
Section 106 Consultation/Cultural Resources	Formulating
Section 404(b)(1) Water Quality Analysis:	Formulating
Streambed Alteration Agreement/Section 1602 or 1605 Streambed Alteration Agreement	Formulating
Section 2081 Incidental Take Permit/State Endangered Species Act (SESA)	Formulating
Central Valley Regional Water Quality Control Board (CVRWQCB) Encroachment Permit	Formulating
California State Lands Commission Lease Agreement	Formulating

CEQA/NEPA compliance status**:** CEQA, North Delta EIR 2010

Estimated Timeline: CEQA, North Delta EIR 2010

Planning and Permitting 2015-2017

Implementation 2017-2018

Project Proponent:

Anitra Pawley, PH.D.
Program Manager
Department of Water Resources/FESSRO
North Delta Program
P.O. Box 942836
Sacramento, CA. 95831
anitra.pawley@water.ca.gov
(916) 651-7014

David P. Lounsbury, PE
Project Engineer (Representing RD 348)
Wagner & Bonsignore, Consulting Civil Engineers
2151 River Plaza Drive, Suite 100
Sacramento, CA 95833
dlounsbury@wbecorp.com
(916) 441-6850

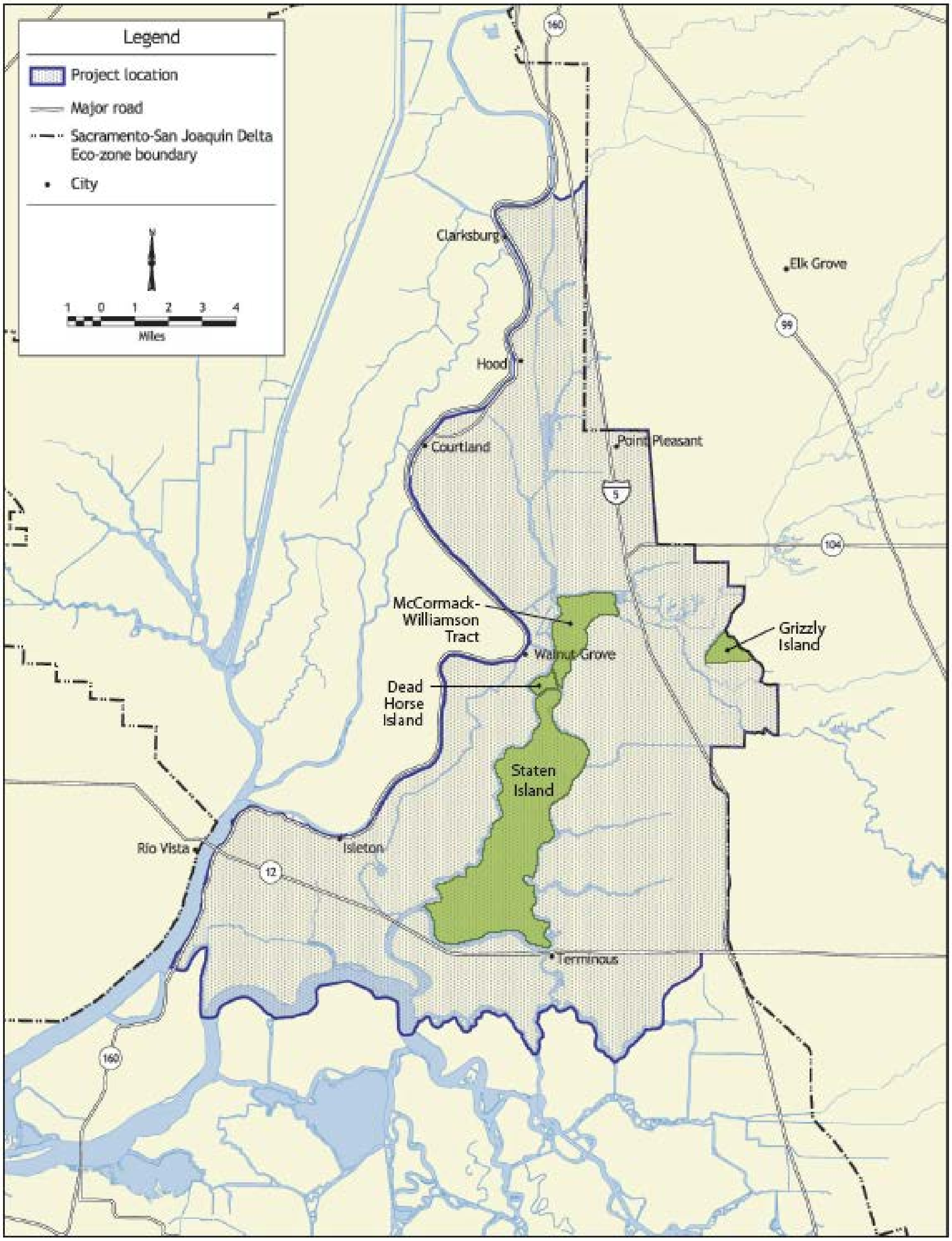


Figure 1 - Project Area of the North Delta Flood Control and Ecosystem Restoration Project

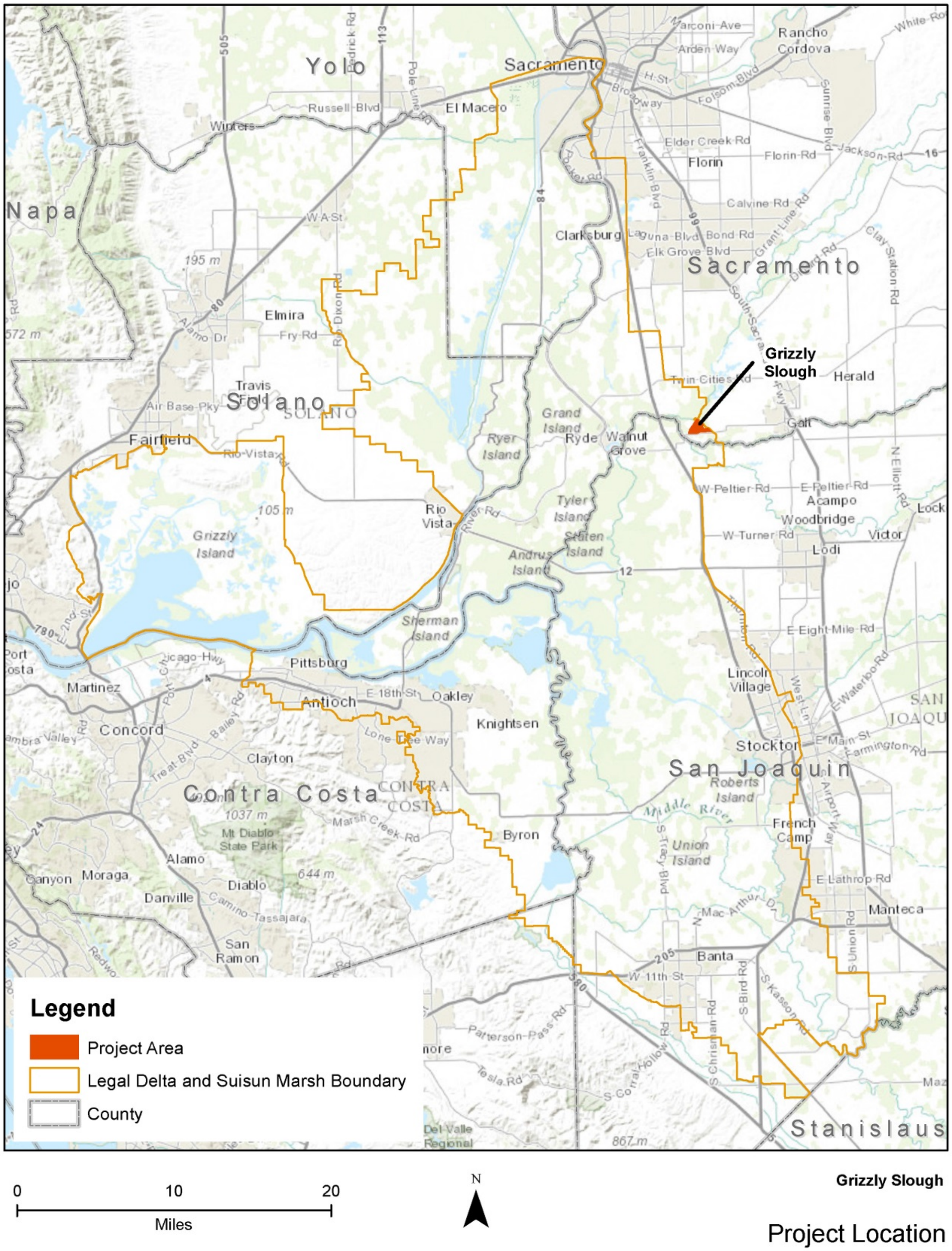


Figure 2: Grizzly Slough Floodplain Project Location.

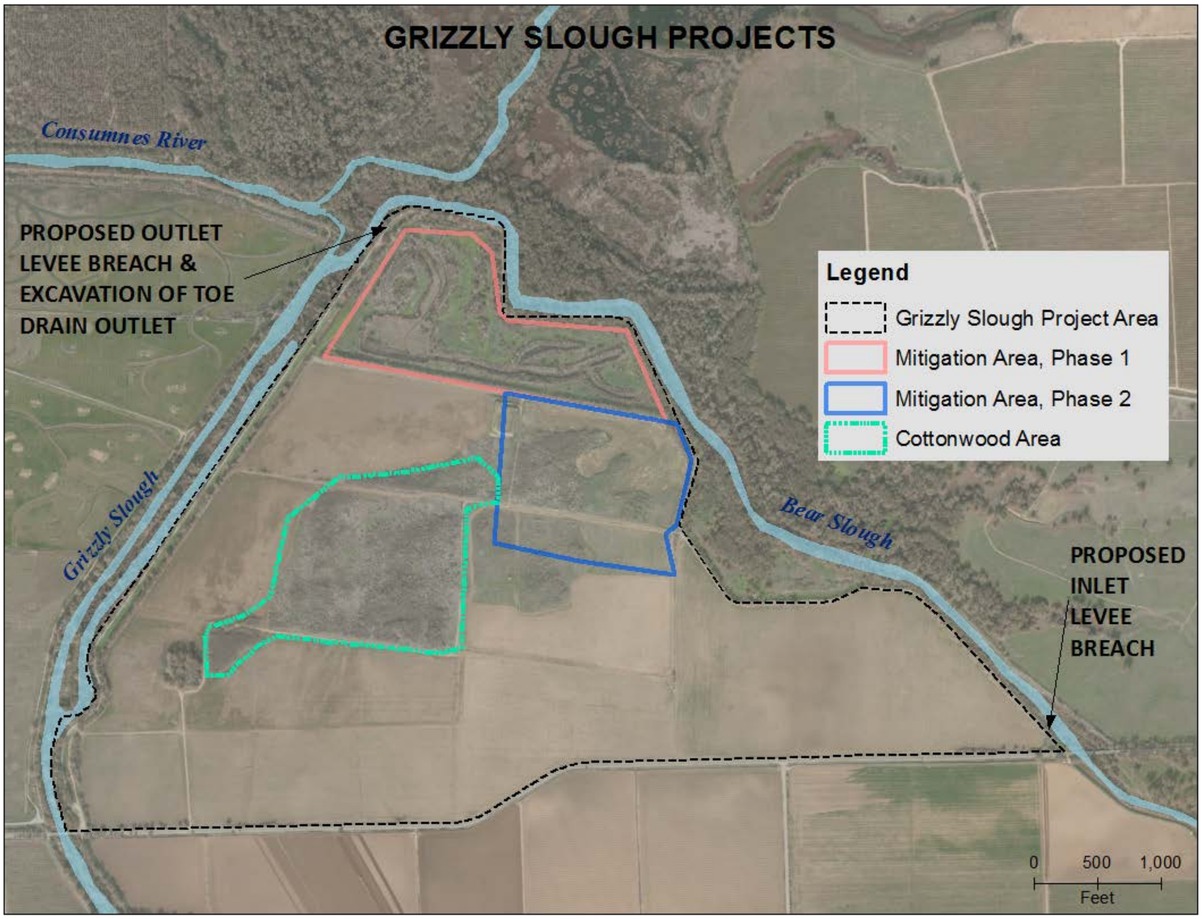


Figure 3 – Proposed Project Plan for the North Delta, Grizzly Slough Floodplain Project.

Appendix 2 Power Analysis

1. For comparisons between sites, Heberger and Robinson

2. For trends over time, Melwani

AQUATIC SCIENCE CENTER

Memo

From: Matthew Heberger and April Robinson, Aquatic Science Center

To: Delta RMP Technical Advisory Committee

Date: September 17, 2019

Subject: Statistical power analysis for the proposed Delta RMP project, "Monitoring of methylmercury in fish tissue in and around wetland restoration project sites."

Executive Summary

Environmental scientists at ASC and AMS performed a statistical power analysis as a part of the planning for the proposed study of mercury in fish tissue at wetland restoration project sites in the Delta. Wetland restoration projects are a key part of the state's strategy to increase habitat and preserve endangered species in the Delta. Yet, restoration projects could have the unintended consequence of causing mercury to enter the food chain, causing harm to fish and wildlife. The proposed study calls for monitoring of small fish as "biosentinels," or an early warning system for in mercury in the food web. The goal is to detect any negative impact before it cascades to larger fish, birds, and humans. Statistical power analysis tells us what sample size we need to make conclusions based on the study data while having confidence in the results.

We conclude, based on available data and the use of standard statistical methods, that we can detect *large* changes in prey fish mercury after only 1-3 years. Smaller changes could take 6 or more years to detect. It can be argued that *small changes* in fish mercury are inconsequential. In the study area in the northwest Delta, mercury levels in prey fish are currently well over the regulatory objective, by a factor of 2 on average. Small changes don't really matter because a small decrease won't get us into compliance. Conversely, a small increase won't make the problem much worse, relatively speaking. On the other hand, if wetland restoration projects are causing a *large increase* in fish mercury, we would like to know about that, and quickly.

Background

Proposed mercury monitoring for the 2019 – 2020 fiscal year (FY19-20) includes monitoring of prey fish (usually Mississippi silversides or similar pinky-size fish) for total mercury, a close surrogate for the element's more toxic form, methylmercury.. The purpose of this monitoring, intended to be conducted over three years and then re-evaluated, is to determine whether wetland restoration projects are linked to changes in mercury in the aquatic food chain. More specifically, we are examining two hypotheses:

1. Do prey fish in and near restoration sites have tissue mercury concentrations that differ from those in fish that live in and near established wetlands (the control or "reference" sites for the experiment)?
2. Is there a trend in fish tissue mercury concentrations over time at sampled locations?

The proposed study design calls for sampling prey fish at 9 different locations. Of these, 3 are long-time existing wetlands; we consider these "reference sites" to be roughly equivalent to a control for the purposes of this study. Another 4 sites had the restoration begun in the recent past, from 2011 to 2014. The final 2 sites were restored recently beginning in 2019 or will begin in 2020.

In this memo, we describe a statistical power analysis we performed in support of this first question. Because of limited time and staff expertise in this subject, we subcontracted with Dr. Aroon Melwani at Applied Marine Sciences to conduct power analyses to address the second question. Dr. Melwani has consulted on statistics for the Delta RMP in the past, in particular, doing power analysis for status and trends mercury monitoring and for the 2018 revision to the monitoring design for pesticides and toxicity. The power analysis for detecting trends over time is described in a separate memo.

Power analysis background

In the simplest terms, power analysis refers to determining the sample size and magnitude of effect for a research study based upon a level of statistical significance. More specifically, power analysis can assist researchers in study design by determining what sample size and magnitude of effect are required to have a reasonable chance of rejecting the *null hypothesis* when the *alternative hypothesis* is true. To do a power analysis, the analyst needs to assume a certain experimental design, sample size, level of significance, and the "effect size" we are trying to detect, or the change in the environmental variable being measured.

In other words, a statistical power analysis tells us how much data we need to collect to detect a meaningful change (e.g., temporal trend, difference between two populations, or among several populations). In general, it is easy to detect large changes, but depending on the sample size and variability of the measurement, small changes can be more difficult to detect, requiring significantly larger numbers of samples.

Statistical power is governed by three factors:

- **The size of the effect we are looking for.** For example, it is easier to detect a large difference between the two populations, and harder to detect a small difference. Similarly, it is easier to detect a large or fast trend, and harder to detect a small or gradual trend.
- **The sample size**. By collecting more data, we can more easily detect small differences between populations. For trends, larger sample sizes help, but it is also important to establish long enough time series.

- **Variability within the sampled populations.** The more variability there is within each of the sampled populations, the more difficult it is to estimate the population average based on a sample. Greater variability means you need a larger sample size to detect differences between populations.

For the standard parametric statistical tests (like t-tests or ANOVA), there are "closed form" solutions to the power analysis, and we can use computer programs to do the power calculations very quickly and easily. The reality, however, is that most research projects are complex and almost defy rational power analysis. In the words of one statistician, a typical power analysis "involves a number of simplifying assumptions, in order to make the problem tractable, and running the analyses numerous times with different variations to cover all of the contingencies."[1] Such is the approach we followed and that is described here. We had to make several simplifying assumptions, any number of which will end up being violated. Nevertheless, this analysis hints at how likely we will be able to answer our research questions with reasonable assuredness.

The current power analysis experiment was designed to detect a difference between two populations (fish collected at two different locations) based on a standard two-sample t-test. The null hypothesis is that there is *no difference* in fish mercury concentrations between the two "populations," for example, fish living in/near wetland restoration sites (the experimental group), and fish at existing wetlands (the control group). The alternative hypothesis is that the experimental group has mercury levels that are either higher or lower than the control group.

For the analysis described here, we set the parameters for "tolerable limits on decision errors" based on commonly used assumptions in environmental science. We chose a significance level (*alpha*) of 0.05 for a two-tailed hypothesis test. A significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference. This is the same as saying that we are willing to tolerate a 5% chance of a *false positive*.

To calculate the necessary sample size, we also need to state, *a priori*, or before conducting the experiment, the desired statistical power, or our tolerance for a *false negative*. This is the probability of incorrectly concluding that there is no difference between the two groups, when in fact there is a difference.

We chose the probability of a false negative (*beta)* of 20%, following a common assumption among scientists. This gives us a statistical power (1 – beta) of 80%. The interpretation, in this case, we have a 20% chance of concluding there is no difference between two groups when in fact there is.[2]

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[1] https://stats.idre.ucla.edu/other/gpower/one-way-anova-power-analysis/

[2] The power of a test can also be stated as "the probability of finding significance if the alternative hypothesis is true."

There are typically 6 steps in conducting a power analysis:

1. Specify a hypothesis test.
2. Specify the significance level of the test.
3. Specify the smallest effect size that is of scientific interest.
4. Estimate the values of other parameters necessary to compute the power function, for example the standard deviation of the variable of interest.
5. Specify the intended power of the test.
6. Run the calculations to determine the required sample size.

We performed the power analysis calculations using the free software G*Power.[3] Exploratory data analysis and visualization was done using Excel and R.

Data Analysis

First, we conducted descriptive analysis of existing data to determine appropriate values of effect size and standard deviation for the power test. The power analysis hinges on the estimate of the variance in our variable of interest, in this case mercury concentration in prey fish. According to statistician John H. McDonald:

> As standard deviation gets bigger, it gets harder to detect a significant difference, so you'll need a bigger sample size. Your estimate of the standard deviation can come from pilot experiments or from similar experiments in the published literature. Your standard deviation once you do the experiment is unlikely to be exactly the same, so your experiment will actually be somewhat more or less powerful than you had predicted.

We used data on mercury concentrations in Delta prey fish from the North Bay Biosentinel Project.[4] This study reported 4 years of data for silversides (*Menidia beryllina*, the target species for the proposed Delta RMP study) and several other prey fish collected in 2013, 2014, 2016, and 2017. We used only data from 2016 and 2017, as we were able to more consistently group the fish data into subpopulations based on the location where they were sampled.

For this study, the research team, led by Dr. Darrel Slotton at UC Davis, collected between 3 and 10 fish at each site. Mercury in fish tissue was analyzed for some individual fish, but most samples were composites of multiple (3-10) similar-sized individuals of a given species. The study showed that there was a strong relationship between fish length and mercury concentration. Therefore, mercury concentrations were "size corrected" prior to conducting our power analyses. The silversides collected ranged in length from 47 to 76 mm. The tissue mercury concentrations were standardized to the median length of 62 mm.

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[3] F. Faul et al., "G* Power 3: A Flexible Statistical Power Analysis Program for the Social, Behavioral, and Biomedical Sciences," *Behavior Research Methods* 39, no. 2 (2007): 175.

[4] April Robinson et al., "North Bay Mercury Biosentinel Project: 2016 - 2017" (Richmond, California: San Francisco Estuary Institute – Aquatic Science Center, 2018).

Figure 1 is a histogram showing the distribution of the entire dataset of size-corrected mercury tissue concentration in silversides collected at 7 locations in the Delta.

Units used in this memo

All results described herein are total mercury concentrations in whole-body composite tissue on a wet-weight basis in units of micrograms per gram (µg/g), equivalent to parts per million (ppm) and to milligrams per kilogram (mg/kg). However, it is well known that nearly all of the total mercury present in fish tissue occurs in the bioavailable, toxic form, methylmercury (e.g., Wiener et al. 2007, Greenfield and Jahn 2010). Therefore, it is assumed that the total mercury concentrations reported herein, are a reasonable approximation for methylmercury concentration. When we refer to mercury throughout this memo, we are referring to total mercury, as a close proxy for methylmercury.

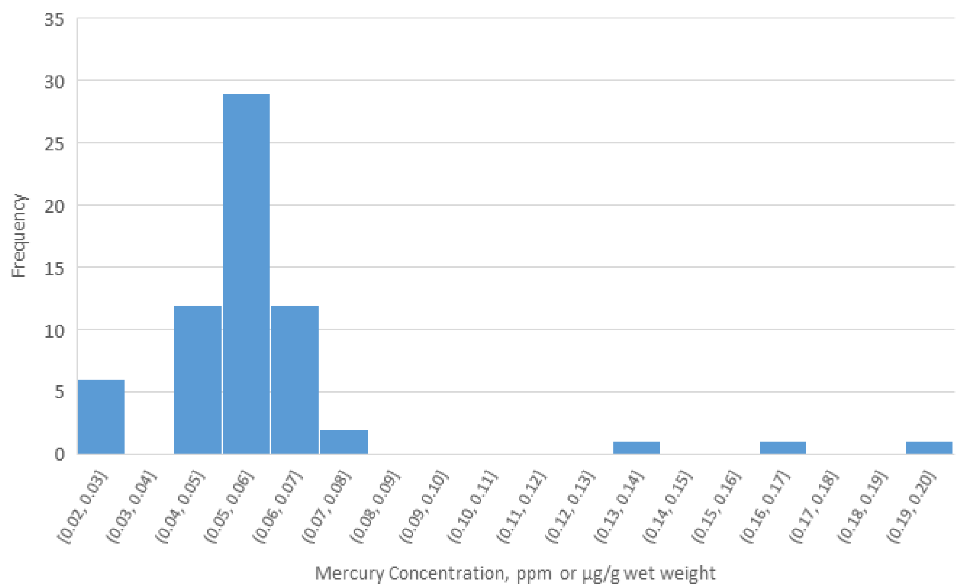


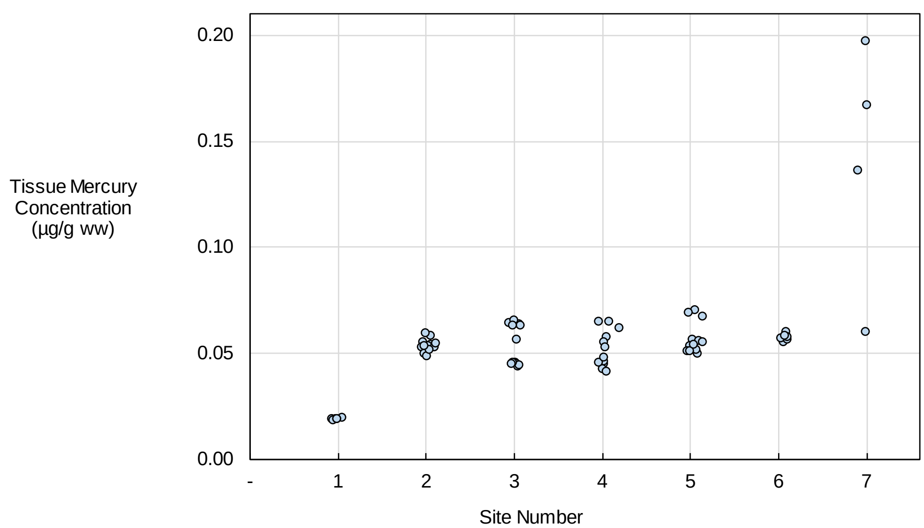
Figure 1. Histogram of mercury concentration in silversides, NBB project, 2016-2017. Values on x-axis are bins of mercury concentrations (e.g. 0.02 – 0.03 ppm)

Reports summary statistics for the entire (pooled) dataset.

Table 1. Summary statistics for mercury concentration in silverside tissue from the NBB project, 2016-2017. Values are in µg/g wet weight or parts per million, ppm.

Number of Samples, n	64
Median	0.054
Average	0.057
Standard Deviation	0.028
--------	--------
Minimum	0.019
10%-ile	0.042
25%-ile	0.046
50%-ile	0.054
75%-ile	0.060
90%-ile	0.065
Maximum	0.197
--------	--------
Coeff. of Variation	0.5
Coeff. of Skew	3.2

Figure 2 shows the mercury concentration in silversides plotted by location. The number of samples at each location ranged from 4 to 12. The mercury levels at Site 6 (Pond 7A) and Site 7 (Steamboat Slough) appear to be different from the other 5 sites.



Site 1	Pond 7A
Site 2	Cullinan
Site 3	Pond 1A
Site 4	Pond 2A
Site 5	Pond 6A
Site 6	Crystalizer Beds
Site 7	Steamboat Slough

Figure 2. Observed tissue mercury concentration in silversides, NBB project, 2016-2017, at the 7 sites sampled.

Boxplots are another way of looking at these data (Figure 3). In Figure 3, the orange dashed line represents the water quality objective for mercury in small fish of 0.03 mg/kg, established in the Basin Plan for the Sacramento River Basin and the San Joaquin River Basin.[5]

[5] Karl E Longley et al., "Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin," 2018, page 3-8.

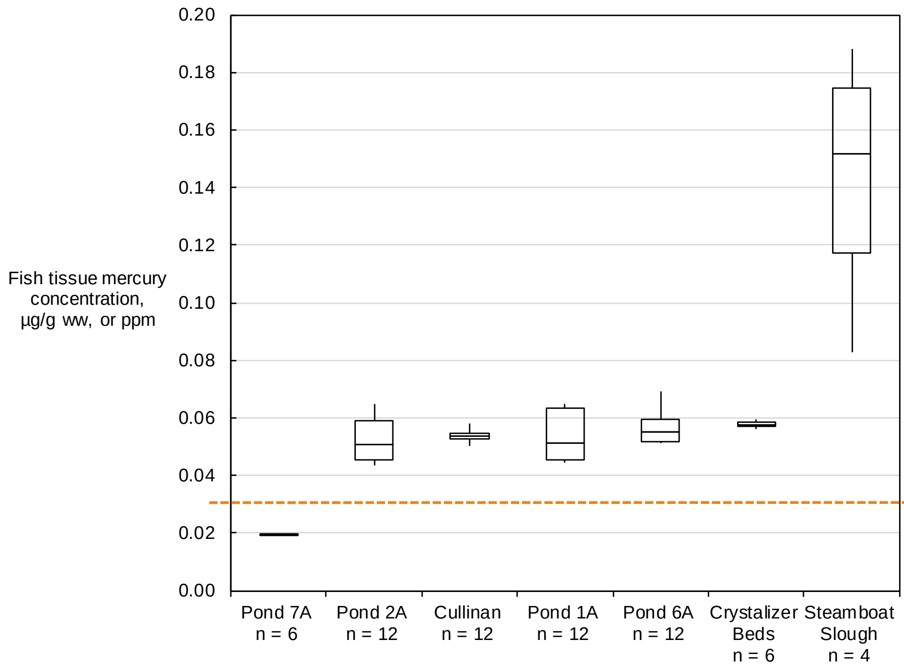


Figure 3. Boxplots of mercury concentration in silversides, NBB project, 2016-2017, at the 7 sampling sites.

The probability plot in Figure 4 shows that the pooled data are approximately normally distributed, when we exclude the 5 low outliers (measurements at Steamboat Slough) and 3 high outliers (measurements at Pond 7A). Data for sites 1 to 5 appear to follow a normal distribution, and that the two outlier sites have mercury concentrations that follow different distributions.

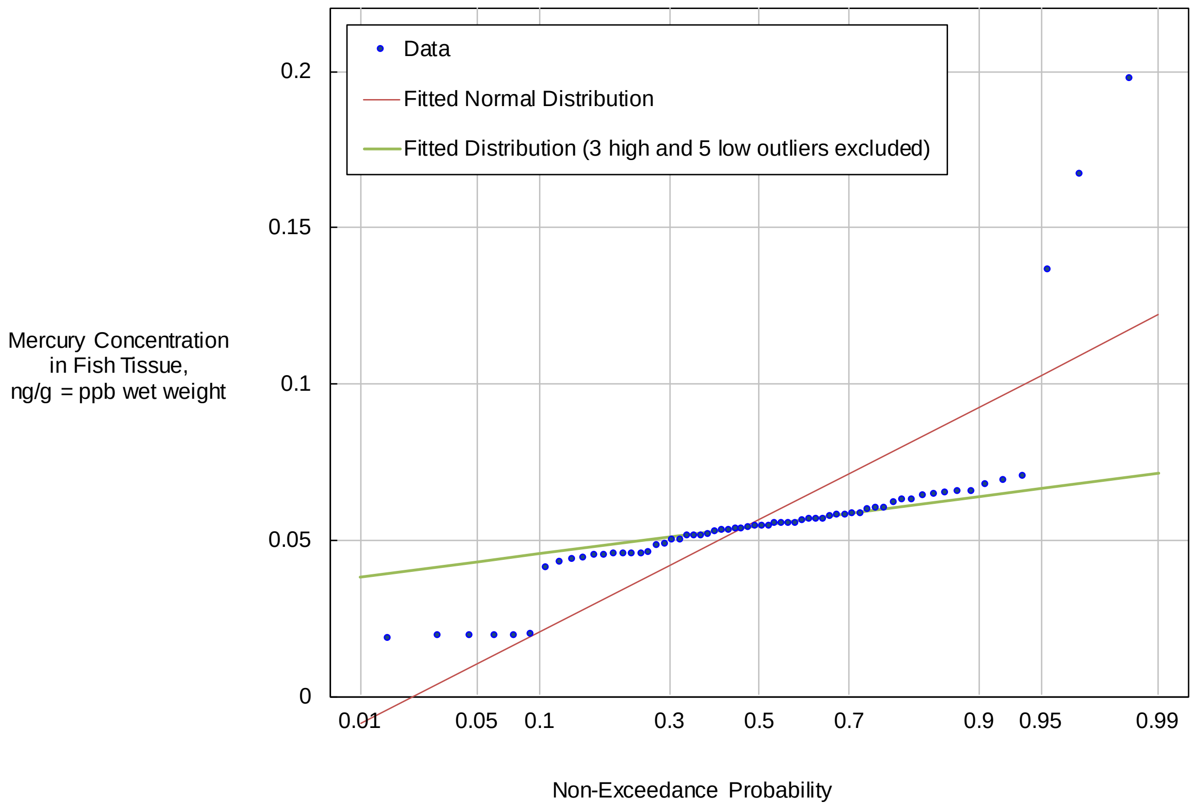


Figure 4. Probability plot of mercury concentration in silversides, NBB project, 2016-2017.

Skewed data are often transformed by taking the logarithm or by applying some other transformation until the data are approximately normal. However, a lognormal distribution did not fit these data well. Nor did other types of transformations improve the fit of a normal distribution.

Based on the characteristics of the dataset, rather than pooling all of the data, we estimated the sample moments for each site individually, then calculated the grand mean (or pooled mean) by taking the "mean of the means." This is the approach commonly used in ANOVA calculations.

We calculated the pooled standard deviation (also known as combined, composite, or overall standard deviation) by calculating the standard deviation for each of the sites, then calculating the weighted average variance using the following formula:

$$s_p^2 = \frac{\sum_{i=1}^{k}(n_i - 1)s_i^2}{\sum_{i=1}^{k}(n_i - 1)}$$

Where S_p^2 is the pooled variance, S_i^2 is the variance of each sample, and n_i is the sample size of each sample.

The mean and standard deviation for the individual sites is reported in Table 2. These sample statistics will be key to the power analysis calculations described below.

Table 2. Summary statistics for mercury in silversides, from the NBB project, 2016-2017, size corrected.

Num	Site	Sample size, *n*	Mean ± standard deviation	Coefficient of Variation
1	Pond 7A	6	0.019 ± 0.004	0.02
2	Cullinan	12	0.054 ± 0.003	0.06
3	Pond 1A	12	0.054 ± 0.010	0.18
4	Pond 2A	12	0.052 ± 0.009	0.16
5	Pond 6A	12	0.057 ± 0.007	0.13
6	Crystallizer Beds	6	0.058 ± 0.002	0.03
7	Steamboat Slough	4	0.140 ± 0.059	0.42
	POOLED		**0.062 ± 0.015**	**0.24**

Effect Size

The "effect size" in the statistical literature and used by statisticians can be confusing. For this memo, we convert the standardized effect size in to "meaningful" units for the purposes of this discussion, when we are able. In environmental science, the "effect size" is often converted to real-world units and referred to as the "minimum detectable change, defined as "the minimum change in a pollutant concentration (or load) over a given period of time required to be considered statistically significant."[6]

The statistician Jacob Cohen defined effect size as the number of standard deviations apart when comparing two means:

$$d = \frac{\bar{x}_1 - \bar{x}_2}{s} = \frac{\mu_1 - \mu_2}{s}.$$

Where μ is the population mean, and $\bar{x}$ is the sample estimate of the mean in populations 1 and 2, and s is the pooled standard deviation, calculated for independent samples as:

$$s = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

Cohen provided rules of thumb for interpreting effect sizes, suggesting that a *d* of |.1| represents a 'small' effect size, |.3| represents a 'medium' effect size and |.5| represents a 'large' effect size.

[6] USEPA, "Minimum Detectable Change and Power Analysis" (US Environmental Protection Agency, 2015), https://www.epa.gov/sites/production/files/2015-10/documents/tech_memo_3_oct15.pdf.

Calculating the effect size for an ANOVA, where we are comparing 3 or more populations, is slightly more complex. It involves estimating how much of the total variance is due to variation between rather than within groups, and cannot be easily translated into real-world units without making certain assumptions.

Determining the effect size that "matters" for this problem is not simple. The average concentration of mercury in prey fish (based on the data from the North Bay Biosentinel study described above) is currently more than double the water quality objective of 0.030 ppm for mercury concentration in small fish set by the Central Valley Water Board. Therefore, the desired goal of environmental managers is to lower the mercury concentrations in Delta prey fish. Any increase should be considered a move in the wrong direction. However, we would need to cut average prey fish mercury in half, or decrease the concentration by more than 0.03 ppm, in order to get below the regulatory threshold. That would be a large change, a decrease of about two standard deviations based on the NBB data.

Therefore, we do not have a particular target in mind for this study. Rather, if wetland restorations cause an increase in fish mercury, it is a move in the wrong direction, and would be bad. On the other hand, if projects are associated with a decrease in fish mercury, that would be good, but we would need to see a large reduction to attain the water quality objective. Therefore, rather than choosing a single effect size, we repeated the power analysis for a variety of effect sizes and reported a range of results.

Power based on a t-test

A t-test is used to test for a difference between the mean, or average, in two different populations. A t-test is not ideal in the context of the proposed study, as we will be collecting data at 9 different sites (6 restoration sites and 3 "reference" or control sites). It would not be appropriate to do a two-way comparison between every combination of the 9 sites. That would mean doing 9(9-1)/2 = 36 different comparisons. If we set alpha = 0.05, we have a 5% chance of a false positive, or concluding that there is a difference between two groups, even when there is no difference. As we repeat the comparison, odds are good that we will have one or more false positive. This phenomena is sometimes referred to as "truth inflation."

Nevertheless, a t-test is relatively easy to visualize and understand, and the power for a t-test is straightforward to compute. So we estimated statistical power for comparing two sites based on a t-test, and present those results here. The idea is that the results are imperfect yet illustrative. Furthermore, statisticians have developed methods to limit truth inflation, such as Tukey's Honest Significant Difference (HSD) procedure which can be used post hoc, or after the data is collected, to evaluate whether observed differences between groups are statistically significant.

An assumption of the t-test is that the variable being measured is *stationary*, or that the mean and variance are not changing over time. This may not be a valid assumption in our case. It is likely that there are trends over time, as well as variability from one year to the next, in response to hydrology for example. Another assumption of the t-test is that each group has the same variance. In other words, the standard deviation of each group should be about the same. As we saw from the North Bay Biosentinel data, this may not always be the case.

When the assumptions of a test are violated, the results are less applicable. It does not mean that we should throw them out altogether, but we should look at alternative analysis methods, if they are available. We may also wish to view the results as underestimates, and round up the answer.

Non-parametric statistical tests offer an alternative that are free of some of these restrictive assumptions. With a non-parametric test, you do not have to make any assumptions about your data, such as that they are normally distributed. The non-parametric equivalent to a t-test is the Mann-Whitney test. One can do a power analysis for any kind of statistical test by using Monte Carlo methods. This refers to using random number generators to create synthetic datasets and performing the statistical test on these artificial data. The analyst can write a computer program to regenerate new random data and repeat the test, say 10,000 times, and then look at how often the test gave the correct result.

However, in order to generate the synthetic data for the power analysis, the analyst needs to specify a distribution for the data. Here, the analyst is not limited to choosing a normal distribution, and can use any distribution she can imagine or look up in a textbook, say an exponential distribution or a Cauchy distribution. Without making an explicit assumption about the distribution, detailed sample size calculations are impossible. Doing calculations like these takes more time and effort and programming expertise. And as we have seen, they also require the analyst to make assumptions about the form of the population data. In our case, this is the largest unknown.

Therefore, we did not think it was worth the extra time to do detailed analyses with more advanced statistics. Rather, we thought it better to repeat some fairly simple calculations, using available data, and varying the input parameters, in order to get an idea of the statistical power of the experiment. As with any power analysis, as we collect experimental data, we can verify whether some of our initial assumptions were accurate, and we can update the power analysis after we have a few years of new field data.

Results

We performed this analysis based on comparing two independent populations with equal sample sizes. There are also tests based on unequal sample sizes. Note that we are not dealing with a "pairwise t-test." In such a test "observations in one sample can be paired with observations in the other sample." This is commonly the case in medicine or biology, for example, suppose we measure 50 people's blood pressure, then give them all a certain medication, then measure their BP again. The samples are "paired" because you’re comparing the same person before and after a treatment.

We computed statistical power for a t-test for comparing two groups with the following parameters: 6 samples per year, significance level of 0.05, statistical power of 0.8, and an average standard deviation per site of 0.015 µg/g as reported in Table 2 above.

We present the results of the power analysis in Table 3 below. The table below shows the statistical power for different effect sizes. The total sample size is the number of samples across 2 sites. As we are planning 6 samples at each site per year, or 12 samples total, we could detect a relatively large difference of 0.030 ppm between two sites in one year. Smaller differences are harder to detect, and require a greater number of samples. Without changing the planned sampling intensity of 6 samples per site per year, it takes longer to detect a larger difference between two populations.

Table 3. Power analysis for a t-test, to detect a difference between two groups.

Difference in mercury concentration between two groups (ppm or µg/g)	Effect size, Cohen's d	Total Sample size required	Years to detect
0.005	0.33	292	19
0.010	0.67	72	6
0.015	1.0	34	3
0.020	1.33	22	3
0.025	1.67	14	2
0.030	2.0	12	1

Table 3 shows how changing the effect size affects the number of samples needed to obtain a desired statistical power. Another way of looking at the problem is by holding the effect size constant, and varying the sample size to compute the statistical power. This can be considered a form of *post hoc* power analysis, where the experiment is designed a certain way (often based on budget or practical considerations) and power analysis is done to compute the statistical power that was achieved. In general, we know that as the sample size increases, we get greater statistical power.

Figure 5 shows how the statistical power varies by sample size for a t-test comparing two means. For this figure, we held the effect size constant at d = 0.67, representing a difference of 0.010 ppm between the population means. In Figure 5, total sample size is for both populations. With our design, there would be 12 samples per year. So after 3 years and 36 samples, we would have a statistical power of 0.5. So this would mean a 50% probability of a false negative. In our context, this means a 50% chance of concluding there is no difference between two groups when in fact there is. Again, with greater statistical power, we have a lower probability of a false negative.

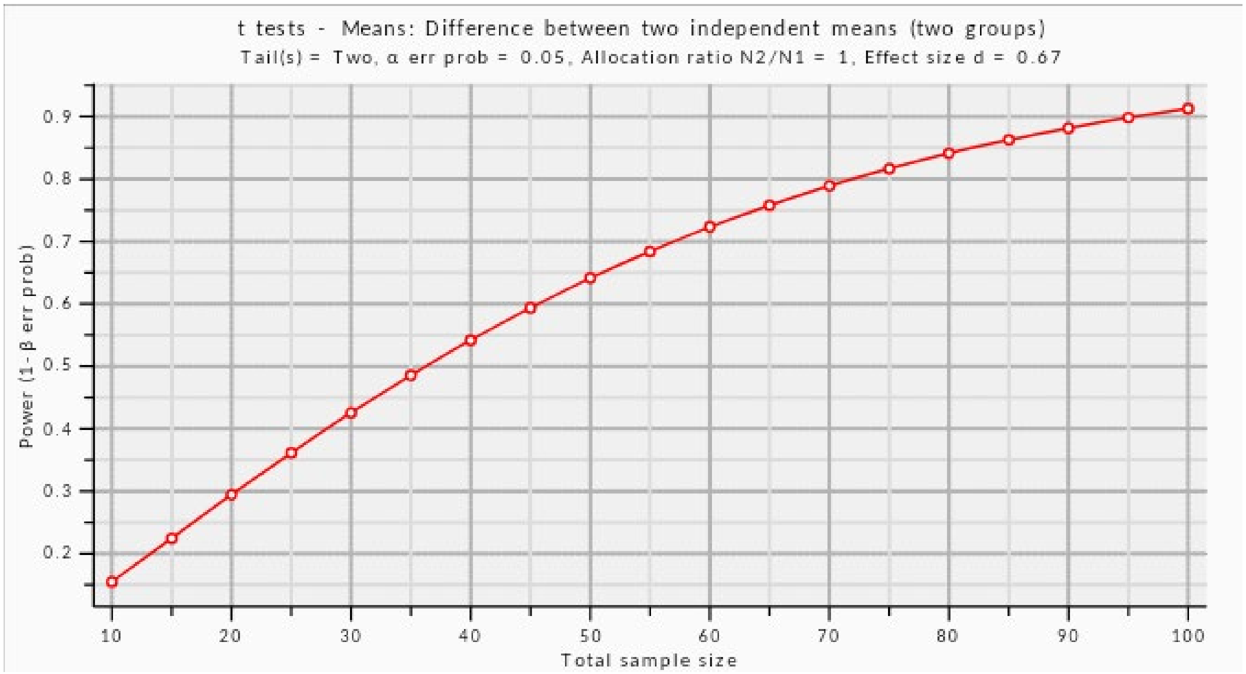


Figure 5. Statistical power for comparing two means as a function of sample size.

Power based on the ANOVA test

In reality, we would like to know whether average fish mercury is different from one site to the next, *comparing multiple groups*. The statistical test for making such comparisons is well-known, and is called an analysis of variance (or ANOVA). Despite its name, which focuses on variance, this is a statistical hypothesis test for comparing sample means. ANOVA lets us compare 3 or more population means. In this test, the null hypothesis is that the mean is the same in each population. Stated mathematically:

$$H_0\colon\ \mu_1 = \mu_2 = \cdots = \mu_k$$

Where μ is the mean, or average, for populations 1 through k, and k is the number of groups we wish to compare. In our case, k = 9, as we plan to sample 9 locations. Compared to the standard t-test, which lets us compare two different populations, the ANOVA test lets us compare many groups at once. The alternative hypothesis is that *at least one* group mean differs from the others. An ANOVA test tells you if the "between group" variance is significantly greater than the "within group variance." However, it *does not provide information regarding where the differences lie.* In other words, it will not tell you which group is different from the others.

A Tukey Test, or Tukey HSD (honestly significant difference), can tell you *which* group mean is statistically different from the others. It is very similar to a t-test. While a t-test lets us compare 2 groups, the Tukey Test adds the ability to compare 3 or more groups, and do multiple pairwise comparisons, but it corrects for the “family-wise error rate.” This refers to the increased likelihood of making a false discovery, or type I error, when performing multiple hypotheses tests. The Tukey Test is typically done *post hoc*, or after experimental data is collected. We are not aware of any "off the shelf" methods for conducting a power analysis for the Tukey Test.

The assumptions for both ANOVA and a Tukey test are:

1. The observations being tested are independent within and among the groups.
2. The groups associated with each mean in the test are normally distributed.
3. There is equal within-group variance across the groups associated with each mean in the test (homogeneity of variance, or homoscedasticity).

In practice, these 3 assumptions are likely to be violated to some extent, adding additional uncertainty to our analysis. For this reason, our estimates of statistical power and required sample size should be considered a “floor,” and we should round up. The Kruskal-Wallis test is a non-parametric equivalent of an ANOVA. We will likely end up using this test to analyze the data from this study. Nevertheless, we did not perform a power analysis based on this or any other non-parametric test, as it is a more complicated, time-consuming analysis and would not likely give major new insights, as described above.

We conducted an *a priori* power analysis for the ANOVA test, where we computed the required sample size based on a given statistical significance (alpha), power (beta), and effect size. We repeated the calculations for a variety of effect sizes, and report the results below. Compared to a t-test for two groups, the effect size for an ANOVA is more complicated and harder to understand. The effect size is based on the portion of the variance that arises from differences among groups, compared to the variance that occurs within groups. We used the effect size calculator built in to the G*Power software.

We can convert an effect size into real-world units if we make certain assumptions. For example, the effect size would be different if there is a difference in the mean in only 1 of the groups. Figure 6 is a visualization of an ANOVA to detect the difference among 9 groups. In this example, 8 of the 9 groups have a mean of 0.062 ppm and a standard deviation of 0.015, based on our silverside data in Table 2. We made the simplifying assumption that every site has the same mean and variance. But in Figure 6, 1 of the 9 sites has an average mercury concentration that is 0.072 ppm, or 0.010 ppm greater than the other 8 sites. This corresponds to an effect size $d = 0.2$. The statistician Cohen would have considered this d value between a small and medium effect size.

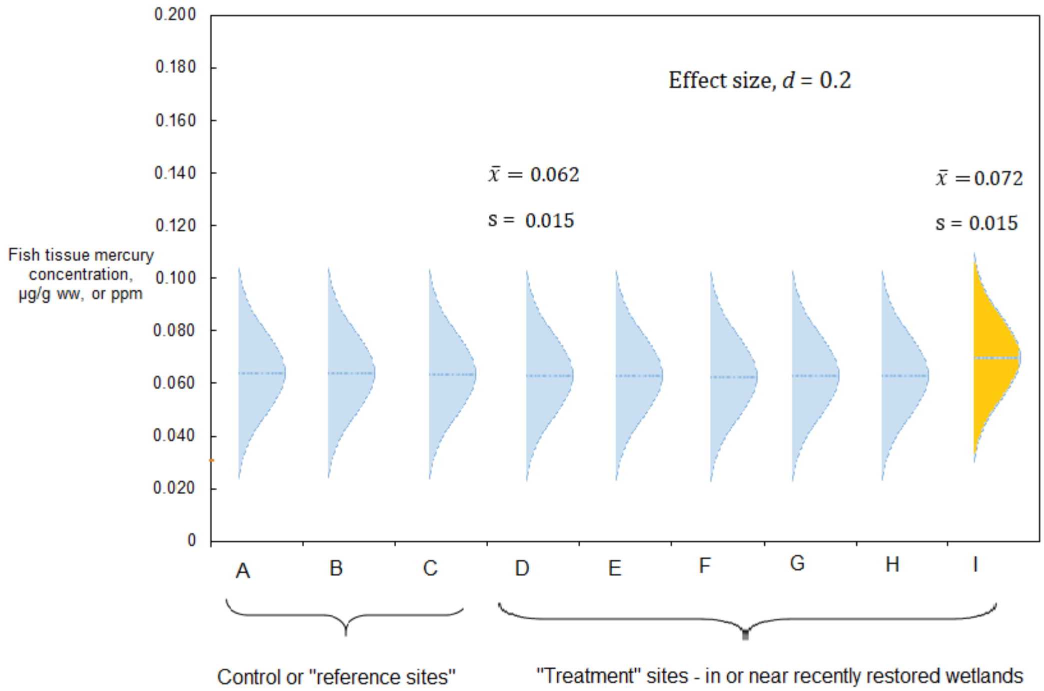


Figure 6. Visualization of an ANOVA to detect the difference among 9 groups. Here, 1 of 9 sites has a 0.010 ppm difference in average mercury concentration, and the effect size is d = 0.2.

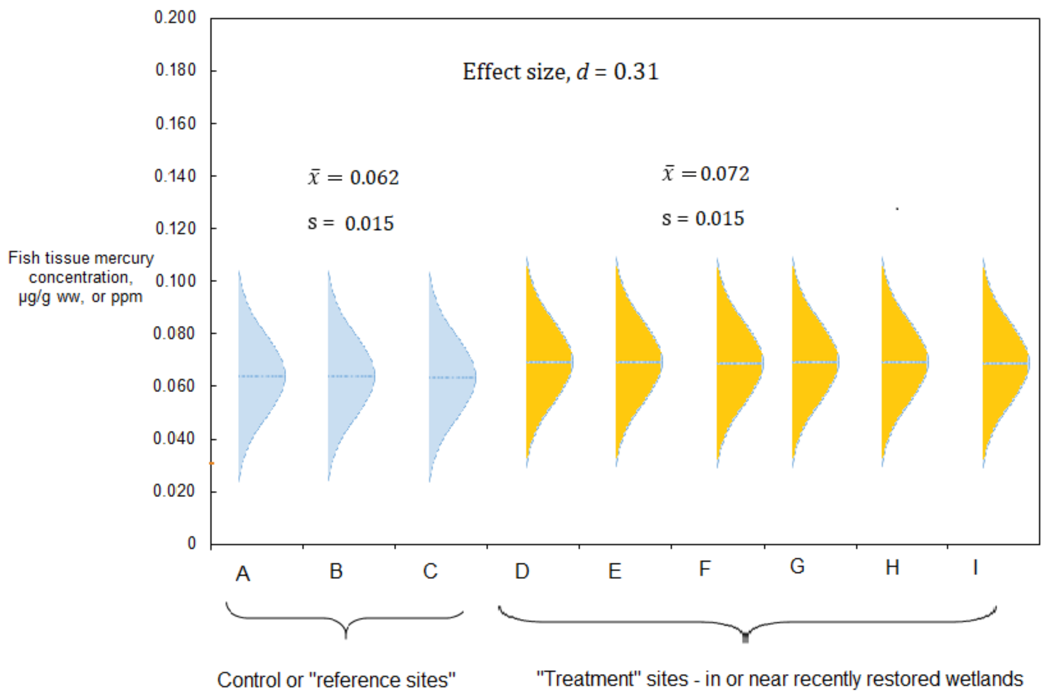


Figure 7. Visualization of an ANOVA to detect the difference among 9 groups. Here, 6 of 9 sites have a 0.010 ppm difference in average mercury concentration, and the effect size is d = 0.31.

Figure 7 shows an example of detecting a higher concentration in all 6 of the “treatment” sites and no change at the 3 reference sites. (This is probably not a likely outcome, but one we are making for demonstration purposes.) Here, the mercury concentration is 0.010 ppm greater than the previous average at 6 of 9 sites. The effect size here is $d = 0.31$, considered a medium effect size by Cohen. As we have seen from the previous two examples, it is not straightforward to translate effect sizes for an ANOVA to real-world units, as it depends on the number of sites where the change has taken place.

Table 4 shows the outcome of the power analysis. This analysis is repeated with the same parameters used before, $\alpha = 0.05$, $1\text{-}\beta = 0.80$. The first column in the table is based on translating an effect size to differences at 6 out of 9 sites, as in the second example above. The output of the power analysis is the total sample size. Our design calls for 9 groups, with 6 samples in each, for a total of n = 54 per year. The right column shows the number of years to achieve the desired statistical power, and was obtained by dividing the total sample size by 54, and rounding up to the nearest whole number. With the proposed experimental design, we are able to observe large effects in a single year of monitoring. For smaller differences, it takes many more samples, and thus a longer time to detect change with the desired statistical power.

Table 4. Power analysis output for ANOVA, to detect differences among groups.

Concentration increase (ppm or µg/g)	Effect size, Cohen's d	Total sample size (across 9 groups)	Years to achieve desired statistical power, 9 groups, with n = 6 samples in each per year (column 3 ÷ 54, rounded to the nearest whole year)
0.005	0.15	684	13
0.010	0.31	171	3
0.020	0.66	45	1

A change in average concentration of 0.005 ppm is relatively small, based on the current average, estimated as 0.062 ppm.

Another way of looking at the statistical power is to calculate the power as a function of samples size. This is shown in Figure 8. The curve is based on an effect size of 0.31, corresponding to the middle row in the table above. In the figure, points are plotted for multiples of n = 54. For such an effect size, we have very good statistical power after 3 to 4 years.

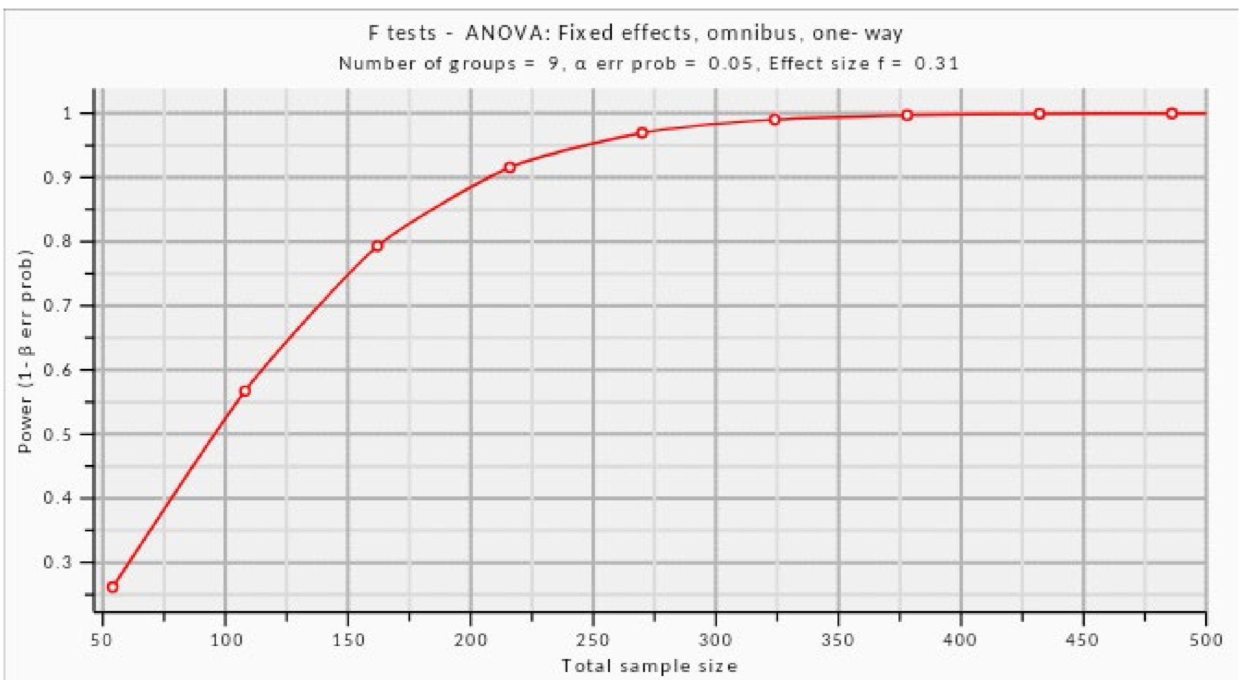


Figure 8. Statistical power for the ANOVA test as a function of sample size.

Technical Memo

Power Analysis of Delta Silversides Mercury Data

Aroon Melwani, PhD
Applied Marine Sciences
amelwani@amarine.com

September 10, 2019

Introduction

The goal of this power analysis was to estimate the statistical power for detecting declining trends in Mississippi Silverside Hg concentrations over time. A power analysis was designed to estimate the frequency of sampling (annual or biennial) and size of trend (2-10 ppb/yr) detectable with 80% power or greater, under several scenarios of intra- and inter-annual variation.

Statistical summaries of Silversides Hg concentrations collected during two years from seven sites by the Delta RMP were the basis of the assessment.

Power was calculated for the following comparison:

H_0 : the slope of the relationship between log mean annual Silverside Hg and year is zero ($\beta=0$)

H_A : the slope of the relationship between log mean annual Silverside Hg and year is less than zero ($\beta<0$)

A Monte-Carlo simulation was used to simulate trends. Statistical power was based on a linear regression of log (Hg) ~ time. Data were size-corrected prior to statistical analysis.

Approach

The population of interest in the power analysis was seven Delta RMP sites sampled in 2016 and/or 2017 for Silverside Hg concentrations. Size: Hg relationships were accounted for prior to power analysis by sampling composites of standard size, followed by regression analysis to predict Hg concentrations for standard length. These size-corrected individual Hg concentrations were employed in the power analysis methods that follow.

Silversides Hg concentrations were simulated for power analysis using local estimates of site-specific mean, inter-annual standard deviation, and intra-annual standard deviation. All statistical summaries were calculated assuming natural log distributed data (Table 1).

Mean Silverside Hg concentrations was determined from the site-specific log Hg mean concentrations. The inter-annual variability was determined from the standard deviation of log Hg mean concentrations between years, and the intra-annual variability determined from the standard deviation of individual log Hg concentrations by year.

Four scenarios were developed based on the estimates of mean and variability as follows: 1) the grand mean Hg concentration and standard deviations; 2) the highest estimates of site mean and standard deviations; 3) the lowest estimates of site mean and standard deviations; and 4) a user-specified set of estimates.

Table 1. Estimates of variability used in power simulations

Scenario	Site Variance	Mean	Intra-annual S.D.	Inter-annual S.D.
1	Grand Mean	53 ppb	150 ppb	100 ppb
2	Max	128 ppb	400 ppb	200 ppb
3	Min	20 ppb	50 ppb	20 ppb
4	User Selected	53 ppb	50 ppb	100 ppb

The approach to simulate data over time was:

1. The log-mean concentration calculated from the baseline Hg data was used to set the year 1 mean Hg concentration

2. A declining trend of 2, 5, or 10 ppb/year including random noise (mean = 0, sd = 1 ppb) and inter-annual variation (mean = 0, sd = Table 1) was applied on each year to generate a time series of mean concentrations for 10, 20, or 30 years (annual or biennial)

3. Individual Silverside Hg concentrations (N = 6) was then simulated for each year using the mean calculated in Step 2 above, and intra-annual variation from Table 1

4. Each scenario was repeated over 5000 simulation runs.

5. Statistical power was assessed as the proportion of runs that resulted in a significant slope at $\alpha = 0.05$ based on a linear regression of log (Hg) ~ time.

Results

Table 2. Power analysis results under four scenarios of inter-annual and intra-annual variability. All scenarios assumed N=6 per year. Red cells: power > 0.80

SCENARIO 1			10 Years		20 Years		30 Years	
Site Variance	**Trend**	**N Comps/Yr**	**Annual**	**Biennial**	**Annual**	**Biennial**	**Annual**	**Biennial**
Grand Mean	2 ppb/yr	6	0.79	0.72	0.86	0.81	0.90	0.85
Grand Mean	5 ppb/yr	6	0.80	0.73	0.87	0.83	0.90	0.86
Grand Mean	10 ppb/yr	6	0.81	0.73	0.88	0.83	0.90	0.86
SCENARIO 2			**10 Years**		**20 Years**		**30 Years**	
Site Variance	**Trend**	**N Comps/Yr**	**Annual**	**Biennial**	**Annual**	**Biennial**	**Annual**	**Biennial**
Max Variability	2 ppb/yr	6	0.60	0.46	0.77	0.67	0.83	0.77
Max Variability	5 ppb/yr	6	0.60	0.48	0.78	0.68	0.84	0.78
Max Variability	10 ppb/yr	6	0.60	0.48	0.78	0.69	0.84	0.78
SCENARIO 3			**10 Years**		**20 Years**		**30 Years**	
Site Variance	**Trend**	**N Comps/Yr**	**Annual**	**Biennial**	**Annual**	**Biennial**	**Annual**	**Biennial**
Min Variability	2 ppb/yr	6	0.83	0.76	0.88	0.83	0.90	0.87
Min Variability	5 ppb/yr	6	0.83	0.78	0.90	0.84	0.92	0.88
Min Variability	10 ppb/yr	6	0.84	0.79	0.91	0.88	0.94	0.91
SCENARIO 4			**10 Years**		**20 Years**		**30 Years**	
Site Variance	**Trend**	**N Comps/Yr**	**Annual**	**Biennial**	**Annual**	**Biennial**	**Annual**	**Biennial**
User Selected	2 ppb/yr	6	0.61	0.48	0.77	0.68	0.84	0.77
User Selected	5 ppb/yr	6	0.61	0.48	0.79	0.71	0.84	0.80
User Selected	10 ppb/yr	6	0.64	0.53	0.84	0.77	0.90	0.85

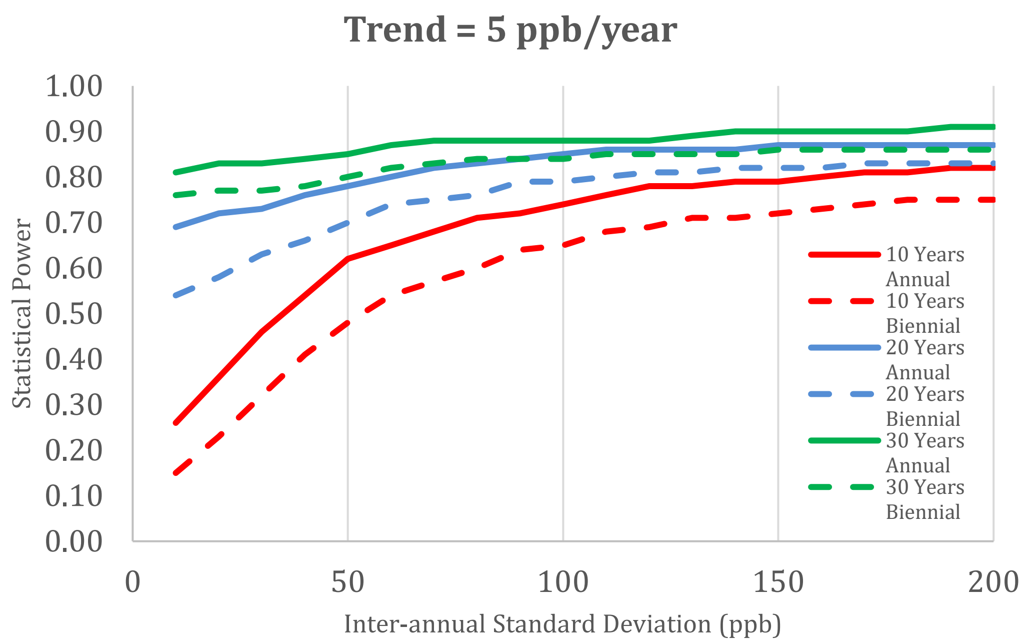


Figure 1. Power as a function of inter-annual variation from 10 to 200 ppb, assuming 10, 20, or 30 years sampled annually or biennially to detect trend of 5 ppb/year. Baseline mean and intra-annual standard deviation based on the Grand Mean scenario.