Mercury and Methylmercury in Fish and Water from the Sacramento-San Joaquin Delta August 2016 – April 2017

Authors:

Jay Davis and Don Yee: San Francisco Estuary Institute – Aquatic Science Center

Wesley Heim, Autumn Bonnema, and Billy Jakl – Moss Landing Marine Laboratories

September 2018

Table of Contents

Appendices

Figures

Tables

Suggested Citation:

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.

Abstract

Monitoring of sport fish and water was conducted by the Delta Regional Monitoring Program (Delta RMP) from August 2016 to April 2017 to begin to address the highest priority information needs related to implementation of the Sacramento–San Joaquin Delta Estuary Total Maximum Daily Load (TMDL) for Methylmercury (Wood et al. 2010). Two species of sport fish, largemouth bass (*Micropterus salmoides*) and spotted bass (*Micropterus punctulatus*), were collected at six sampling locations in August and September 2016. The length-adjusted (350 mm) mean methylmercury (measured as total mercury, which is a routinely used proxy for methylmercury in predator fish) concentration in bass ranged from 0.15 mg/kg or parts per million (ppm) wet weight at Little Potato Slough to 0.61 ppm at the Sacramento River at Freeport. Water samples were collected on four occasions from August 2016 through April 2017. Concentrations of methylmercury in unfiltered water ranged from 0.021 to 0.22 ng/L or parts per trillion. Concentrations of total mercury in unfiltered water ranged from 0.91 to 13 ng/L.

Over 99% of the lab results for this project met the requirements of the Delta RMP Quality Assurance Program Plan, and all data were reportable. This data report presents the methods and results for the first year of monitoring. Historic data from the same or nearby monitoring stations from 1998 to 2011 are also presented to provide context. Monitoring results for both sport fish and water were generally comparable to historic observations.

For the next several years, annual monitoring of sport fish will be conducted to firmly establish baseline concentrations and interannual variation in support of monitoring of long-term trends as an essential performance measure for the TMDL. Monitoring of water will solidify the linkage analysis (the quantitative relationship between methylmercury in water and methylmercury in sport fish) in the TMDL. Water monitoring will also provide data that will be useful in verifying patterns and trends predicted by numerical models of mercury transport and cycling being developed for the Delta and Yolo Bypass by the California Department of Water Resources (DWR).

Introduction

Concentrations of methylmercury (MeHg) in fish from the Sacramento-San Joaquin Delta (the Delta) (Figure 1) exceed thresholds for protection of human and wildlife health. The Delta Methylmercury TMDL (Wood et al. 2010) is the driver of actions to control MeHg in the Delta, establishing water quality goals and directing various discharger groups to conduct monitoring and implement measures to minimize impairment of beneficial uses.

MeHg concentrations in largemouth bass[1] are the most important performance measure of progress in addressing MeHg impairment in the Delta. The TMDL established three water quality objectives for MeHg in fish tissue: 0.24 ppm in muscle of large, trophic level four (TL4) fish such as black bass[2]; 0.08 ppm in muscle of large TL3 fish such as common carp (*Cyprinus carpio*); and 0.03 ppm in whole TL2 and TL3 fish less than 50 mm in length such as inland silverside (*Menidia beryllina*). Furthermore, the TMDL established an implementation goal of 0.24 ppm in largemouth bass muscle 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 from 1998 to 2007 for largemouth bass were a foundation for the development of the TMDL, including the division of the Delta into eight subareas (Figure 1).

Additional data on MeHg in water has also been identified as a high priority information need. The analysis conducted for the TMDL established that there is a statistically significant relationship between the annual mean concentration of MeHg in unfiltered water and mean MeHg in 350 mm largemouth bass when the data are organized by subarea. This linkage provides a connection, essential for management, between MeHg inputs from various pathways (e.g., municipal wastewater effluent, municipal stormwater, agricultural drainage, sediment flux associated with water management, 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 MeHg. In response to TMDL control study requirements, the Department of Water Resources (DWR) is developing numerical MeHg transport and

---

[1] Nearly all of the mercury present in edible fish muscle is MeHg, and analysis of fish tissue for total mercury provides a valid, cost-effective estimate of MeHg concentration (Wiener et al. 2007).

[2] "Black bass" refers collectively to largemouth bass [*Micropterus salmoides*], smallmouth bass [*Micropterus dolomieu*], and spotted bass [*Micropterus punctulatus*].

cycling simulation models for the Delta and Yolo Bypass. Monitoring of aqueous MeHg 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 MeHg 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.

Applicable Management Decisions and Delta RMP Assessment Questions

The Delta Methylmercury TMDL is the embodiment of management decisions for MeHg in the Delta, establishing goals for cleanup and calling for a variety of control studies and actions. The Delta RMP is conducting mercury monitoring in order to support TMDL implementation.

Two tiers of assessment questions have been defined for the mercury monitoring program. **Primary** assessment questions are those that are explicitly addressed by the monitoring and drive the monitoring design. Secondary assessment questions are addressed to some extent by the monitoring, but are not drivers of the monitoring design. The monitoring will contribute some information but will not fully answer the secondary assessment questions.

Primary Assessment Questions

One priority question for this initial phase of MeHg monitoring is from the Status and Trends category of the Delta Regional Monitoring Program management and assessment questions:

Status and Trends

ST1. What are the status and trends in ambient concentrations of methylmercury and total mercury in sport fish and water, particularly in subareas likely to be affected by major existing or new sources (e.g., large-scale restoration projects)?

ST1.A. Do trends over time in methylmercury in sport fish vary among Delta subareas?

Question 1A is a high priority for managers that relates to the TMDL, and is a primary driver of the sampling design for fish monitoring. Annual monitoring of methylmercury in fish tissue is urgently needed to 1) firmly establish a baseline for each Delta subarea 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 establish a foundation for tracking the effectiveness of management actions - another category of the Delta RMP core management questions.

Sources, Pathways, Loadings and Processes

SPLP1. Which sources, pathways and processes contribute most to observed levels of methylmercury in fish?

SPLP1.A. What are the loads from tributaries to the Delta (measured at the point where tributaries cross the boundary of the legal Delta)?

A mass budget for MeHg in the Delta is a critical element of the TMDL. The mass budget provides essential context for understanding the importance of inputs from discharges and internal sources and processes. Obtaining data to expand and update the dataset on MeHg inputs to the Delta is a high priority to support TMDL refinement and implementation. MeHg export from the Delta is similarly an important component of the mass budget and a high priority information need.

Fish-Water Linkage Analysis

(new priority question articulated by Mercury Subcommittee)

FWLA1. Are there key datasets needed to strengthen the technical foundation of contaminant control programs?

Another priority question that will be addressed relates to the linkage analysis discussed in the previous section, which is a key element of the technical basis for the TMDL. This question was not articulated in the core management questions and assessment questions established by the Steering Committee, but was nevertheless identified as a priority by the Mercury Subcommittee. Additional data on MeHg in water is one of the key datasets needed to strengthen the technical foundation of the TMDL.

Secondary Assessment Questions

Status & Trends

ST1. What are the status and trends in ambient concentrations of methylmercury and total mercury in sport fish and water, particularly in subareas likely to be affected by major existing or new sources (e.g., large-scale restoration projects)?

ST1.B. How are ambient levels and trends affected by variability in climate, hydrology, and ecology?

The time series for MeHg in fish and water that are created to answer the primary assessment questions will also be influenced by variation in climate, hydrology, and ecology, and will provide information on the role of these factors. For example, the first two years of monitoring 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 MeHg concentrations in fish and water.

Sources, Pathways, Loadings and Processes

SPLP1. Which sources, pathways and processes contribute most to observed levels of methylmercury in fish?

SPLP1.B. How do internal sources and processes influence methylmercury levels in fish in the Delta?

SPLP1.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 methylmercury levels in fish in the Delta?

Forecasting Scenarios

FS1. 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?

These secondary assessment questions relating to Sources, Pathways, Loadings, and Processes and Forecasting Scenarios for this initial phase of MeHg monitoring relate to one of the major control studies called for in the TMDL: an effort to combine modeling, field data, and laboratory studies to evaluate the potential effects of water project operational changes on MeHg in Delta channels. The Department of Water Resources (DWR) is currently developing two mathematical models, one each for the Delta and Yolo Bypass, that will allow testing of various land and water management scenarios (DiGiorgio et al. 2016). These models will be useful in addressing this set of Delta RMP management questions. The opportunity to inform these models, which are being developed with a considerable investment of funding from the California Department of Water Resources (DWR), makes monitoring to address these questions a near-term priority for the Delta RMP. The water monitoring included in this proposal will generate data that are valuable for verifying trends and patterns predicted by the MeHg models. It should be noted that these models will predict concentrations of MeHg in the water column, but will not include a bioaccumulation component that translates the water concentrations into fish tissue concentrations.

This Report

This data report presents the methods and results for the first year of monitoring by the Delta Regional Monitoring Program. In 2016 the Delta RMP initiated mercury monitoring of fish and water. Black bass were collected in late summer (August and September) from six stations distributed across the subareas. Quarterly sampling of total mercury and MeHg (and ancillary parameters) in water began in August 2016. Monitoring of sediment was not included in this first year (2016/17), but was added in 2017/18. Historic data from the same or nearby monitoring stations are also presented to provide context.

Methods

Sample Collection

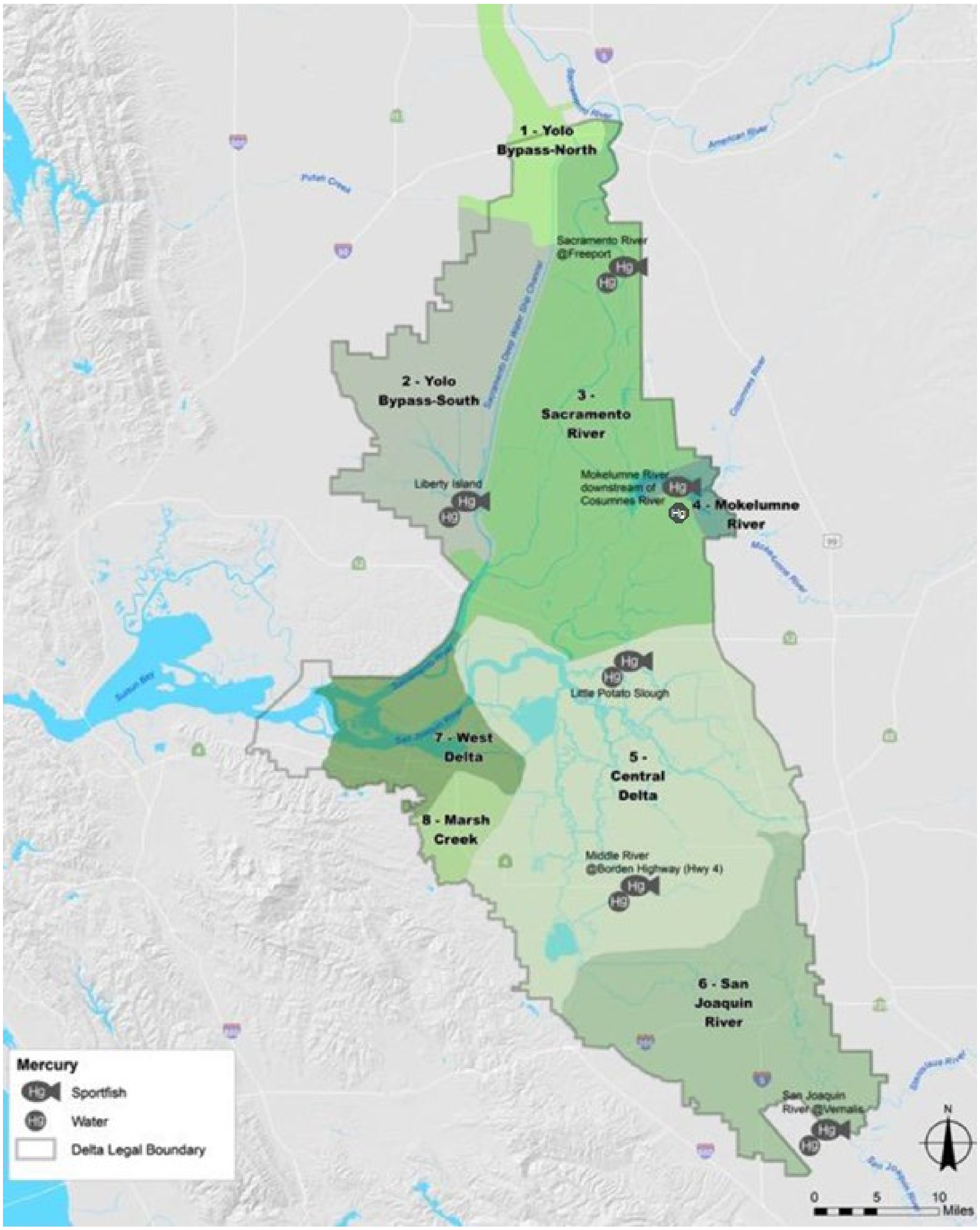
Fish samples were collected from six stations in the Delta and water sample collections were co-located with fish stations with the exception of Mokelumne River (fish-only station) (Figure 1). Fish collections were completed between August and September 2016 and water collections occurred four times between August 2016 and April 2017. Details on sampling stations and dates are listed in Table 1 and in greater detail in the cruise report (Appendix 1).

Table 1 Sampling station code, name, latitude, longitude, and collection dates.

Station Code	Station Name	Latitude	Longitude	Fish Collection Dates	Water Collection Dates
510ST1317	Sacramento R @ Freeport	38.4556	-121.5019	2016-08-22	2016-08-22, 2016-11-14, 2017-02-28, 2017-04-25
510ADVLIM	Cache Slough at Liberty Island Mouth	38.2421	-121.6854	2016-08-23	2016-08-22, 2016-11-14, 2017-02-28, 2017-04-25
544LILPSL	Little Potato Slough	38.0963	-121.4960	2016-08-23	2017-08-22, 2016-11-15, 2017-02-28, 2017-04-25
544MDRBH4	Middle R @ Borden Hwy (Hwy 4)	37.8908	-121.4883	2016-08-23	2016-08-22, 2016-011-15, 2017-02-28, 2017-04-25
544ADVLM6	Lower Mokelumne R 6	38.2554	-121.4401	2016-08-22	Not included
541SJC501	San Joaquin R @ Vernalis/Airport Way	37.6756	-121.2642	2016-09-13	2016-08-23, 2016-11-14, 2017-02-28, 2017-04-25

Fish collection methods are briefly described here with greater detail given in Appendix 1. Eleven individual bass were collected from each station by electrofishing. At each location, all fish collected were of the same species: at 5 of the 6 sampling locations, we collected largemouth bass, however at the Sacramento River at Freeport, field crews captured spotted bass. Upon collection, each fish collected was tagged with a unique ID. Physical parameters measured for each individual fish included: weight, total length, fork length, and presence of any abnormalities. Large fish were partially dissected in the field using the following protocol: fish were placed on a cutting board covered with a clean plastic bag where the head, tail, and entrails were removed using a

Figure 1 Map showing the boundary of the Delta, the eight subareas delineated in the TMDL, and the sampling stations for fish and water. Note: Mokelumne River downstream of Cosumnes River was not sampled for water in 2016/17.



clean cleaver. Fish samples were stored on dry ice for the duration of transport to the Marine Pollution Studies Laboratory (MPSL) at Moss Landing Marine Labs (MLML) in Moss Landing, CA. At MPSL, samples were stored in a -30 °C freezer until processed for authorized dissection and analysis.

A handheld YSI instrument was calibrated before and after each fish sampling event and was used to measure the following ancillary water column parameters: temperature, pH, dissolved oxygen concentration, conductivity, salinity, and turbidity.

Water sampling methods are briefly described here and in greater detail in Appendix 1. Water samples were collected using a depth-integrated sampler (SWAMP Clean Water Team Standard Operating Procedures [SOP] 2.1.1.4) modified to accommodate a 4 L glass bottle and to collect trace metal samples cleanly. Care was taken to lower and raise the bottle through the water column at a sufficient rate so that the bottle was not completely filled upon retrieval. A new pre-cleaned bottle was used for each station and sampling event.

Aliquots of raw water for the determination of MeHg, total Hg, and total suspended solids (TSS) were collected, prior to collecting filtered samples, by vigorously shaking 4 L and pouring off unfiltered water sample aliquots.

Aliquots of filtered water for the determination of dissolved organic carbon (DOC), MeHg and total Hg were filtered in the field using an E/S portable peristaltic pump, acid-cleaned tubing sets, and trace metal clean 0.45 μm groundwater filters.

Samples for chlorophyll-*a* analysis were field-filtered by forcing water with a 60-mL syringe through a filter holder containing a 25 mm glass microfiber filter. Filters were placed on dry ice for transport to MPSL.

All water samples were immediately stored on wet ice (4°C) following collection and transported to MPSL.

Sample Preparation and Analytical Methods

Water samples for mercury determination were preserved by acidification within 24 hr of collection. Aqueous total Hg and MeHg analysis followed modified U.S. Environmental Protection Agency (USEPA) Method 1631E and Method 1630, respectively. Total mercury[3] in fish tissue was determined using a Milestone Direct Mercury Analyzer (DMA-80) following USEPA Method 7473.

Analysis of TSS and volatile suspended solids (VSS) was conducted by passing a subsample through a 0.45 µm pre-combusted glass fiber filter, drying at 105 °C, and determining TSS as the mass of material retained on the filter. The same filter was dried further at 550 °C for 3 hours, with the difference in mass determining VSS.

Samples were analyzed for chlorophyll *a* by fluorescence following USEPA Method 445.0 using a Turner Instruments TD700.

Quality Assurance

About 15% of all samples that were analyzed were for quality assurance and quality control purposes. Over 99% of the lab results met the requirements of the Delta RMP Quality Assurance Program Plan (QAPP). There was one deviation from the QAPP (one water sample's hold time was exceeded by 1 day) which was flagged, but the result is still reported. All data for this project were reportable. Analyses yielded results above the limits of detection for all analytes aside from 3% of total suspended solids (TSS) and 7% of volatile suspended solids (VSS) samples. A detailed assessment of the QA data for this dataset is provided in Appendix 2.

Statistical Methods

The measurement of MeHg in individual bass samples (Appendix 3) provided a foundation for statistical procedures to adjust for the relationship with fish length (Figures 2 and 3; Appendices 4 and 5). A length of 350 mm has been used for length-adjustment of black bass in the TMDL and in past studies (e.g., Davis et al. 2008, Melwani et al. 2009, Wood et al. 2010), and represents the middle of the distribution of legal-sized (>305 mm, or 12 inches) fish that are commonly caught.

Estimates of length-adjusted means presented in this report are based on simple linear regressions of the data for each station. This approach provides an independently-derived estimate of the station mean that can be compared to any other station mean of interest: other station means from the same sampling period; means from the same station in past sampling; or any other station mean of interest.

---

[3] Nearly all of the mercury present in edible fish muscle is MeHg, and analysis of fish tissue for total mercury provides a valid, cost-effective estimate of MeHg concentration (Wiener et al. 2007).

Figure 2 Length-adjusted (350 mm) mean MeHg concentration (ppm wet weight) in black bass at each station, August–September 2016.

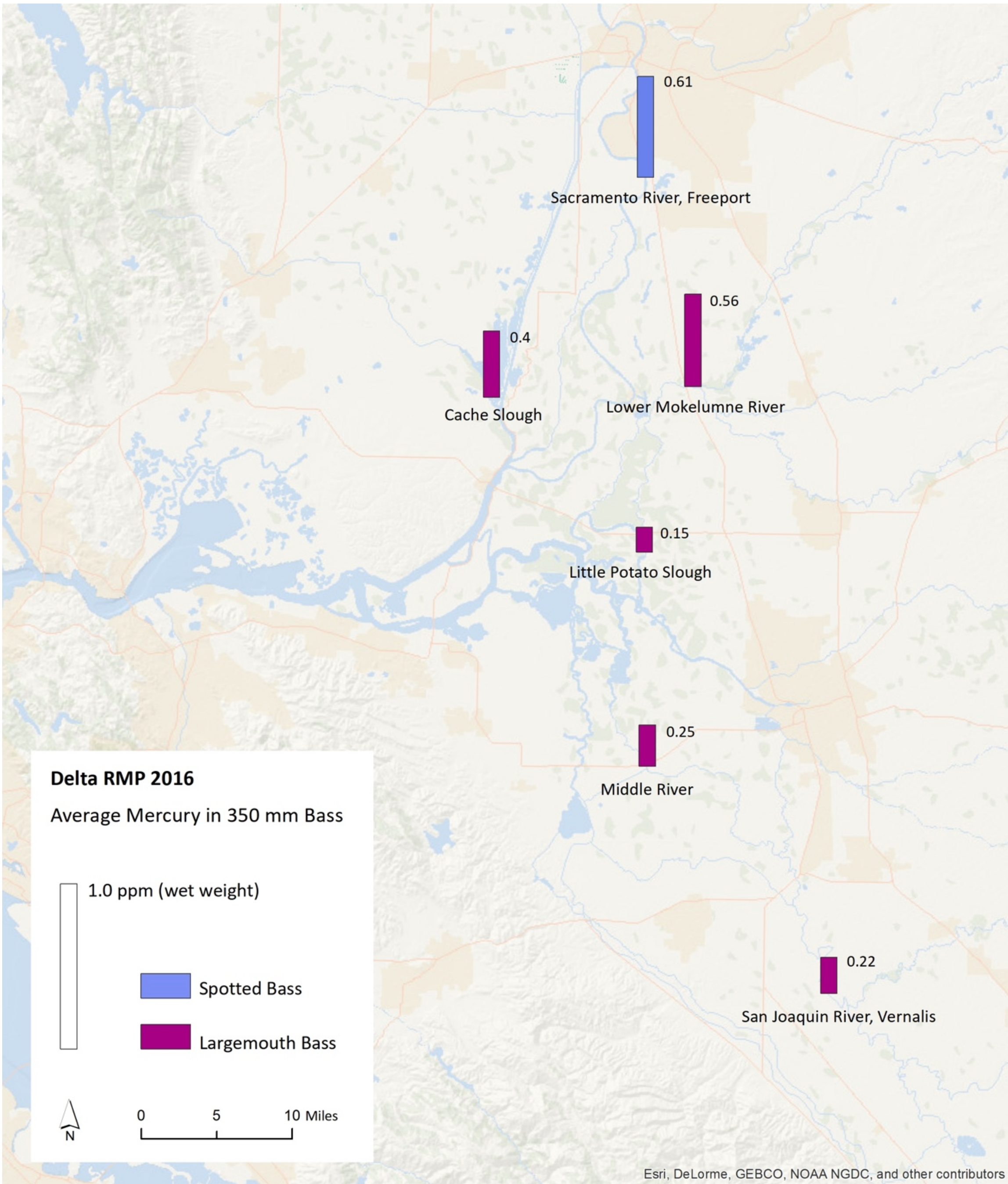


Figure 3 Long-term time series of mean MeHg (ppm wet weight) in black bass for Delta RMP stations and nearby stations sampled historically. Details on following page.

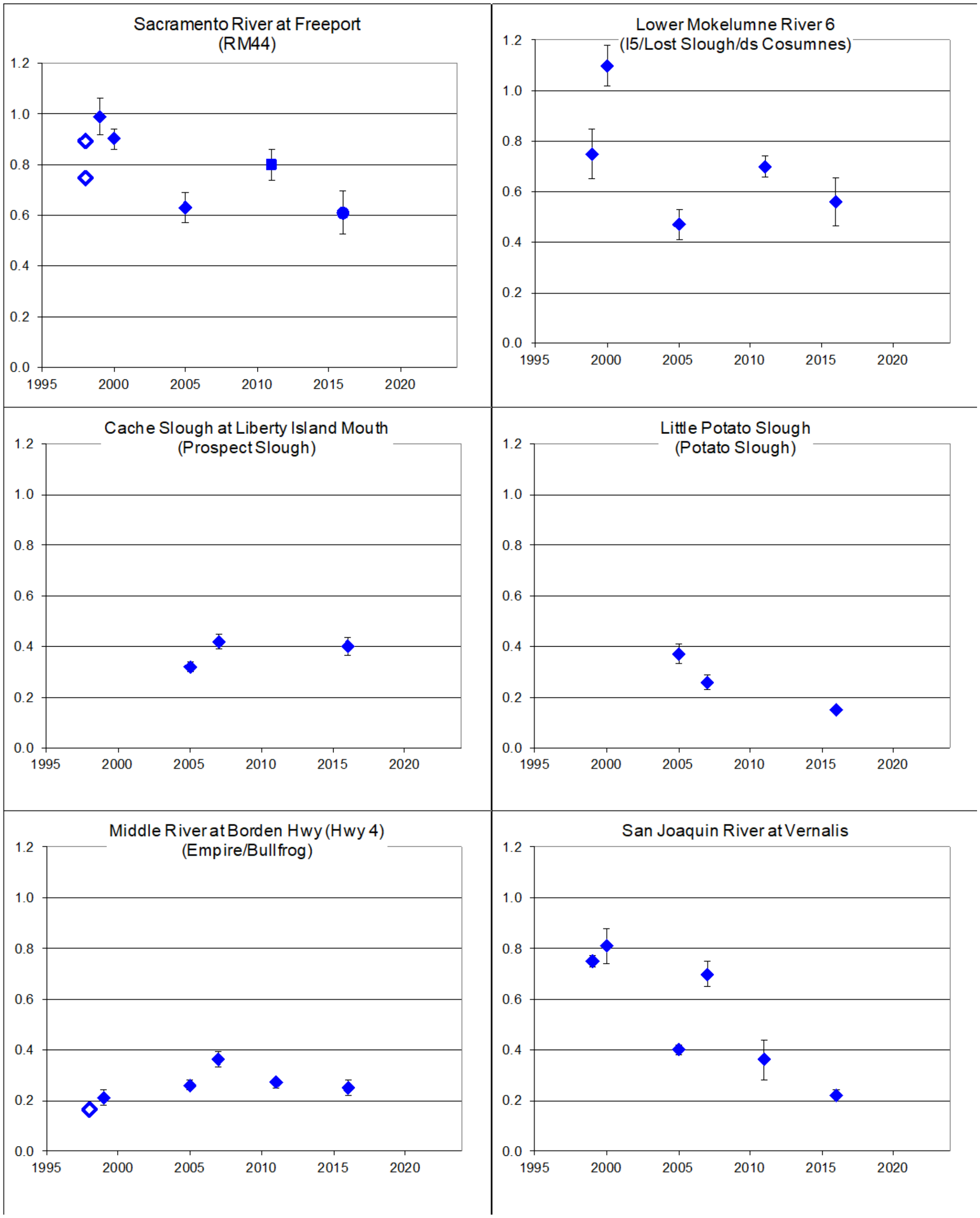


Figure 3 Details

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 to MeHg 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.

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 Highway (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

Results

Fish

Results from the first round of Delta RMP fish monitoring are presented in Figure 3, with data from prior fish sampling in or near these stations provided for context in Figure 3. 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.

Length-adjusted (350 mm) bass means ranged from 0.15 mg/kg or ppm MeHg (all fish results presented in wet weight) at Little Potato Slough to 0.61 ppm at Sacramento River at Freeport.

Variation in the availability of largemouth bass at the Sacramento River at Freeport continues to pose a problem. In 2016, spotted bass were collected, while previous efforts obtained smallmouth bass (2011) and largemouth bass (1998, 1999, 2000, and 2005). Largemouth bass have been collected consistently over the years at the other stations.

The data suggest a preliminary answer to management question ST1A, on whether MeHg in fish is trending up or down. The time series for San Joaquin River at Vernalis suggest a decline over the period of record (1999 to present), while concentrations appeared to be more stable at the other stations. Therefore, the data give a preliminary indication that trends do vary among the Delta subareas. Additional rounds of consistent sampling are needed to confirm this preliminary interpretation. Delta RMP scientists have estimated how many samples are needed and over how many years to detect trends. This "power analysis" is described in the Fiscal Year 2017–2018 Delta RMP Workplan (Delta RMP 2017).

Water

Appendix 6 presents a tabulation of results for all of the parameters measured in water.

The concentration of MeHg in unfiltered water ranged from 0.021 – 0.22 ng/L. Figure 4 presents long-term time series of March to October annual means of unfiltered MeHg concentrations for Delta RMP sites. Sacramento River concentrations have remained constant with good agreement between historic data and current data. Cache Slough's 2016 and 2017 concentrations were similar to the range reported previously in 2005. No historic data are available for Little Potato Slough. Middle River MeHg concentrations were highly variable with 2016–17 concentrations within the range of historic data. The San Joaquin River 2016 MeHg concentration was lower than previously reported values (Figure 4). However, the 2017 measurement was the highest concentration ever reported for this site.

Particulate MeHg concentrations (calculated as the difference of unfiltered and filtered MeHg) ranged from 0.014 – 0.15 ng/L. Particulate MeHg was positively correlated to volatile suspended solids (VSS) (correlation data not shown). Filtered MeHg concentrations averaged 61% of unfiltered MeHg concentrations.

Unfiltered total Hg concentrations ranged from 0.91 – 13 ng/L. Filtered total Hg concentrations ranged from 0.49 – 2.1 ng/L. Total Hg was found to be predominantly in the particulate form and was positively correlated to TSS concentrations.

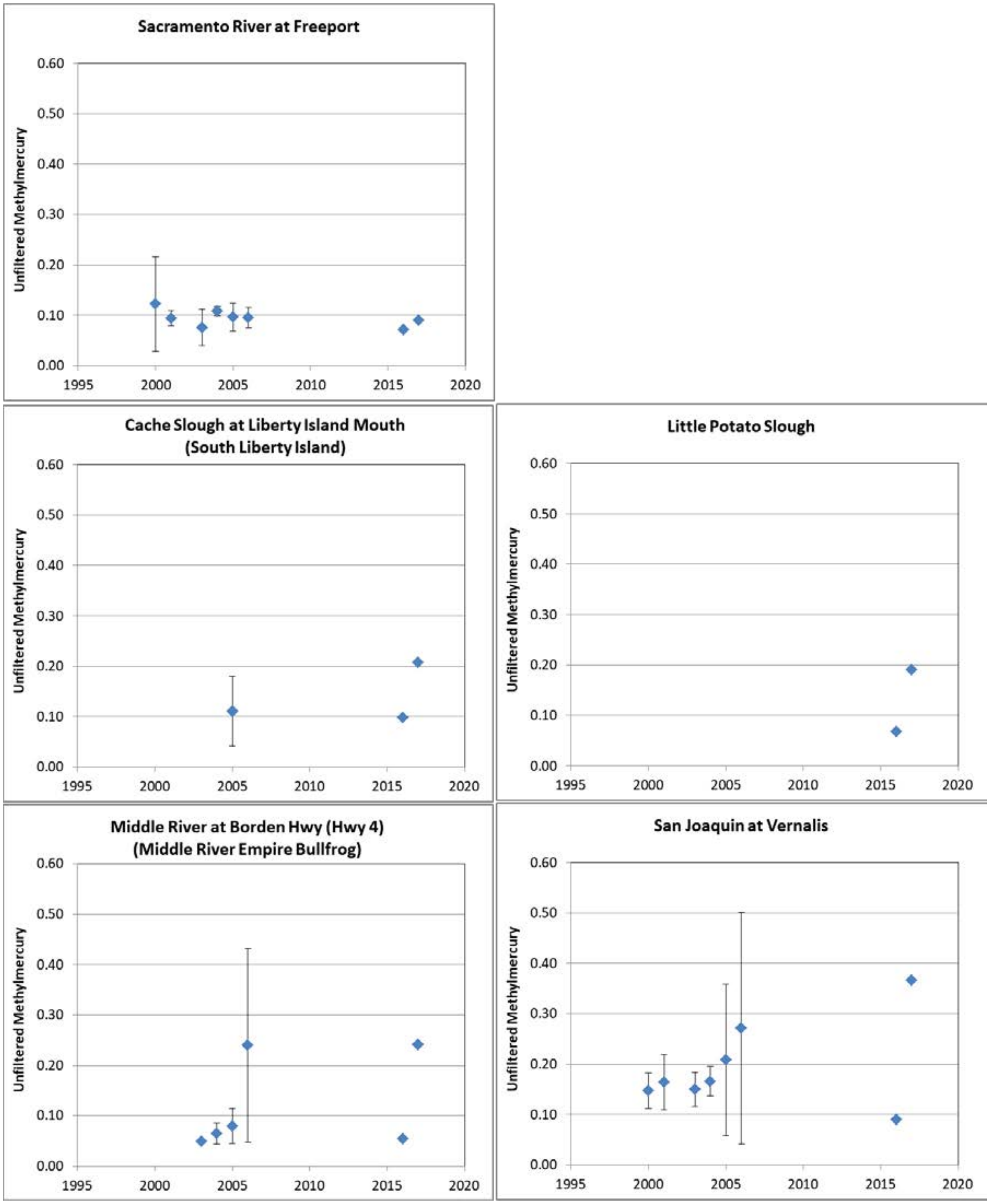
The following ranges in ancillary parameters were measured in Delta surface water over the 4 sampling events: temperature = 9.4 – 24.4 °C; pH = 7.1 – 8.7; dissolved oxygen = 7.4 – 14.8 mg/L; dissolved oxygen = 76 – 130% saturation; specific conductivity = 68- 750 µS/cm; salinity = 0–0.4‰; turbidity = 3 – 100 NTU.

Concentrations of DOC in the Delta were fairly consistent ranging from 1.8 to 4.5 mg/L for all sites and sampling events.

Chlorophyll *a* concentrations varied widely across sites and time with a range of less than the reporting limit to 12 µg/L.

Similarly, TSS concentrations had a large range both spatially and temporally. The range of TSS was 3.0 – 83 mg/L with the highest concentrations observed during the high flows that occurred in the first quarter of 2017 and ended a five-year drought. In contrast, VSS concentration was less variable (ranging from less than the reporting limit to 12.0 mg/L) and highest concentrations were measured in the spring.

Figure 4 Annual mean aqueous unfiltered MeHg concentration in ng/L at each Delta RMP monitoring station sampled from August 2016 through April 2017. Plots based on March-October data.



References

Davis, J.A., M.D. May, G. Ichikawa, and D. Crane. 2000. Contaminant Concentrations in Fish from the Sacramento–San Joaquin Delta and Lower San Joaquin River, 1998. San Francisco Estuary Institute, Richmond, CA.

Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2003. Mercury in Sport Fish from the Delta Region. San Francisco Estuary Institute, Oakland, CA. http://loer.tamug.tamu.edu/calfed/Reports/Final/Task%202A%20-%20Text%20and%20Figures.pdf

Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2008. Mercury in sport fish from the Sacramento–San Joaquin Delta region, California, USA. Science of the Total Environment 391: 66-75.

Davis, J.A., J.R.M. Ross, S.N. Bezalel, J.A. Hunt, G. Ichikawa, A. Bonnema, W.A. Heim, D. Crane, S. Swenson, and C. Lamerdin. 2013. Contaminants in Fish from California Rivers and Streams, 2011. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA.

Delta Regional Monitoring Program. 2017. FY17/18 Detailed Workplan and Budget. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_regional_monitoring/wq_monitoring_plans/drmp_fy1718_detailed_wrkpln.pdf

DiGiorgio, C. , H. Amos, J. Anderson, M. Bahia, C. Beals, D. Beals, D. 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.

Melwani, A.R., S.N. Bezalel, J.A. Hunt, J.L. Grenier, G. Ichikawa, W. Heim, A. Bonnema, C. Foe, D.G. Slotton, J.A. Davis. 2009. Spatial trends and impairment assessment of mercury in sport fish in the Sacramento–San Joaquin Delta watershed. Environmental Pollution. 157: 3137-3149.

Sacramento River Watershed Program. 2002. Annual Monitoring Report: 2000-2001. Prepared by Larry Walker Associates for the Sacramento River Watershed Program.

Wiener, J.G., R.A. Bodaly, S.S. Brown, M. Lucotte, M.C. Newman, D.B. Porcella, R.J. Reash, and E.B. Swain. 2007. Monitoring and evaluating trends in methylmercury accumulation in aquatic biota. Chapter 4 in *Ecosystem responses to mercury contamination: indicators of change*, R. C. Harris, D. P. Krabbenhoft, R. P. Mason, M. W. Murray, R. J. Reash, and T. Saltman (editors). SETAC Press, Pensacola, Florida.

Wood, M. L., C. G. Foe, J. Cooke, and S. 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.

Appendix 1: Cruise Report

Appendix 1
Cruise Report for the
Delta Regional Monitoring Program (Delta RMP)
Monitoring For Status and Trends of Mercury in Black Bass and Water
Sampling Dates: August 22, 2016-May 25, 2016

Written by: Chris Beebe, Billy Jakl,
CDFW/Marine Pollution Studies Laboratory (MPSL) at Moss Landing Marine Laboratories

Introduction

This report describes the sampling activities in different subareas of the Delta region of California. This sampling effort focuses on providing essential performance measures for evaluating the effectiveness of the methylmercury (MeHg) TMDL in the Delta. The TMDL is a key management plan that utilizes a conceptual model for MeHg in the Delta that has been based on extensive monitoring and research conducted by CALFED in the 2000s. This conceptual model shows an observed linkage between MeHg concentration in water and the concentrations in predator fish. The observed linkage was strongest with the black bass species, specifically largemouth bass, which represents the indicator of impairment and water quality objectives. Sampling activities included the collection of fish tissue (black bass) and quarterly water samples with basic field parameters. Samples were collected by California Department of Fish and Wildlife (CDFW)/Marine Pollution Studies Laboratory (MPSL) at Moss Landing Marine Laboratories (MLML).

1.0 Cruise Report

1.1 Objectives

The objectives were to provide spatial and temporal fish and water data to update the TMDL conceptual model. Black bass were collected annually using an electrofisher boat at six fixed stations selected for long-term monitoring. Eleven black bass were collected spanning a broad size range for each station. Each bass was analyzed individually for mercury in to support analysis of covariance for size:mercury relationshipThe annual fish collection was paired with quarterly water collection at five of the six fish stations.

Water collections provide the methylmercury (MeHg) TMDL water concentrations to track performance relative to the established 0.06 ng/L unfiltered MeHg goal and provides a valuable tool for understanding processes leading to accumulation in fish and impairment. Depth-integrated water samples were collected in the thalweg at 5 stations that are strategically located to correlate with the fish monitoring and to provide information that will be useful input to the mercury model in development for the Delta by DWR. The paired fish and water data will allow further assessment of the strength of the correlation between these two matrices. The chemical analyte groups for the water collection include: total mercury (Hg), filtered Hg, unfiltered MeHg and filtered MeHg. Ancillary water parameters, such as: chlorophyll a, DOC, total suspended solids, and volatile suspended solids were collected to aid in interpretation of the MeHg data.

1.2 MPSL/CDFW Sampling personnel

Gary Ichikawa	Environmental Scientist, Crew Lead
William Jakl	Project Associate, Crew Lead
Chris Beebe	Research Tech, Crew Lead
April Guimaraes	Research Tech
Stephen Martenuk	Project Assistant

1.3 Authorization to collect samples

All sampling personnel are MPSL staff (San Jose State University Foundation and the California Department of Fish and Wildlife) contracted through San Francisco Estuary Institute to conduct the sample collection activities listed herein.

1.4 Station selection

Based upon the recommendations of the Delta RMP Steering Committee and Technical Advisory Committee with representatives from the Central Valley Regional Water Quality Control Board, USEPA, California Department of Water Resources, the State and Federal Contractors Water Agency, and various discharger groups, selected stations represent key subareas of the delta.

1.5 Summary of types of samples authorized to be collected

Up to eleven black bass individuals of the same species were collected using an electrofisher for each of the six stations. The eleven individuals spanned broad size range to support assessment of the size:mercury relationship and ANCOVA analysis. Upon collection, each fish collected was tagged with a unique ID that corresponded to the latitude/longitude where it was collected. Physical parameters were collected for each individual fish, which included: weight, total length, fork length, and presence of any abnormalities. Large fish were partially dissected in the field using the following protocol: fish were placed on a cutting board covered with a clean plastic bag where the head, tail, and guts are removed using a clean (laboratory detergent, DI) cleaver. The cleaver and cutting board were re-cleaned between fish species, per site if multiple stations are sampled. Fish samples were stored on dry ice for the duration of the trip.

At the MPSL lab, samples were stored in a freezer until they were processed for authorized dissection and analysis.

A depth-integrated water sample was collected at five stations following MPSL Field SOP v1.1 using a bucket sampler (SWAMP Clean Water Team SOP 2.1.1.4) modified to accommodate a trace metal cleaned 4L glass bottle (I-Chem Part # 145-4000) (MPSL-101). In the thalweg, the bucket sampler with the 4L was lowered to 0.5m from the bottom and raised through the water column at a sufficient rate so that the bottle is not completely filled upon retrieval achieving a depth-integrated sample. Using trace metal clean tubing and a peristaltic pump, samples were aliquoted into analyte specific bottles. Filtered samples were collected by attaching a 45µm ground water filter to the tubing and aliquoted to the analyte specific bottle. A new trace metal-cleaned 4L glass bottle, tubing and filter were used for each site. At each water station four analytes were collected: total mercury, filtered mercury, unfiltered MeHg and filtered MeHg. Ancillary water samples were collected to help interpretation of mercury data at each station: chlorophyll a, DOC, total suspended solids, and volatile suspended solids. Basic field parameters (temperature, pH, specific conductance, dissolved oxygen concentration, dissolved oxygen saturation, and turbidity) along with station information (station depth, location, weather) were also noted.

1.6 Discussion

A total of 6 stations were successfully sampled for fish tissue. Of the 6 stations, 5 were sampled using a dedicated electrofishing vessel. At station 541SJC501(San Joaquin River at Vernalis) water levels were so low that launching the dedicated electrofishing vessel was not possible. At this station a small aluminum boat was outfitted with electrofishing equipment and was utilized to collect the fish tissue samples at that station.

In addition, following the sampling design which was limited to 5 water stations due to budgetary limitations, 5 of the stations were successfully sampled for depth-integrated water samples and basic water parameters. Following retrieval the depth-integrated water sample was aliquoted in the field into appropriate sample containers for analysis. The chemical analyte groups for this monitoring element include: total mercury, filtered mercury, unfiltered MeHg, filtered MeHg, and ancillary parameters. Field blanks were collected at a rate of 5%, or a minimum of 1 field blank per collection event.

1.7 Results

One MPSL team sampled the six subareas for fish tissue. Several MPSL crews completed the quarterly water sampling efforts. A detailed fish catch, fish total length, descriptions and maps of sample collection for all stations can be found in Table 1.7 below. Also included in the table are the dates of the depth-integrated water sampling events.

1.7 Table of Contents for Delta RMP Cruise Report

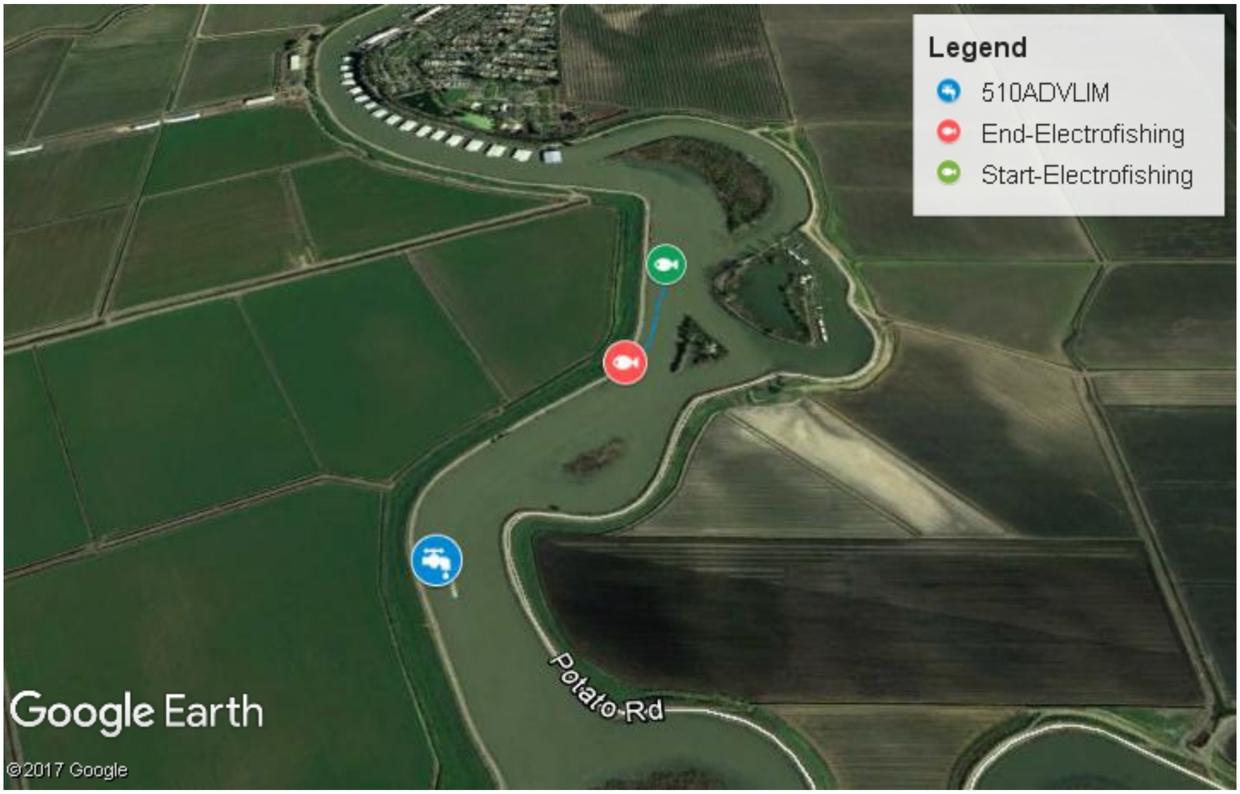
Cache Slough at Liberty Island Mouth (510ADVLIM)

Latitude: 38.24213
Longitude: -121.68539
Collection Objective: Fish (Annually) Water (Quarterly)
Collection Method: Electrofishing vessel and depth-integrated water sampler
Date of Fish Collection: 8/23/16
Date (s) of Water Collection: 8/22/16, 11/14/16, 2/28/17, and 4/25/17
Samplers: Gary Ichikawa, Chris Beebe, Stephen Martenuk, and Billy Jakl

Sportfish Caught: Largemouth Bass, TL (mm)										
223	232	278	283	312	331	343	318	343	363	443

Comments: The sampling vessel was launched from the Arrowhead Marina launch ramp in Clarksburg, CA. Eleven Largemouth bass were sampled along the transect adjacent to the target station. All water collection was done in close proximity of the target station (510ADVLIM) where the channel discharge was greatest.

Little Potato Slough (544LILPSL)

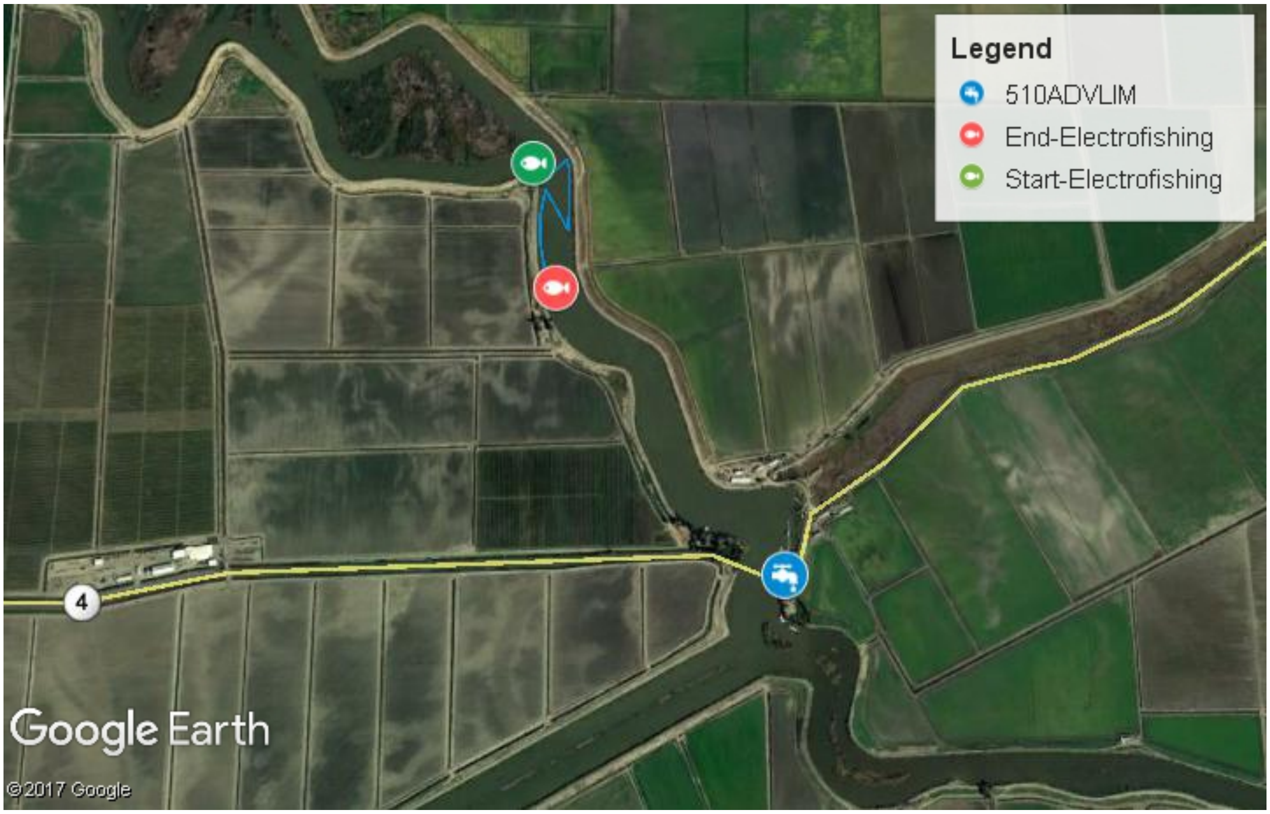


Latitude: 38.09627
Longitude: -121.49602
Collection Method: Electrofishing vessel and depth-integrated water sampler
Date (s) of Fish Collection: 8/23/17
Date (s) of Water Collection: 8/22/17, 11/15/16, 2/2817, and 4/25/17
Samplers: Gary Ichikawa, Chris Beebe, Stephen Martenuk, Billy Jakl, and April Guimaraes.

Sportfish Caught: Largemouth Bass, TL (mm)										
223	232	278	283	312	331	343	318	343	363	443

Comments: The sampling vessel was launched from the Tower Marina. Eleven Largemouth bass were collected along the sampling transect. Water collection was done in close proximity of the target station where the channel discharge was the greatest.

Middle River at Borden Hwy (544MDRBH4)

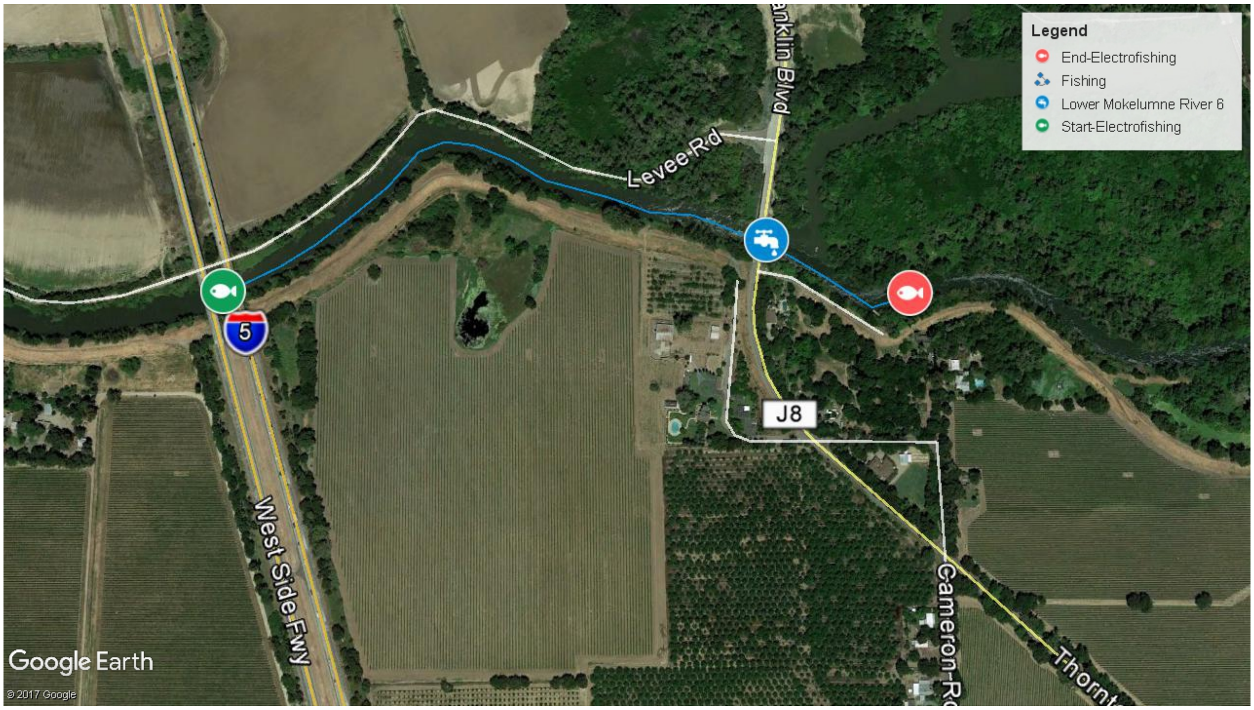


Latitude: 37.89083
Longitude: -121.48833
Collection Method: Eletrofishing vessel and depth-integrated water sampler
Date (s) of Fish Collection: 8/23/2016
Date (s) of Water Collection: 8/22/17, 11/15/16, 2/2817, and 4/25/17
Samplers: Gary Ichikawa, Chris Beebe, Stephen Martenuk, Billy Jakl, and April Guimaraes.

Sportfish Caught: Largemouth Bass, TL (mm)										
223	232	278	283	312	331	343	318	343	363	443

Comments: The sampling vessel was launched from the Discovery Bay Marina. Eleven Largemouth bass were collected along the sampling transect. Water collection was done in close proximity of the target station where the channel discharge was the greatest.

Lower Mokelumne River 6 (544ADVLM6)

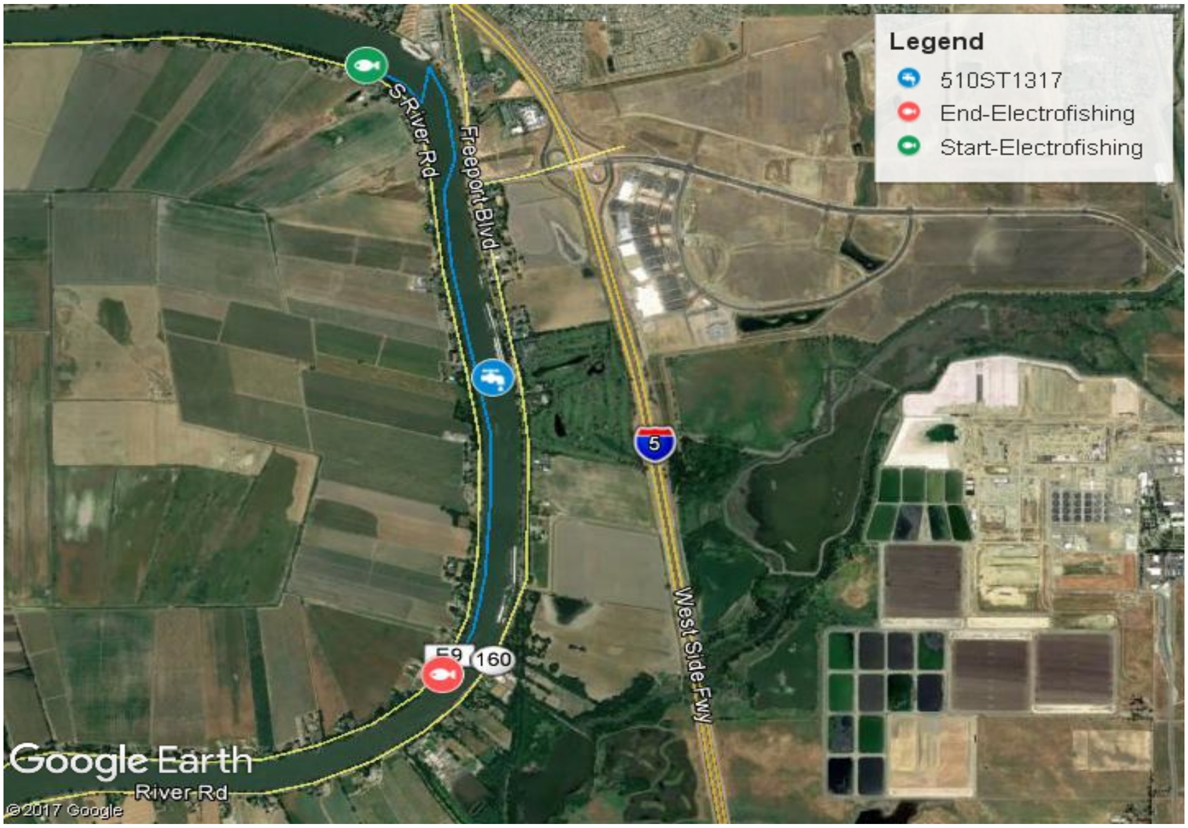


Latitude: 38.4556
Longitude: -121.50189
Collection Objective: Fish (Annually)
Collection Method: Electrofishing Vessel
Date (s) of Fish Collection: 8/22/2016
Samplers: Gary Ichikawa, Chris Beebe, Stephen Martenuk, Billy Jakl, and April Guimaraes.

Sportfish Caught: Largemouth Bass, TL (mm)										
244	236	268	304	307	309	362	336	346	408	408

Comments: The sampling vessel was launched from the New Hope Landing launch ramp. Water levels were lower than expected. Eleven Largemouth bass were collected along the sampling transect. Water collection was done in close proximity of the target station where the channel discharge was the greatest.

Sacramento River at Freeport (510ST1317)



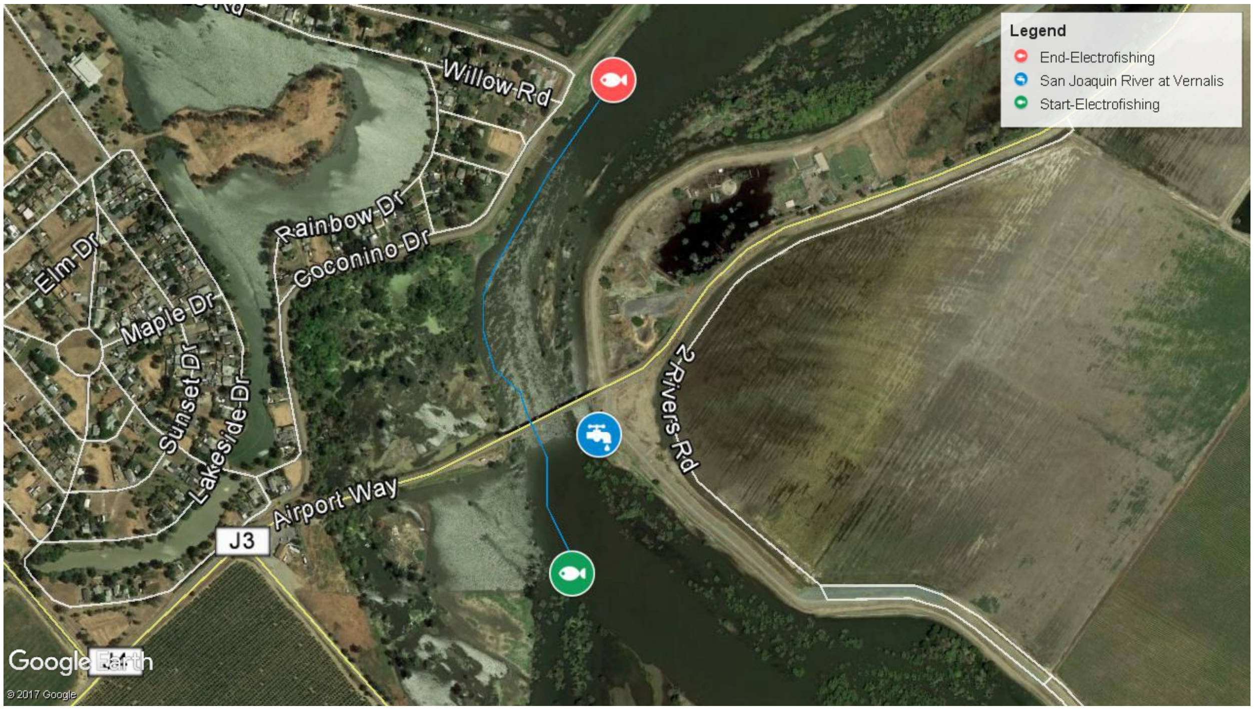
Latitude: 38.4556
Longitude: -121.50189
Collection Method: Electrofishing Vessel
Date (s) of Fish Collection: 8/22/2016
Date (s) of Water Collection: 8/22/17, 11/15/16, 2/2817, and 4/25/17
Samplers: Gary Ichikawa, Chris Beebe, Stephen Martenuk, Billy Jakl, and April Guimaraes.

Sportfish Caught: Spotted Bass, TL (mm)											
200	248	258	291	305	291	292	306	309	354	332	365

Sportfish Caught: Largemouth Bass, TL (mm)			
251	404	410	422

Comments: The sampling vessel was launched from the Garcia Bend Park launch ramp. Eleven Largemouth bass were collected along the sampling transect. Water collection was done in close proximity of the target station where the channel discharge was the greatest.

San Joaquin River at Vernalis/Airport (541SJC501)



Latitude: 37.67556
Longitude: -121.26417
Collection Method: Electrofishing Vessel
Date (s) of Fish Collection: 9/13/16
Date (s) of Water Collection: 8/23/17, 11/14/16, 2/2817, and 4/25/17
Samplers: Chris Beebe, Stephen Martenuk, Billy Jakl, and April Guimaraes.

Sportfish Caught: Largemouth Bass, TL (mm)										
215	206	290	300	343	348	371	365	374	398	408

Comments: The sampling vessel was launched from the bank. Eleven Largemouth bass were collected along the sampling transect. Water collection was done in close proximity of the target station where the channel discharge was the greatest.

Appendix 2: Quality Assurance Review of FY 2016–2017 Delta RMP Mercury Sampling Data

Date: December 13, 2017

From: Donald Yee, ASC QA Officer

To: Delta RMP Technical Advisory Committee

Re: Quality assurance review of FY 2016–2017 Delta RMP mercury sampling data

General summary

This memo summarizes the quality assurance (QA) review of the Delta Regional Monitoring Program (Delta RMP) 2016–2017 data for laboratory analyses of mercury and ancillary measurements in water and fish. This review was conducted by ASC scientists and technical staff under the supervision of QA officer Dr. Donald Yee. All samples were collected and analyzed by scientists and technicians from the Marine Pollution Studies Laboratory (MPSL) in Moss Landing, California.

We have found over 99% of the lab results met the requirements of the Delta RMP Quality Assurance Program Plan (QAPP).[1] Table 1 provides a high-level quality assurance summary of the chemical analytical results, which are described in greater detail below.

There was one deviation from the QAPP (one water sample's hold time was exceeded by 1 day) which we flagged, but the result is still reported. Analyses yielded results above the limits of detection for all analytes aside from 3% of total suspended solids (TSS) and 7% of volatile suspended solids (VSS) samples.

Based on our review, we are making one recommendation to the lab. Future matrix spikes on fish tissue should be made at 2 to 5 times native concentrations in order to quantify recovery more accurately. Lab staff have confirmed that they plan to spike at

[1] Jabusch, Thomas, Don Yee, and Amy Franz. "Delta Regional Monitoring Program Quality Assurance Program Plan." San Francisco Estuary Institute – Aquatic Science Center, September 30, 2016. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_regional_monitoring/wq_monitoring_plans/2016_0930_drmp_qapp.pdf.

these higher concentrations in the future. Nevertheless, analyses of certified reference materials (CRMs) and matrix spikes provided sufficient evidence of recovery.

Table 1. QA Summary for chemical analytical results (RPD = relative percent difference)

Analyte	% Exceeding hold time	% Non-detects	% Results < 3x Blank	Average % Recovery	Average RPD
Water					
Mercury	2%	0%	0%	102%	4%
Methylmercury	0%	0%	0%	89%	3%
Chlorophyll-a	0%	0%	0%	107%	8%
Dissolved Organic Carbon	0%	0%	0%	95%	2%
Total Suspended Solids	0%	3%	0%	NA	9%
Volatile Suspended Solids	0%	7%	0%	NA	7%
Fish					
Mercury	0%	0%	0%	101%	4%

Approach

About 15% of all mercury samples that were analyzed were for quality assurance and quality control purposes.

For our QA review, we used the data electronically submitted by the laboratory and compiled it into a local database to verify that the correct number of field samples and required number of QC samples are reported for the requested analyses, as specified in the project QAPP. We compared the results for QC samples to the acceptance criteria listed in the QAPP. We did this by independently recalculating reported precision (as relative percent difference, RPD, or relative standard deviation, RSD) for lab replicates, and percent recovery for samples of a known concentration. In order to verify that contamination of samples had not occurred in sampling or lab analysis, we compared the results for blank samples (both field and lab blanks) to method detection limits. In cases where an analyte is detected in a blank, we compare the measured concentration in the blank sample to concentrations measured in in field samples to determine the proportion of the signal that originates from lab contamination.

Where deviations from the project's measurement quality objectives (MQOs) were found, we attached a flag or qualifier to the record. In some cases, records may have already been flagged by the reporting lab. Qualifiers added by ASC or the lab indicates that there has been a deviation from the project's quality criteria, and are meant to warn data users that certain records may be inaccurate or imprecise.

In the most severe cases, data may be rejected and not reported. However, for this project, all data were reportable, as we did not find serious violations of the quality objectives that would lead to rejection of data.

Mercury in Fish Tissue

Delta RMP monitoring analyzed two types of sport fish: largemouth bass (*Micropterus salmoides*), and spotted bass (*Micropterus punctulatus*). The targeted fish species was largemouth bass. The goal was to collect 11 individuals spanning a range of total length from 200 – 500 mm at each site. Specimens of similar predator species were to be collected if the desired number of individuals of the primary target fish species could not be collected at a site. At one site, Sacramento River at Freeport, the field team could not collect enough largemouth bass, but were able to collect 11 spotted bass.

All fish were in the desired size range except for a single specimen, a largemouth bass collected at Middle River at Borden Hwy (Hwy 4), which was 548 mm (21.6 inches) long, slightly above the "target range" listed in the QAPP (200 – 500mm). Because mercury concentrations are reported normalized to size via regression analysis (detailed in the main report), the upper limit on target fish size will be removed from future versions of the QAPP.

General findings and recommendations

All of the field data were reportable for the target analytes, therefore all results are considered reportable.

We have recommended to the lab that, in the future, matrix spikes should be done with larger doses of mercury. Matrix spikes are created by splitting a sample and "spiking," or adding a known concentration of the target analyte to a portion of the sample. Matrix spikes are performed in order to assess the accuracy and precision (if run in duplicate) of an analytical method, and can help determine whether there is any interference from the sample matrix. In general, matrix spikes should be 1 to 5 times the background mercury concentration. In other words, spiked samples should ideally contain 2 to 6 times the concentration of mercury as the original sample. Some of the fish tissue matrix spike samples (4 of 10) were not spiked at high enough levels to meet this desired range.

For matrix spike samples, the results met the acceptability criteria in the QAPP (within ±25% of the expected value). This was true where the resulting concentration *was* high enough (the spiked sample contained at least double the background concentration), as well as for those samples where the spike was lower than desired. For future monitoring, the lab should spike at slightly higher levels to ensure measurements of matrix spike recovery more consistently in a quantitative range, by assuming that native concentrations may occur in the upper range of results reported to date for these sites.

Hold time

All of the fish tissue samples were analyzed within less than 50 days of collection, well within the 1-year hold time limit.

Completeness

Results were reported for moisture content (percent water by weight) and total mercury concentration in largemouth bass collected at 6 sites in the Delta. Samples were collected on a single day at each site. Field crews collected tissue samples for analysis from 66 fish (11 individual fish at each of 6 sites). In addition, lab replicates were analyzed for 3 sites and 2 non-project samples analyzed in the same batches. Analysis of 15 blanks, 10 matrix spikes (MS), and 10 certified reference material (CRM) results were also reported by the lab, with QC sample results summarized in Table 1 above.

Sensitivity

The lab reported results above the method detection limit for all field samples of fish tissue for both total mercury and moisture. This indicates that the analysis methods used were of sufficient sensitivity.

Blank contamination check

Accurate measurement of analytes at low concentrations sometimes requires correcting for background sources of contamination, such as traces in reagents, solvents, glassware, or other sample processing hardware used in the analysis. Analyzing method blanks lets us demonstrate that these materials are free from contamination that would interfere with analysis of the sample. Mercury concentrations measured in blanks were all below the reporting limit and therefore met the program's quality assurance criteria as described in the QAPP.

All samples were reported blank corrected (also called blank subtracted). Blank correction (akin to taring of a scale) is used for reporting of analytes with irremovable background concentrations in the lab environment that would otherwise elevate reported concentrations.

Precision

The precision of analysis methods (ability to consistently obtain the same result) is determined by analyzing replicate or duplicate samples. The lab analyzed lab replicates (split and analyzed in the laboratory) to assess the repeatability of measurements, and samples collected within each site could be considered field replicates (two or more samples collected in the same place at the same time).

For mercury lab replicates, all results were within 6% relative percent difference (RPD) of the expected value or better. This is well within the 25% target for RPD in the QAPP, and indicates good precision. Variation among individual fish from a site was larger (average relative standard deviation [RSD] ~40% within each site), as would be expected given wide variations among individual organisms often found within a site. Much of this variation is driven by size differences, discussed in the main report. Field replicate precision criteria typically developed for homogeneous media (e.g. water samples) usually should not be applied to tissue samples, due to the large and expected variation among individual fish that is typically observed.

Accuracy

For mercury, samples with a known concentration, consisting of certified reference material (CRM), were run at a minimum frequency of one per analytical batch (for analytical batches consisting of up to 20 field samples) or per 20 (field) samples for larger analytical batches. Analysis of CRMs allows us to evaluate measurement accuracy, or how close our measurement comes to a consensus/expected value. Matrix spikes, where a sample is spiked with a known amount of mercury, provide an alternative determination of method accuracy that can account for matrix interferences or other analytical problems.

Recovery errors averaged <3% for CRMs, and averaged <10% for matrix spikes that were spiked to at least double the native (unspiked) concentration. The results of QC samples were all within the measurement quality objectives in the QAPP which state that results should be within ±25% of the expected value.

Comparison to previous data

We compared the observed mercury concentration in fish tissue measured by the 2016 sampling program with results to other studies, as a simple way to ensure that the results are realistic and within the expected bounds. We found that the range of mercury concentrations about 0.2 to 0.7 μg/g wet weight in largemouth bass is broadly similar to results of prior studies. Further information on comparison to historic data is provided in the main report.

Mercury and Ancillary Parameters in Water Samples

In this section, we describe the analysis of water samples for mercury (Hg), methylmercury (MeHg), and ancillary water quality parameters chlorophyll-a (Chl-a), dissolved organic carbon (DOC), total suspended solids (TSS), and volatile suspended solids (VSS). The QA for these analyses was also previously summarized in Table 1.

Hold time

All but one of the project samples were analyzed within their hold time limit, with one water sample analyzed at 91 days (past its 90 day limit). That result was flagged "VH" for a hold time exceedance, but is still reported.

Completeness

Water results were reported for 5 sites, for 4 events each (Aug/Nov/Feb/Apr), resulting in 20 collections for all the analytes (Hg, MeHg, TSS, VSS, chl-a, DOC). QC samples reported included 4 field blanks for all analytes, lab blanks (18 Hg, 15 MeHg, 8 TSS, 8 VSS, 8 chl-a, and 4 DOC), matrix spikes (24 Hg, 20 MeHg, and 6 DOC), 6 CRMs for Hg, and laboratory control samples (LCSs, 5 MeHg, 4 DOC, 2 chl-a).

Sensitivity

The method was sufficient to detect nearly all analytes in all samples, with 101 out of 104 results above the method detection limit. However, there was 1 chl-a result, and 2 VSS results below detection limits.

Blank contamination check

Samples were reported NOT blank corrected for DOC and MeHg, but blank corrected for the other analytes. Lab blanks were all below reporting limits, so no results were qualified for blank contamination. DOC was detected in one field blank at a concentration of 0.48 mg/L, about double the detection limit of 0.23 mg/L, but still about 4x lower than the minimum field sample result.

Precision

Precision averaged <10% RPD for lab replicates on all the analytes. The measured concentration for all analytes were large enough to quantify reliably; as shown in Table 1, all results were at least three times the MDL. (When results are near the MDL, we can conclude that the analyte is present in the sample with reasonable confidence, but it cannot be accurately quantified. Results less than three times the MDL may be in error by as much as ±50% of the actual concentration.) Lab precision was well within the 25% target for all analytes. Variation among field duplicates from individual sites was somewhat larger, but still averaged less than 15% RPD.

Accuracy

Of the reported analytes, only mercury had CRM results, with average recovery errors of 8% and an average recovery of 102%. Recovery errors on MS samples averaged less than 15% for all analytes, within the 20% target for chl-a, DOC, 25% for Hg, and 30% for MeHg.

Comparison to previous data

This was the first year of sampling for most of these analytes at these sites in water for the Delta RMP, so there are no previous data from the same project for comparison. However, there is a wealth of water quality monitoring data available for the Delta. For example, here we compare observations from 2016 Delta RMP monitoring to observations in a historical Delta and North Bay Water Quality Conditions Report covering conditions in 2011.[2] Results for ancillary parameters in the present study are within the range of the historic data (Table 2). Further comparisons of this program's monitoring results to historic observations of mercury are provided in the main report.

[2] DWR. *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2011.* Department of Water Resources, Division of Environmental Services, 2012. http://www.water.ca.gov/bdma/reports/

Table 2. Comparison of water quality measurements to historical observations

Parameter	Delta RMP (range)	Historical observations
Ancillary Parameters		**2011 range (DWR, 2012)**
TSS	3–85 mg/L	1–144 mg/L
DOC	1.8–4.5 mg/L	
VSS	<1–12 mg/L	<1–23 mg/L
chl-a	<0.5–12 μg/L	0.35–18 μg/L

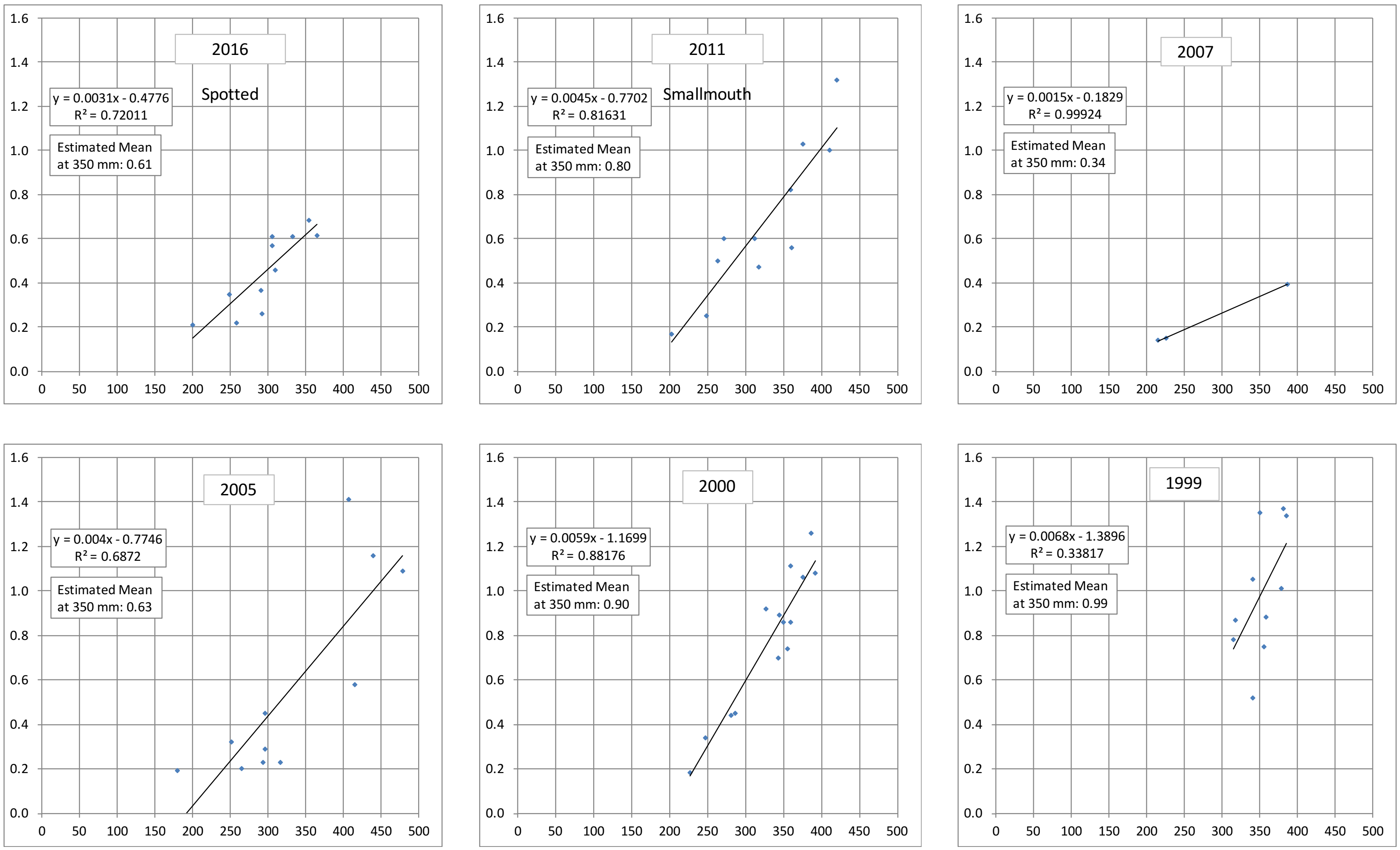
Appendix 3: Mercury Concentrations and Ancillary Measurements in Individual Fish

Sample Date	Station	Common Name	SampleID	Parameter	Result	Unit	Total Length (mm)
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2396	Mercury	0.20	ug/g ww	223
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2397	Mercury	0.17	ug/g ww	232
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2398	Mercury	0.23	ug/g ww	278
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2399	Mercury	0.28	ug/g ww	283
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2400	Mercury	0.30	ug/g ww	312
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2403	Mercury	0.23	ug/g ww	318
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2401	Mercury	0.33	ug/g ww	331
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2404	Mercury	0.44	ug/g ww	343
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2402	Mercury	0.30	ug/g ww	343
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2405	Mercury	0.43	ug/g ww	363
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	I_510ADVLIM_B2406	Mercury	0.73	ug/g ww	443
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2385	Mercury	0.15	ug/g ww	209
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2386	Mercury	0.16	ug/g ww	237
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2387	Mercury	0.15	ug/g ww	252
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2388	Mercury	0.16	ug/g ww	260
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2391	Mercury	0.17	ug/g ww	310
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2389	Mercury	0.16	ug/g ww	313
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2390	Mercury	0.17	ug/g ww	315
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2393	Mercury	0.17	ug/g ww	317
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2392	Mercury	0.20	ug/g ww	332
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2394	Mercury	0.24	ug/g ww	420
8/23/16	Little Potato Slough	Largemouth Bass	I_544LILPSL_B2395	Mercury	0.28	ug/g ww	481
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2364	Mercury	0.71	ug/g ww	236
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2363	Mercury	0.30	ug/g ww	244
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2365	Mercury	0.31	ug/g ww	268
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2366	Mercury	0.58	ug/g ww	304
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2367	Mercury	0.45	ug/g ww	307
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2368	Mercury	0.47	ug/g ww	309
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2370	Mercury	0.49	ug/g ww	336
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2371	Mercury	0.58	ug/g ww	346
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2369	Mercury	0.69	ug/g ww	362
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2373	Mercury	0.63	ug/g ww	408
8/22/16	Lower Mokelumne River 6	Largemouth Bass	I_544ADVLM6_B2372	Mercury	0.66	ug/g ww	408
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2374	Mercury	0.12	ug/g ww	205
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2375	Mercury	0.12	ug/g ww	228
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2377	Mercury	0.20	ug/g ww	252
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2376	Mercury	0.16	ug/g ww	284
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2378	Mercury	0.18	ug/g ww	315
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2379	Mercury	0.21	ug/g ww	318
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2380	Mercury	0.15	ug/g ww	321
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2381	Mercury	0.33	ug/g ww	344
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2382	Mercury	0.20	ug/g ww	389
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2383	Mercury	0.40	ug/g ww	465
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	I_544MDRBH4_B2384	Mercury	0.62	ug/g ww	548
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2347	Mercury	0.21	ug/g ww	200
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2348	Mercury	0.35	ug/g ww	248
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2349	Mercury	0.22	ug/g ww	258
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2350	Mercury	0.37	ug/g ww	291
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2353	Mercury	0.26	ug/g ww	292
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2351	Mercury	0.61	ug/g ww	305
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2354	Mercury	0.57	ug/g ww	306
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2355	Mercury	0.46	ug/g ww	309
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2357	Mercury	0.61	ug/g ww	332
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2356	Mercury	0.68	ug/g ww	354
8/22/16	Sacramento River/Freeport	Spotted Bass	I_510ST1317_B2358	Mercury	0.61	ug/g ww	365
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2551	Mercury	0.11	ug/g ww	206
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2550	Mercury	0.13	ug/g ww	215
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2552	Mercury	0.16	ug/g ww	290
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2553	Mercury	0.19	ug/g ww	300
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2554	Mercury	0.30	ug/g ww	343
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2555	Mercury	0.19	ug/g ww	348
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2557	Mercury	0.22	ug/g ww	365
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2556	Mercury	0.27	ug/g ww	371
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2558	Mercury	0.27	ug/g ww	374
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2559	Mercury	0.22	ug/g ww	398
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	I_541SJC501_B2560	Mercury	0.25	ug/g ww	408

Appendix 4: Mercury Concentration versus Length at Each Station, Including Historic Data

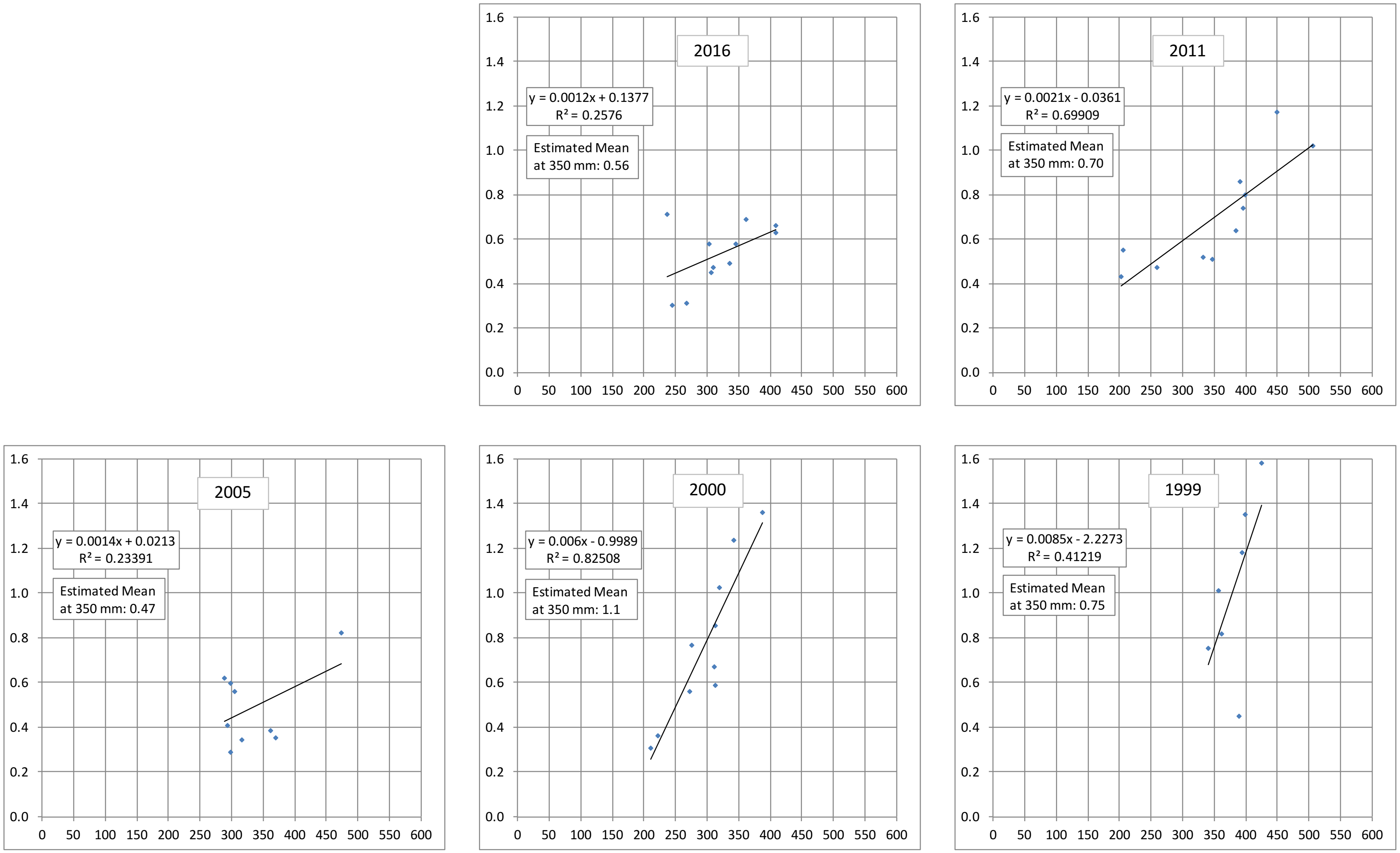
Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

Sacramento River at Freeport



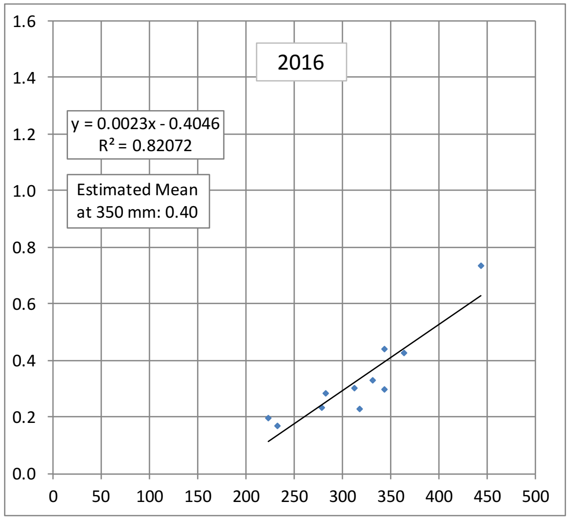
Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

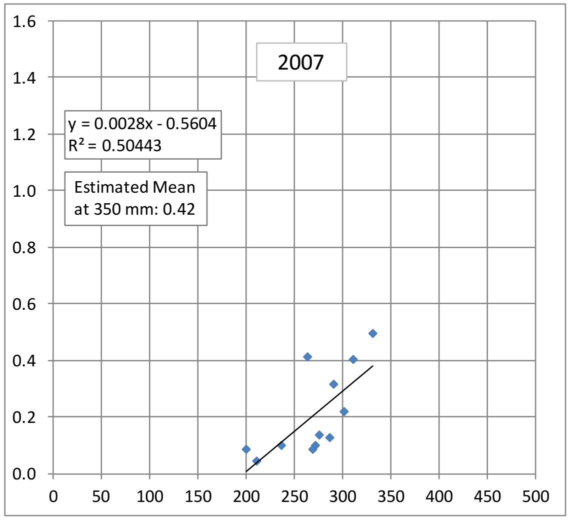
Lower Mokelumne River 6

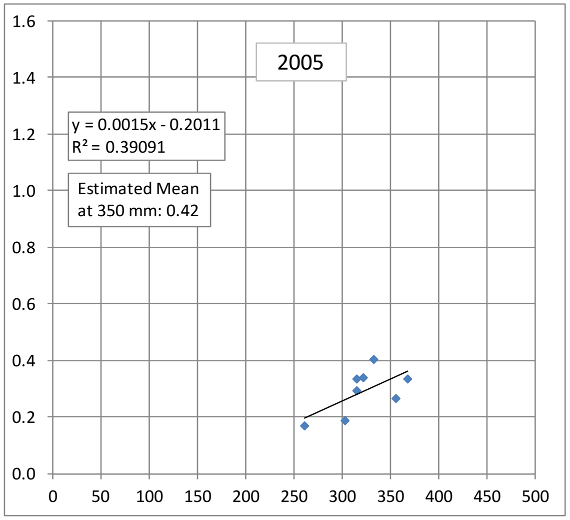


Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

Cache Slough at Liberty Island Mouth

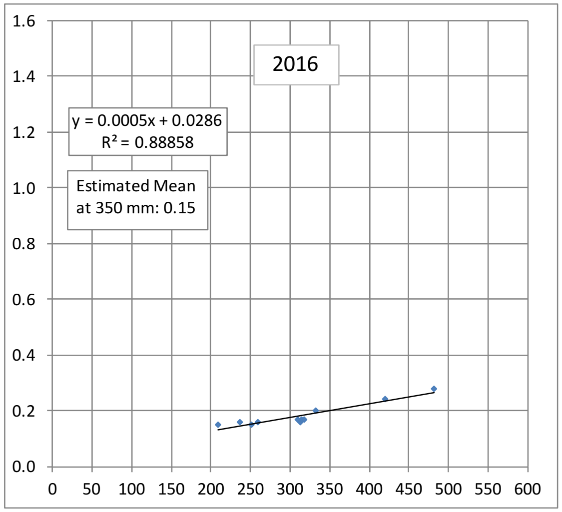


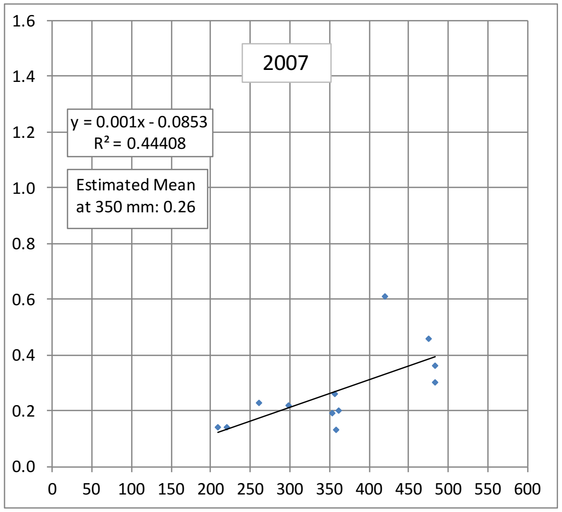


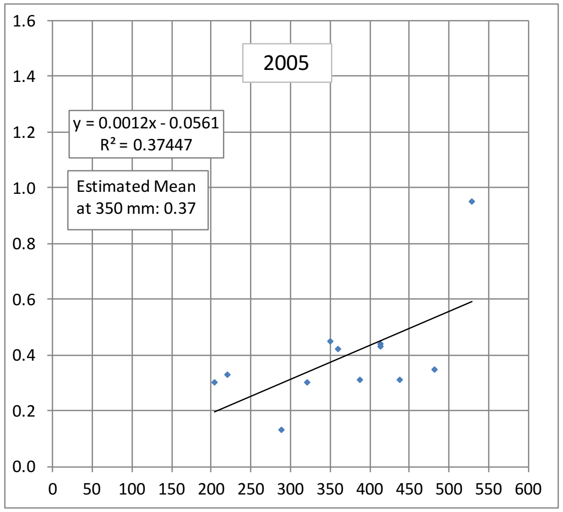


Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

Little Potato Slough

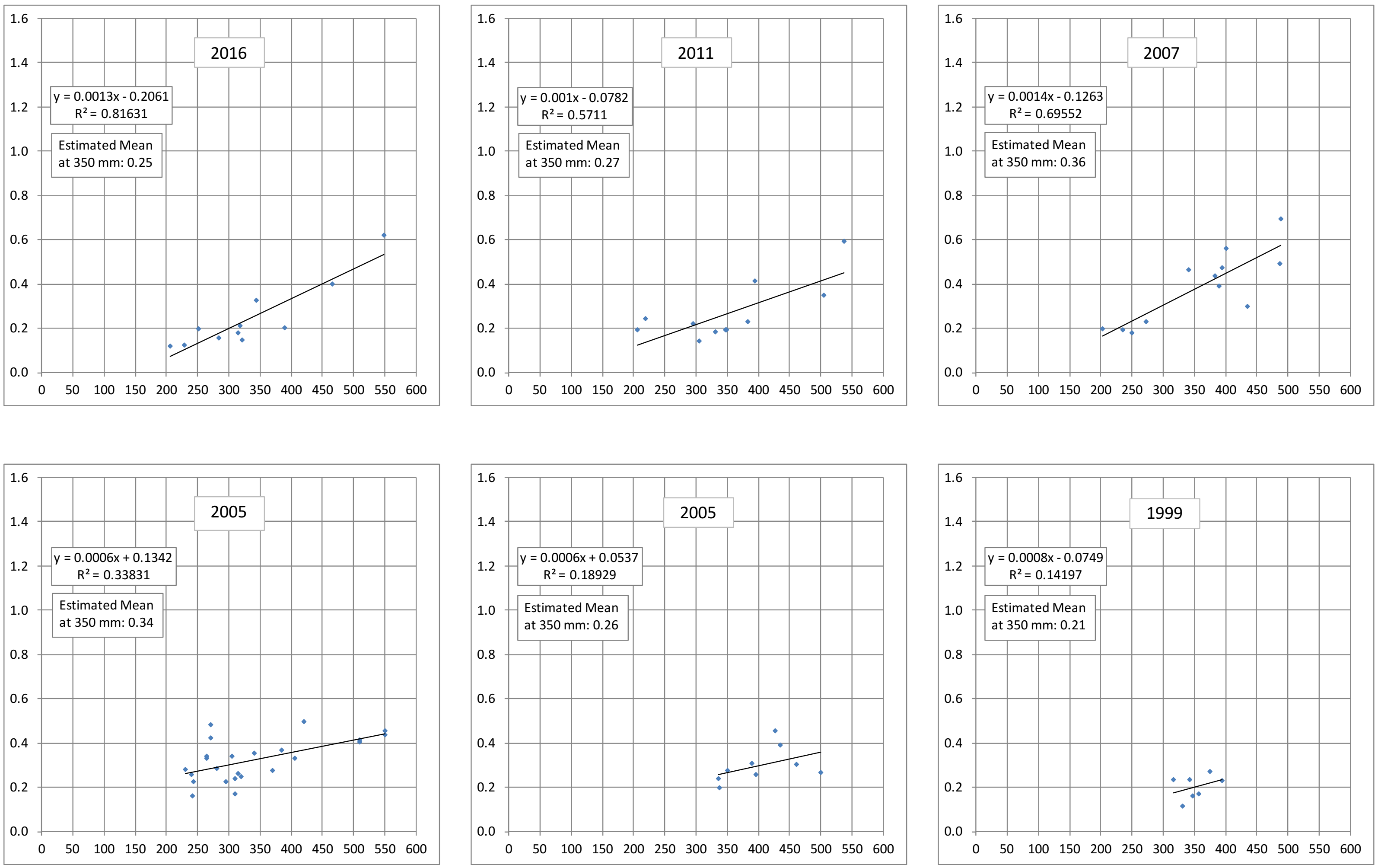






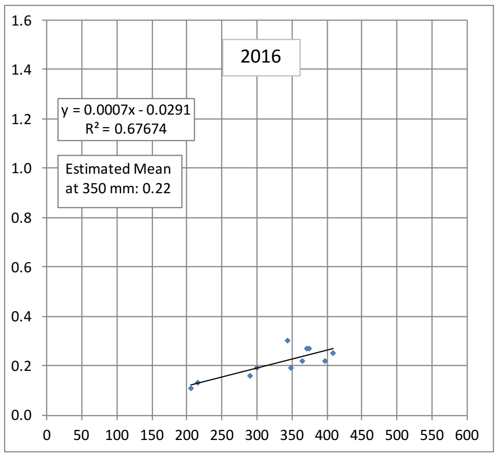
Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

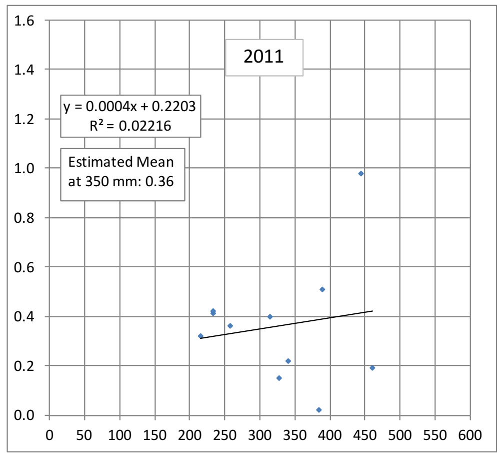
Middle River at Borden Hwy (Hwy 4)

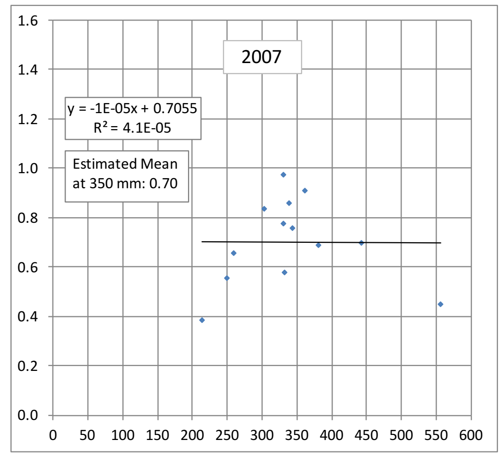


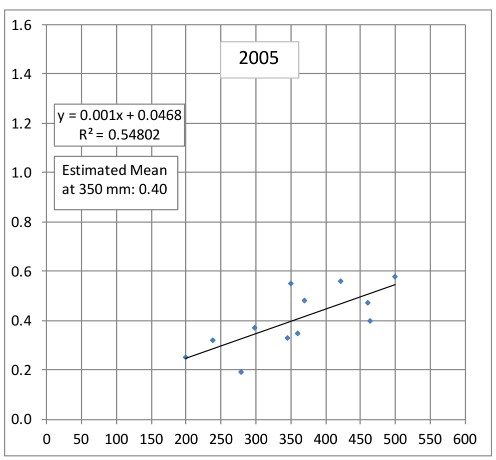
Vertical axis: total mercury in ppm wet weight; Horizontal axis: total length in mm. Largemouth bass unless otherwise noted. See Figure 3 caption for information on slight variation in locations over the years.

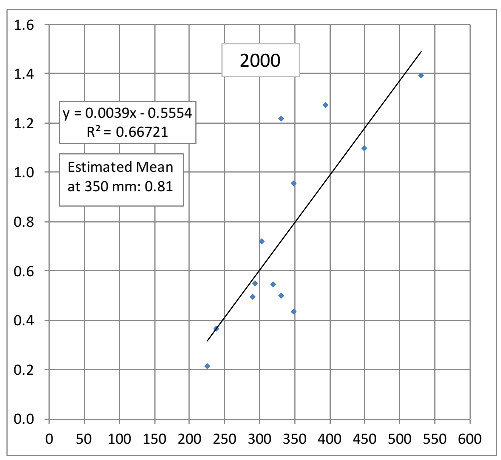
San Joaquin River at Vernalis

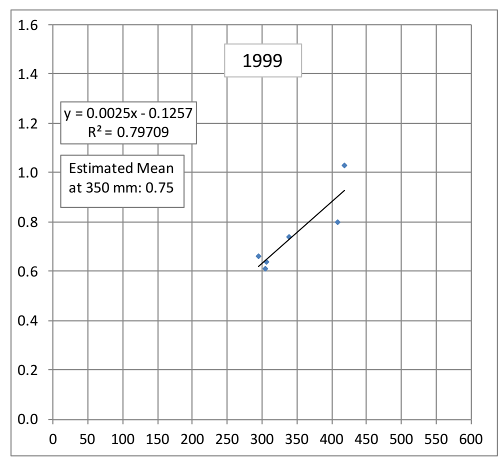












Appendix 5: Length-adjusted Average Mercury Concentrations in Black Bass

Sample Date	Station	Common Name	Sample ID	Number Of Fish In Sample	Tissue Code	Prep Preservation	Parameter	Result	Unit	Sample Type
8/23/16	Cache Slough at Liberty Island Mouth	Largemouth Bass	NA	11	FIL	Skin off	Mercury	0.40	ug/g ww	350 mm Length-adjusted Mean
8/23/16	Little Potato Slough	Largemouth Bass	NA	11	FIL	Skin off	Mercury	0.15	ug/g ww	350 mm Length-adjusted Mean
8/22/16	Lower Mokelumne River 6	Largemouth Bass	NA	11	FIL	Skin off	Mercury	0.56	ug/g ww	350 mm Length-adjusted Mean
8/23/16	Middle River at Borden Hwy (Hwy 4)	Largemouth Bass	NA	11	FIL	Skin off	Mercury	0.25	ug/g ww	350 mm Length-adjusted Mean
8/22/16	Sacramento River/Freeport	Spotted Bass	NA	11	FIL	Skin off	Mercury	0.61	ug/g ww	350 mm Length-adjusted Mean
9/13/16	San Joaquin River at Airport Way near Vernalis	Largemouth Bass	NA	11	FIL	Skin off	Mercury	0.22	ug/g ww	350 mm Length-adjusted Mean

Appendix 6: Mercury and Ancillary Concentrations in Water

StationCode	Station	Sample Date DD/MMM/YYYY	DOC (mg/L)	Chl a (ug/L)	TSS (mg/L)	VSS (mg/L)	ufTHg (ng/L)	fTHg (ng/L)	ufMeHg (ng/L)	fMeHg (ng/L)
510ADVLIM	Cache Slough at Liberty Island Mouth	22/Aug/2016	2.84	12.0	11.1	3.16	1.88	0.659	0.098	0.050
510ADVLIM	Cache Slough at Liberty Island Mouth	14/Nov/2016	3.38	2.70	5.28	2.85	1.36	0.832	0.088	0.065
510ADVLIM	Cache Slough at Liberty Island Mouth	28/Feb/2017	2.32	1.00	82.6	12.0	13.4	1.47	0.147	0.045
510ADVLIM	Cache Slough at Liberty Island Mouth	25/Apr/2017	2.20	6.66	16.0	6.00	4.78	0.885	0.207	0.110
510ST1317	Sacramento R @ Freeport	22/Aug/2016	3.23	1.30	4.70	3.72	2.15	0.746	0.072	0.055
510ST1317	Sacramento R @ Freeport	14/Nov/2016	2.48	<RL	5.84	1.46	2.00	0.823	0.094	0.077
510ST1317	Sacramento R @ Freeport	28/Feb/2017	1.79	0.528	29.1	5.59	8.58	1.27	0.045	0.021
510ST1317	Sacramento R @ Freeport	25/Apr/2017	1.83	1.90	22.3	3.88	4.58	0.777	0.090	0.040
541SJC501	San Joaquin R @ Vernalis/Airport Way	23/Aug/2016	3.51	10.0	9.00	2.40	2.41	1.71	0.090	0.050
541SJC501	San Joaquin R @ Vernalis/Airport Way	14/Nov/2016	4.39	5.30	14.2	1.35	3.13	0.859	0.152	0.093
541SJC501	San Joaquin R @ Vernalis/Airport Way	28/Feb/2017	4.54	2.04	20.6	3.92	5.37	2.07	0.219	0.131
541SJC501	San Joaquin R @ Vernalis/Airport Way	25/Apr/2017	3.16	1.33	13.5	4.73	3.55	1.42	0.367	0.217
544LILPSL	Little Potato Slough	22/Aug/2016	2.98	1.30	7.32	3.80	1.34	0.586	0.068	0.050
544LILPSL	Little Potato Slough	15/Nov/2016	3.62	1.30	4.00	<RL	2.02	0.960	0.079	0.063
544LILPSL	Little Potato Slough	28/Feb/2017	3.37	0.987	11.5	1.84	6.11	1.82	0.168	0.110
544LILPSL	Little Potato Slough	25/Apr/2017	2.29	1.280	9.12	3.71	3.24	1.36	0.190	0.144
544MDRBH4	Middle R @ Borden Hwy (Hwy 4)	22/Aug/2016	3.54	5.30	3.80	1.68	1.35	0.492	0.055	0.027
544MDRBH4	Middle R @ Borden Hwy (Hwy 4)	15/Nov/2016	3.31	2.00	3.01	1.08	0.913	0.603	0.045	0.031
544MDRBH4	Middle R @ Borden Hwy (Hwy 4)	28/Feb/2017	4.24	1.38	25.4	3.95	5.71	2.02	0.167	0.102
544MDRBH4	Middle R @ Borden Hwy (Hwy 4)	25/Apr/2017	3.46	2.32	9.41	4.46	2.44	1.46	0.241	0.177
		Method Detection Limit	0.24	0.045	1.00	1.00	0.200	0.200	0.011	0.011
		Reporting Limit	1.00	0.045	3.00	3.00	0.200	0.200	0.031	0.031