

California Regional Water Quality Control Board
San Francisco Bay Region

2021 Fish Mercury Data from Select Reservoirs



Final Staff Report
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CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD

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1 Executive Summary

In 2021, the State Water Resources Control Board's [Safe to Eat Workgroup](#) ("STEW") sampled fish from many reservoirs to assess their contaminant levels, particularly mercury. The San Francisco Bay Regional Water Quality Control Board (Water Board) contributed funds to this program for additional fish collection and mercury analysis from five reservoirs (see Figure 1 and Table 1). This technical memorandum provides and summarizes mercury data from five reservoirs.

These five reservoirs were selected to provide baseline mercury data for the Water Board's Reservoir Mercury Management Program (Mercury Program). The Mercury Program is a joint fact-finding effort to identify feasible and reproducible methods that reliably reduce fish mercury concentrations in lakes and reservoirs to protect humans and wildlife that consume fish.

Also, as part of the Mercury Program, the Water Board, East Bay Municipal Utility District, and Marin Municipal Water District contributed funds to an extensive baseline monitoring program in San Pablo Reservoir. Those results are reported separately in the *Pre-oxygenation Mercury Baseline Conditions and Cycling in San Pablo Reservoir: 2019-2021 Data Evaluation* (available upon request).

The fish species and sizes caught varied between reservoirs partly by design and partly because of variations in species abundance.

For sport-size largemouth bass caught in 2021, Soulajule and Calero Reservoirs had higher total mercury concentrations than Camden, Lafayette, and Shadow Cliffs reservoirs. This was expected as both Calero and Soulajule Reservoirs are impacted by upstream mercury mines. However, it is important to note that fish tissue concentrations in all five reservoirs were higher than the Statewide Sport Fish Mercury Water Quality Objective.

Time-trend analyses were conducted for sport-size largemouth bass at each reservoir to compare the 2021 mercury concentrations against historical concentrations at a standardized length (350 mm). When comparing 2021 predicted concentrations at each reservoir against the standardized fish total mercury concentration for previous years, there were no consistent changes through time. For Camden Pond, Shadow Cliffs, and Soulajule reservoirs, the total mercury concentrations for 350 mm fish in 2021 were higher than concentrations from previous years. For both Camden and Soulajule Reservoirs, total mercury concentrations in 2021 were higher compared to historical data. In contrast, total mercury concentrations in 2021 for Calero and Lafayette Reservoirs were lower than in previous years, and these differences were also statistically significant. For Calero Reservoir, the decrease in total mercury concentration was attributed to cleanup of an upstream mine (SFBRWQCB, 2022). However, the reason for differences in total mercury concentrations across years at the other reservoirs require further investigation. Possible hypotheses to explore in the future are whether the differences in total mercury concentrations are due to interannual variation, changes in mercury bioaccumulation in the food web, or a combination of these factors.

This study also sampled and analyzed small fish, which can be a better indicator of short-term change in bioaccumulation and impacts to birds that eat prey fish. Remediation Effectiveness Indicators (REIs) are young-of-year largemouth bass to serve as biosentinel fish, meaning that they are sensitive changes in the food web before, during, and after treatment (e.g., oxygenation or aeration). In 2021, Calero REIs had much higher mercury concentrations than those in Camden Ponds or Lafayette Reservoir. We attempted to conduct time trend analyses for REI and prey fish at each reservoir. However, REI fish were only collected at Calero Reservoir, and there were no clear trends from 2004-2021. Regarding prey fish, Calero and Soulajule Reservoirs were the only

reservoirs with multiple years of data, and mercury concentrations consistently exceeded the Statewide Prey Fish Mercury water quality objective. For Lafayette Reservoir, the single prey fish composite sample was far below the water quality objective. Lastly, for Shadow Cliffs Reservoir, there were no consistent patterns in mercury concentrations in prey fish, some species were above the water quality objective while others were below. The variation in mercury concentrations among different prey fish species could possibly be explained by different feeding habits. This highlights the importance of collecting the same fish species at each location.

Details of this baseline mercury data set are provided in the following sections.

2 Introduction

2.1 Reservoirs sampled

Figure 1 provides a map and Table 1 provides a list of reservoirs included in this 2021 sampling.

Water Board staff selected these six reservoirs for mercury monitoring in 2021 primarily because they are already—or are potential future—pilot test sites to reduce fish mercury concentrations as part of the San Francisco Bay Regionwide Reservoir Mercury Management Program (Mercury Program). The State Water Resources Control Board's Safe to Eat Workgroup ("STEW") program was already paying for fish collection from Calero, Lafayette, Shadow Cliffs, and Soulajule Reservoirs. Hence, it was cost-effective to supplement their work with young-of-year largemouth bass and additional fish species that were previously collected (described in Section 1.4). Camden Percolation Pond previously had low mercury concentrations, so we wanted to confirm if Hg was still low and if so, consider what is unique about that water body compared to others in the Bay Area. After Table 1, we provide more information on why each of these reservoirs were selected.

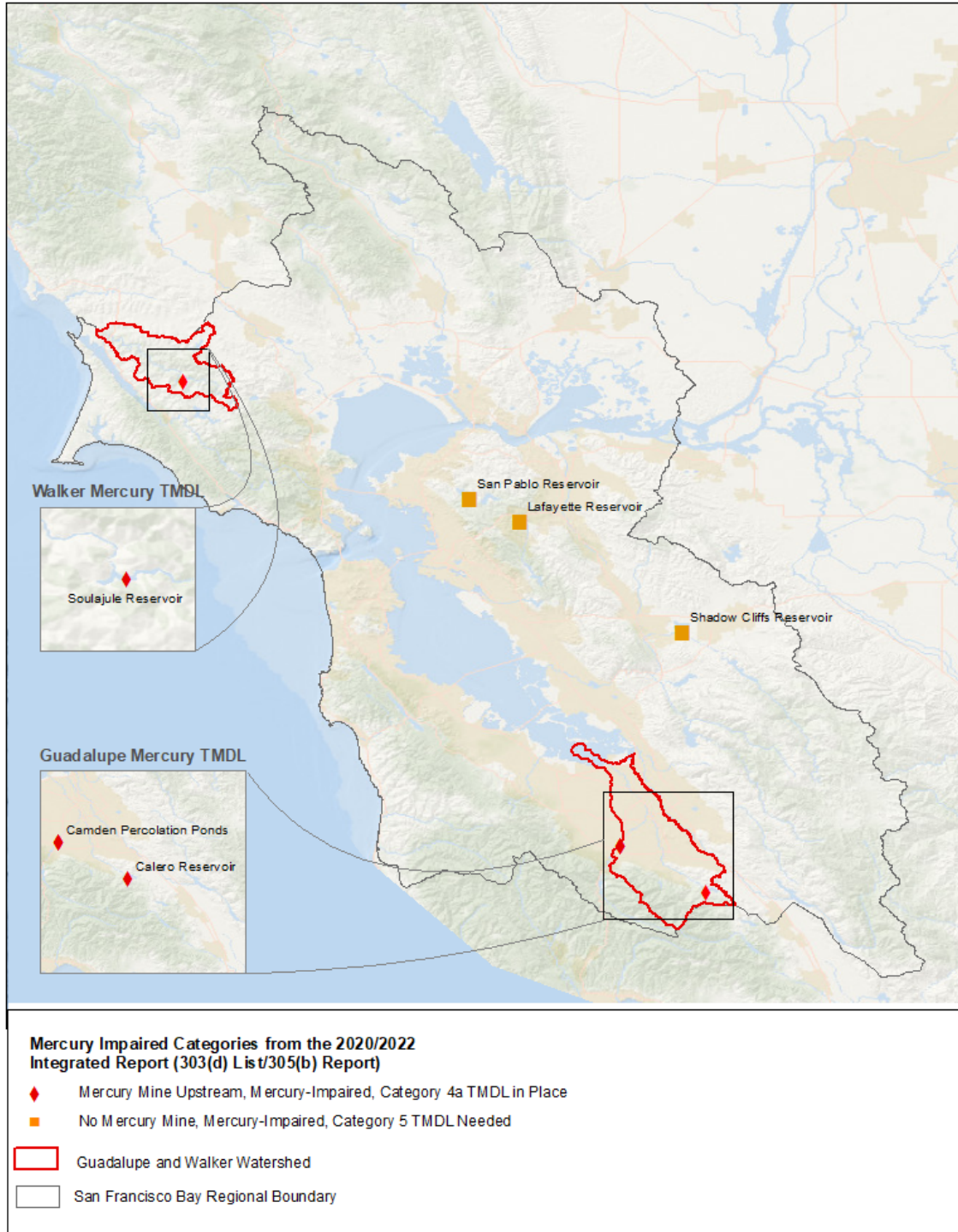


Figure 1. Map of Reservoirs Sampled in 2021

This report includes data from five reservoirs: Calero Reservoir, Camden Percolation Ponds, Lafayette Reservoir, Shadow Cliffs Reservoir, and SoulaJule Reservoir. Data for San Pablo Reservoir will be reported separately. The specific Camden Pond is Camden Percolation Pond below Los Gatos Creek Park #3 (37.26696, -121.95138).

Table 1. Reservoirs Sampled in 2021

Reservoir Name STEW station code Sample Date	County	Owner	Mercury- impaired	TMDL
Calero Reservoir 205PCR128 9/8/2021	Santa Clara	Valley Water	Yes	Guadalupe River Watershed Mercury TMDL
Camden Percolation Pond North 205CPP003 6/14/2021	Santa Clara	Valley Water	No	None
Lafayette Reservoir 207PLF001 9/15/2021	Contra Costa	East Bay Municipal Utility District	Yes	Region 2 Reservoir Mercury Management Program, Mercury TMDL Alt
Shadow Cliffs Reservoir 204PSC113 5/1/2021	Alameda	East Bay Regional Park District	Yes	Region 2 Reservoir Mercury Management Program, Mercury TMDL Alt
Soulajule Reservoir 201PSL093 5/10/2021	Marin	Marin Municipal Water District	Yes	Walker Creek Watershed Mercury TMDL

Calero

These 2021 data from Calero Reservoir will provide a robust data set for use in Valley Water’s assessment of their on-going hypolimnetic oxygenation pilot test ([see Valley Water website](#)). We have transmitted these 2021 data for Valley Water to use data for fish with tissue type, size, and species that matches their monitoring program in their 2022–2023 Biennial Report.

Camden

These 2021 data from the Camden Percolation Pond are for comparison to 2011 low fish mercury concentrations. We did not know why the pond had low mercury concentrations in 2011 or if these low concentrations were reproducible. This report compares the temporal trends for this site. In the future, as part of the Mercury Program, the next step will be to undertake a desktop analysis of available data to determine the factors why fish mercury concentrations increased between 2011 and 2021, and if any of these are controllable factors to achieve low fish mercury concentrations.

Lafayette

The purpose of these 2021 data from Lafayette Reservoir is to assemble a robust baseline dataset for the Mercury Program. Lafayette Reservoir is an optimal pilot test site for fisheries manipulation because it is not actively used for any purpose other than recreation, it rarely spills so fish can’t escape, and if it does spill it does not flow directly into creeks that support anadromous fish.

Shadow Cliffs

The purpose of these 2021 data from Shadow Cliffs Reservoir is to assemble a robust baseline dataset for the Mercury Program. Shadow Cliffs Reservoir is an optimal pilot test site for fisheries manipulation because it is not actively used for any purpose other than recreation and it does not spill, so fish can't escape. In addition, it is not upstream of a native salmonid population so the manipulation of fisheries in the lake are unlikely to have downstream impacts to a listed species. Water is pumped into the reservoir from Arroyo del Valle for the sole purpose of groundwater recharge. Shadow Cliffs Reservoir is adjacent to the Arroyo del Valle, a tributary to Alameda Creek; but the reservoir is not directly connected.

Soulajule

The purpose of these 2021 data from Soulajule Reservoir is to ensure a robust baseline dataset for the Water Board's Reservoir Mercury Management Program. In the future, these 2021 data can be used to conduct long-term trend analysis to compare with historical data. We note that Marin Municipal Water District (MMWD) contributed financially in 2020 and 2021 to a coordinated pilot test in San Pablo Reservoir. Currently, MMWD is working on various reports which can benefit from these 2021 data.

2.2 Methods and quality assurance

All fish collection and analysis was performed in accordance with STEW's [Long-term Monitoring Survey of Bass Lakes](#) sampling plan (June 2015) and quality assurance project plan (September 2017). Staff of the [Marine Pollution Studies Laboratory \(MPSL\)](#) of San Jose State University's Research Foundation collected the fish and performed the laboratory analysis. The fish collection report ("cruise report") is available [here](#).

Total mercury in fish tissue was analyzed by U.S. EPA method 7473 with reporting limit of 0.009 ug/g wet wt. for Camden and 0.01 ug/g wet wt. for all other locations. Mercury was not detected in one of ten individual sculpin prey from Shadow Cliffs Reservoir; there were no other laboratory quality assurance qualifiers. Total selenium was analyzed by U.S. EPA method 200.8M with reporting limit of 0.70 ug/g wet wt. Scales from sport-size black bass from Camden were used to age the fish following methods described by Campana, S.E., 2001. Scales from sport-size black bass from the other reservoirs were archived in the hopes of finding sufficient STEW funding in the future to analyze them.

2.3 Data and reports available on the internet

The State and Regional Water Boards ensure that our data and reports are publicly accessible. Each year, MPSL field staff summarize their STEW fish collection effort in a cruise report that is posted here: [Long-term Monitoring Survey of Bass Lakes](#). When MPSL is satisfied that their laboratory analysis meets or exceeds their quality standards, they submit their laboratory reports to the State Water Resources Control Board who perform a quality review and post approved data to the [California Environmental Data Exchange Network \(CEDEN\)](#). STEW contractors write up yearly and decadal data analysis reports and post them here: [Long-term Monitoring Survey of Bass Lakes](#).

2.4 Fish collected

STEW analysis includes mercury for all fish (individuals and composites), selenium for some composites in some locations, and age for individual sport-size black bass. STEW analyzes young fish whole and sport fish as skinless fillet.

The Water Board supplemented the STEW work with additional fish for mercury analysis using Regional SWAMP funds. At three reservoirs (Calero, Lafayette, and Shadow Cliffs), we supplemented the STEW work with young-of-year largemouth bass. At Soulajule, we supplemented the STEW work with both young-of-year largemouth bass and fish to match previously collected TMDL target fish. Lastly, at Camden, we collected sport largemouth bass and young-of-year largemouth bass. All supplemented fish were analyzed for total mercury as individual fish. Young fish were analyzed whole and sport fish as skinless fillet. Scales from sport black bass were analyzed for age.

We supplemented STEW with young-of-year largemouth bass to serve as biosentinel fish. Biosentinels are a useful measure of recent changes in methylmercury bioaccumulation. Characteristics of good biosentinel fish include that they are young and have high site fidelity, so that we know when and where they accumulated their mercury. We have previously used age-1 (young-of-year) largemouth bass, which have high site fidelity, as biosentinel “Remediation Effectiveness Indicators” (REIs) for the [Guadalupe River Watershed Mercury TMDL](#). We have also been using REIs in San Pablo Reservoir to test the effects of a hypolimnetic oxygenation system. Therefore, in 2021 we targeted collection of young-of-year largemouth bass for this supplemental work.

The fish categories for this work are the following:

- Prey100: whole fish, preferably 50–100 mm total length, species other than largemouth bass. STEW aims to collect prey fish in this size range, or down to as small as 25 mm, and they are analyzed as composites;
- REI: largemouth bass, whole fish, from 50-100 mm total length, and analyzed as individuals;
- Sport: skinless fillet, greater than 150 mm total length, and analyzed as individuals; and
- Other: some collected fish do not fit into any of the previous categories.

The site-specific mercury water quality objectives (WQO) for the Guadalupe River and Walker Creek Watersheds Mercury TMDLs apply to both Calero and Soulajule Reservoirs. The WQO category for this work is the following:

- WQO150: whole fish, 50–150 mm total length, species other than largemouth bass, and they are analyzed as composites. Both Calero and Soulajule have TMDL targets (equal to water quality objectives) for this size range.

The fish species and sample dates are listed on Table 2.

Table 2. Fish Collected in 2021 by Species, Category, and Waterbody

Species	Category	Calero	Camden	Lafayette	Shadow Cliffs	Soulajule
Black Crappie	Sport					10
Brown Bullhead	Sport					10
Channel Catfish	Sport				5	
Largemouth Bass	Sport	14	10	14	16	14
Rainbow Trout	Sport				10	
Largemouth Bass	REI	20	12	20		5
Bluegill	Prey				10	15
Crappie	Prey	2		10		
Green sunfish	Prey				10	
Sacramento Sucker	Prey				10	
Sculpin	Prey				10	10
Threadfin shad	Prey	10				
Sample Date		9/1/21	6/14/21	9/15/21	5/11/21- 5/12/21	5/10/21

Notes:

Table 2 is summarized from MPSTL’s 2021 cruise report and CEDEN. The two crappie prey from Calero were not analyzed because they are too few to form a composite.

Tissue: Sport fish are individual, skinless fillet; REI are individual, whole fish; Prey fish are composites of 10 whole fish.

Soulajule Reservoir is sometimes spelled “Soulejuoule Lake” in the SWAMP database and CEDEN.

3 2021 Fish Mercury Results

This section presents 2021 fish mercury results in order from largest to smallest fish (sport, REIs, and prey fish). Summary mercury data are provided on Table 3 at the end of this section and detailed results. All these data can be found on CEDEN using the station codes from Table 1.

These samples were also analyzed for selenium and will be only briefly discussed here. All but one selenium result was below the detection limit of 0.23 ug/g wet wt, which is well below the proposed EPA aquatic life criteria of 8.5 ug/g whole body or 11.3 ug/g skinless fillet. The exception being a prey fish composite of bluegill at Shadow Cliffs Reservoir at 0.28 ug/g wet wt.

3.1 Sport fish mercury concentrations

All sport fish are skinless fillets and the fish species collected were:

- Largemouth bass (individuals) collected from all 5 reservoirs;

- Channel catfish (composite) and rainbow trout (individuals) were collected from Shadow Cliffs Reservoir; and
- Black crappie and brown bullhead (composites) were collected from Soulajule Reservoir.

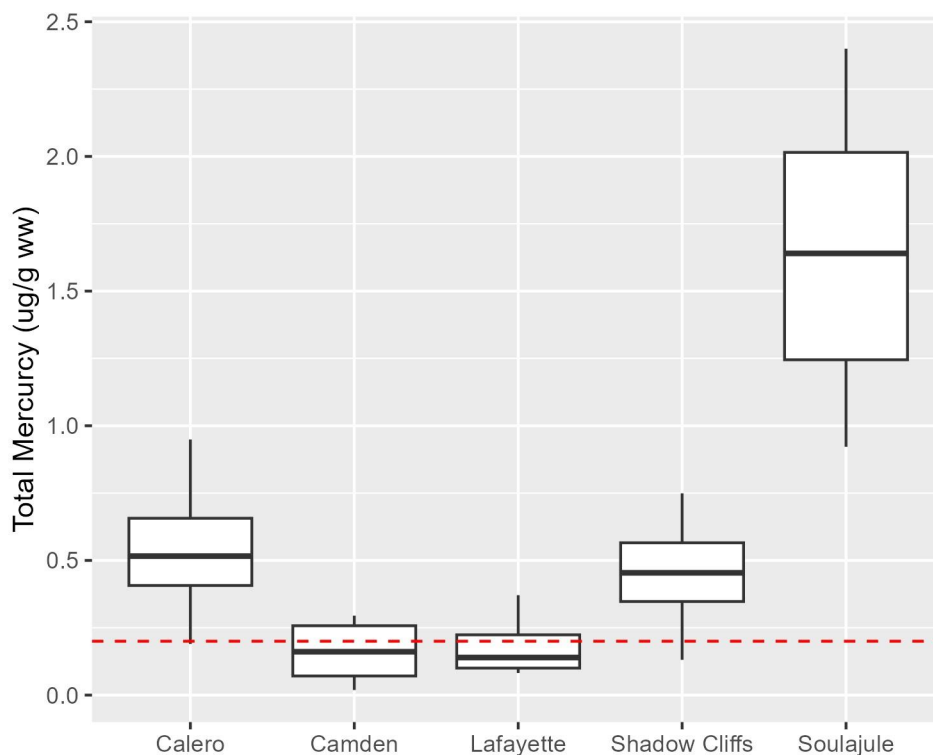


Figure 2. Boxplot of 2021 Sport-Size Largemouth Bass Mercury Concentrations by Reservoir

The dashed line is the Statewide Sport Fish Mercury Water Quality Objective (WQO) for trophic level 4 fish ranging from 200 to 500 mm in total length and is equal to 0.2 ug/g ww (WQO discussed in more detail in Section 3.4). This statewide sport fish WQO applies to Camden, Lafayette, and Shadow Cliffs Reservoirs. Although the trophic level 4 sport fish WQO does not officially apply to Calero or Soulajule Reservoirs, it is helpful to consider whether fish are safe to eat from those waterbodies because people do fish from those reservoirs.

In 2021, Soulajule Reservoir had much higher mercury concentrations in sport-size largemouth bass than the other reservoirs. The second highest mercury concentrations were observed at Calero Reservoir. These results were expected as both Soulajule and Calero Reservoir are impacted by upstream mercury mines. However, each reservoir sampled contained fish samples above the Statewide Sport Fish Mercury WQO.

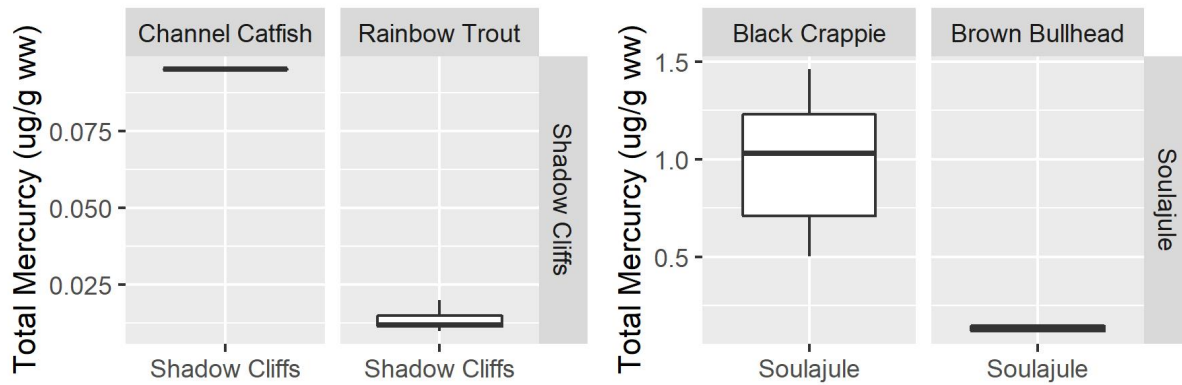


Figure 3. Boxplot of Additional 2021 Sport Fish Mercury Concentrations by Species and Reservoir

Note change in scale of the vertical axis between reservoirs.

For Shadow Cliffs Reservoir, the channel catfish had higher mercury concentrations than the rainbow trout. This is expected as channel catfish are trophic level 4 fish, while rainbow trout are trophic level 3 fish and are also stocked, so the fish have little time to bioaccumulate mercury. Both these species' mercury concentrations were below any levels of environmental concern per the statewide mercury objectives. For Soulajule Reservoir, the black crappie had higher mercury concentrations than the brown bullhead. Like Shadow Cliffs, this difference can partially be explained due to black crappie being trophic level 4 fish while brown bullhead are trophic level 3 fish. It is important to note that the black crappie from Soulajule Reservoir have mercury concentrations nearly as high as largemouth bass (See Figure 2).

3.2 REI fish mercury concentrations

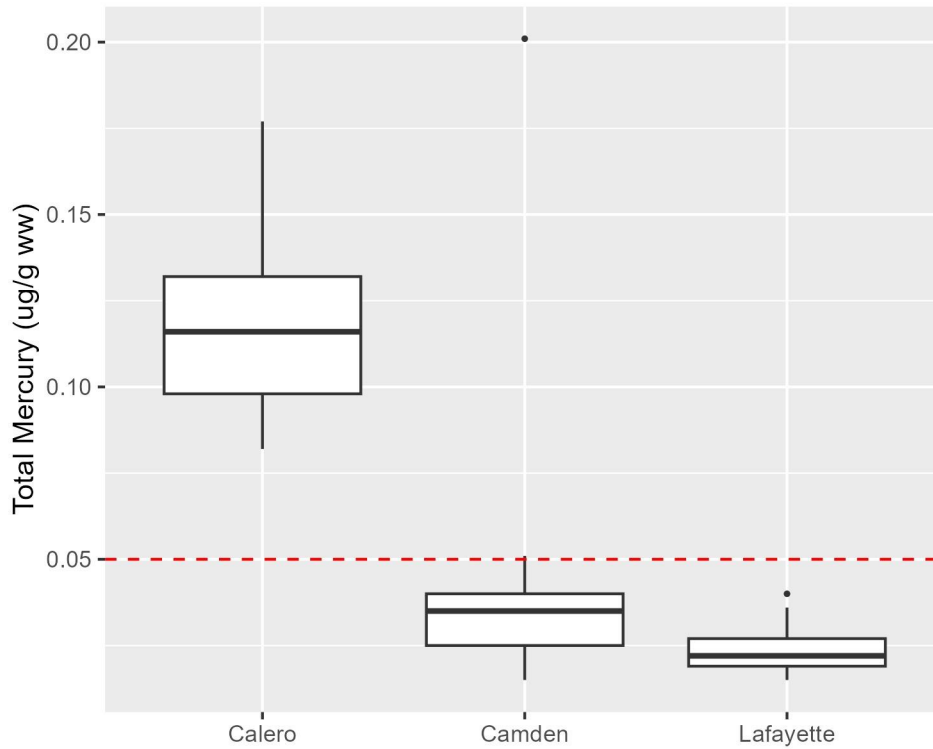


Figure 4. Boxplot of 2021 REI Fish Mercury Concentrations by Reservoir

REIs are whole largemouth bass from 50–100 mm, except that the smallest fish from Lafayette Reservoir was 47 mm (see Table 3). Although we intended to collect REIs from all 5 reservoirs, none were found in Shadow Cliffs or Soulajule Reservoirs. The dashed line is the Statewide Prey Fish Mercury WQO which protects birds who consume prey fish between 50 to 150 mm total length and is equal to 0.05 ug/g ww (WQO discussed in more detail in Section 3.4). The dashed line also represents the methylmercury target for the Guadalupe River Watershed Mercury Total Maximum Daily Load that applies to prey fish 50-150 mm in length and protects aquatic organisms and wildlife.

REIs are biosentinels first established for the [Guadalupe River Watershed Mercury Total Maximum Daily Load](#) (Guadalupe TMDL) to facilitate comparison of before-and-during treatment. We expect REIs to be useful for the Water Board’s Reservoir Mercury Management Program. Calero REIs have much higher mercury concentrations than Camden or Lafayette, as expected and likely due to upstream mercury mines.

3.3 Prey fish mercury concentrations

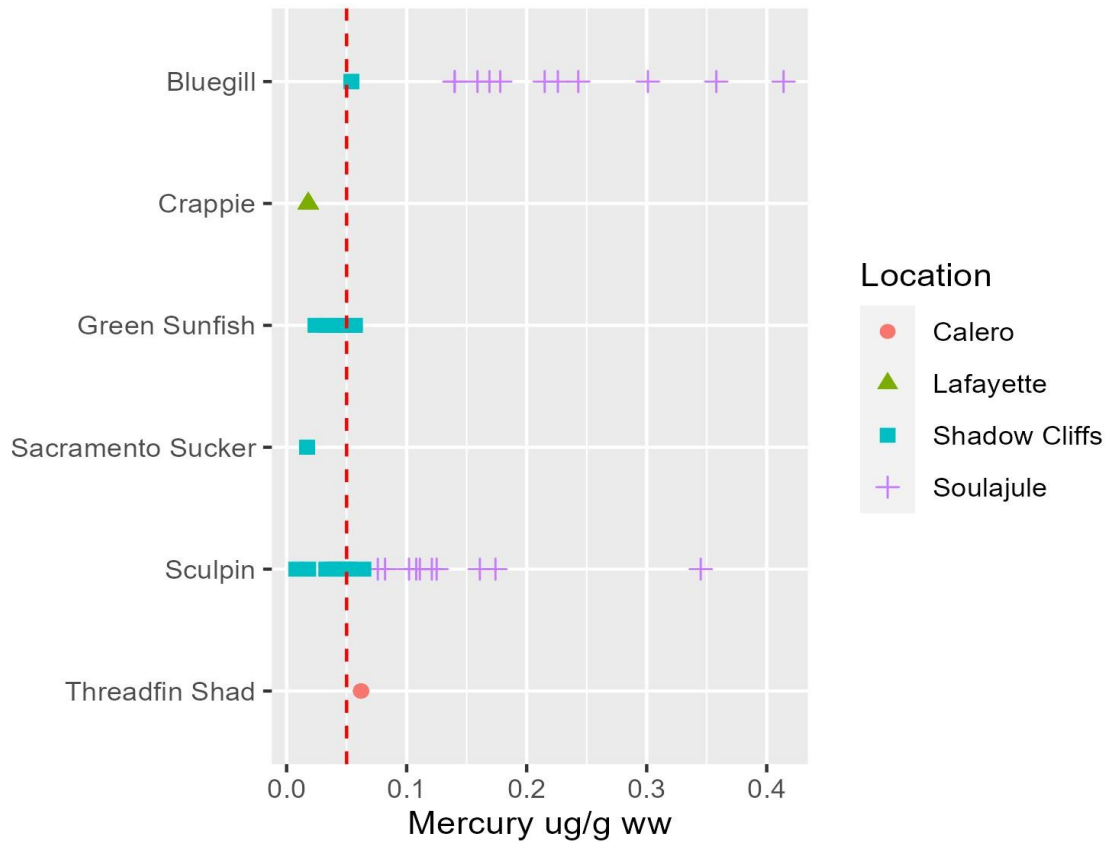


Figure 5. Scatterplot of 2021 Prey Fish Mercury Concentrations by Species and Reservoir

Prey fish are whole fish from 50–100 mm total length, except some of the bluegill, Sacramento sucker, and sculpin from Shadow Cliffs Reservoir were smaller (see Table 3). Crappie, Sacramento sucker, and threadfin shad were analyzed as composites of 10 fish. Bluegill, green sunfish, and sculpin were analyzed individually. The dashed line represents the Statewide Prey Fish WQO (applies to Lafayette and Shadow Cliffs) and the Walker Creek (applies to Soulagule) and Guadalupe River WQOs (applies to Calero).

Both bluegill and sculpin were collected from Shadow Cliffs and Soulagule Reservoirs; Soulagule prey fish had higher mercury concentrations than Shadow Cliffs.

Table 3. Summary of 2021 Fish Mercury Data

Location	Category	WQO	Common Name	n	Mercury (ug/g wet wt.) Mean	Total Length (mm) Minimum	Total Length (mm) Maximum
Calero	Prey100	WQO150	Threadfin Shad	10	0.062	60	68
Calero	REI		Largemouth Bass	20	0.12	56	99
Calero	Sport		Largemouth Bass	14	0.51	214	475
Camden	REI		Largemouth Bass	12	0.046	51	98
Camden	Sport		Largemouth Bass	10	0.17	190	420
Lafayette	Prey100		Crappie	10	0.018	68	89
Lafayette	REI		Largemouth Bass	20	0.023	47	69
Lafayette	Sport		Largemouth Bass	14	0.17	245	488
Shadow Cliffs	Prey100		Bluegill	10	0.054	48	67
Shadow Cliffs	Prey100		Green Sunfish	10	0.041	52	98
Shadow Cliffs	Prey100		Sacramento Sucker	10	0.017	36	43
Shadow Cliffs	Prey100		Sculpin	10	0.041	46	88
Shadow Cliffs	Sport		Channel Catfish	5	0.10	442	631
Shadow Cliffs	Sport		Largemouth Bass	14	0.43	160	462
Shadow Cliffs	Sport		Rainbow Trout	10	0.013	315	461
Shadow Cliffs	Other		Largemouth Bass	2	0.13	136	136
Soulajule	Prey100	WQO150	Bluegill	10	0.24	54	75
Soulajule	Prey100	WQO150	Sculpin	10	0.14	62	85
Soulajule	Sport		Black Crappie	10	1.00	196	269
Soulajule	Sport		Brown Bullhead	10	0.13	204	368
Soulajule	Sport		Largemouth Bass	14	1.71	239	472
Soulajule	Other		Largemouth Bass	5	0.43	103	132
Soulajule	Other	WQO150	Bluegill	5	0.18	106	149

3.4 Comparison of 2021 fish mercury concentrations to water quality objectives

The [Statewide Sport Fish Mercury Water Quality Objective](#) (WQO) protects humans who consume locally caught fish. It also protects most birds. Calendar year mean fish mercury should not exceed 0.2 ug/g wet wt. The sport fish WQO applies to the highest trophic level in skinless fillet. These reservoirs all have trophic level 4 sport fish, for which the WQO size ranges between 200 to 500 mm in total length. This statewide sport fish WQO applies to Camden, Lafayette, and Shadow Cliffs Reservoirs. The objective does not apply to Calero or Soulajule Reservoirs because those water bodies have site-specific objectives per respective TMDLs, but this threshold still provides a helpful statewide comparison point.

The [Statewide Prey Fish Mercury](#) WQO protects birds who consume prey fish between 50 to 150 mm total length. Calendar year mean fish mercury should not exceed 0.05 ug/g wet weight (wet wt.) during the bird breeding season (generally February 1 through July 31). The statewide WQO applies to Camden, Lafayette and Shadow Cliffs Reservoirs. Not coincidentally, the site-specific mercury WQO for this size of prey fish for both the Guadalupe River and Walker Creek watersheds is also 0.05 ug/g wet wt. and applies to Calero and Soulajule Reservoirs. This site-specific objective was established as part of the respective TMDLs in each watershed.

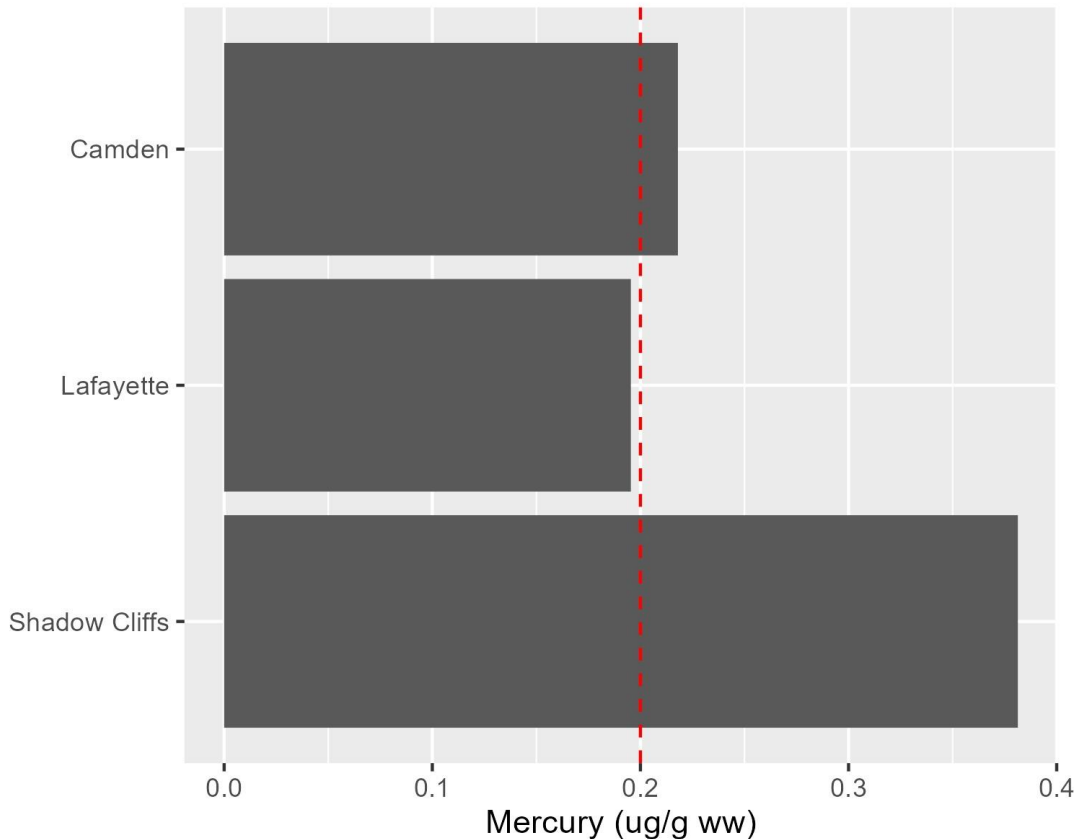


Figure 6. Bar Chart of Mean 2021 Sport Fish Mercury Concentrations Compared to Statewide Sport Fish WQO

The [Statewide Sport Fish Mercury](#) WQO (shown in the vertical red line) applies to the highest trophic level of sport fish, skinless fillet. These three reservoirs all have trophic level 4 fish, for which the WQO size range is between 200 to 500 mm total length or adjusted for legal catch size restrictions. Largemouth bass were collected from all 3 reservoirs; ranging between legal size minimum of 304 to less than 500 mm total length;

and were analyzed individually. Channel catfish were collected from Shadow Cliffs and are not included because 4 of 5 fish in the composite are longer than 500 mm. Rainbow trout were the only trophic level 3 sport fish species and are not included.

Mean mercury in both Camden Pond and Shadow Cliffs Reservoir exceeds the sport fish WQO, but not in Lafayette Reservoir.

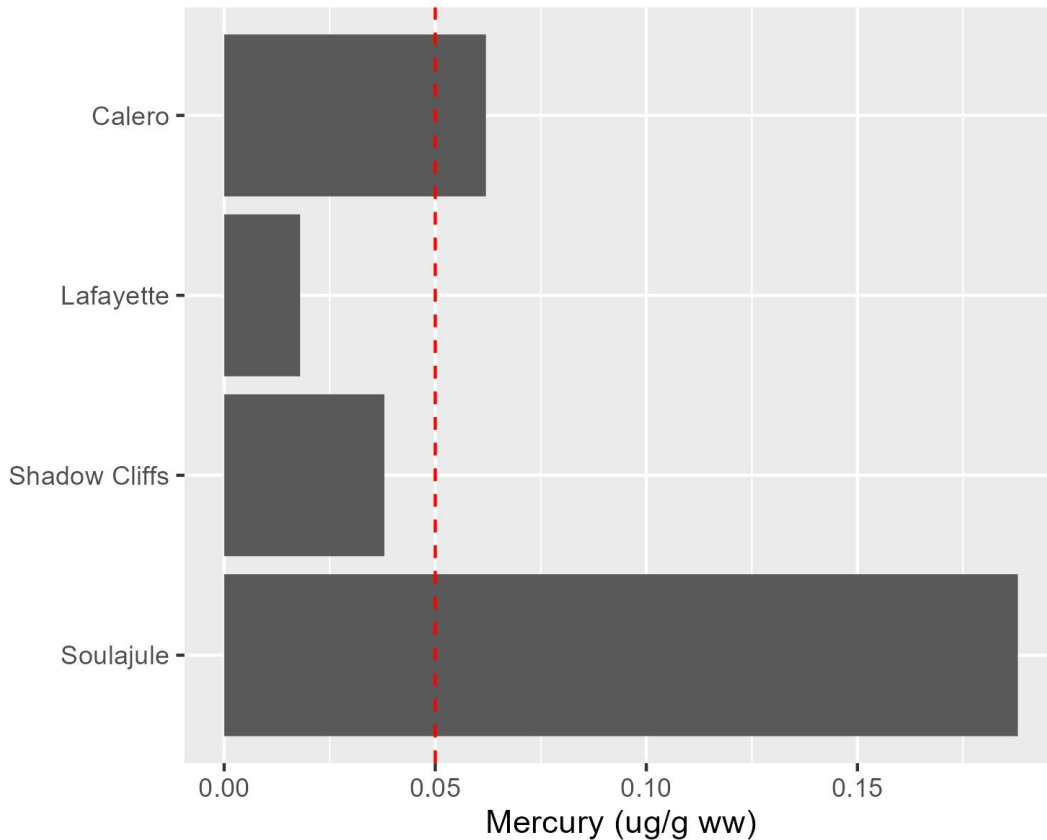


Figure 7. Bar Chart of Mean 2021 Prey Fish Mercury Concentrations Compared to Statewide Prey Fish WQO

These are the mean mercury concentrations for the fish included in Figure 5. The red vertical line is both the [Statewide Prey Fish Mercury](#) WQO and the site-specific mercury WQO for this size of prey fish which applies to the Guadalupe River and Walker Creek watersheds. Only Shadow Cliffs and Soulajule prey fish were collected during the bird breeding season (generally February 1 through July 31). Calero and Lafayette were sampled after the end of that window, but we still find the data appropriate to analyze as described below.

Data are available in Calero Reservoir to investigate possible differences in prey fish mercury concentrations between samples collected during or outside the breeding season. Of the 14 prey fish samples collected from 2011-2021 in Calero, the four samples collected during the breeding season had a mercury concentration of 0.134 ± 0.0333 ug/g, and the 10 collected outside the breeding season had a mercury concentration of 0.114 ± 0.0346 ug/g. Although the sample size is small, and only for Calero Reservoir, the small differences in these results suggest that these samples are from the same underlying population, so it is appropriate in our assessment to compare data collected outside the breeding season to the water quality objective.

Calero and SoulaJule Reservoirs are directly affected by historical mercury mines and are subject to the Guadalupe River and Walker Creek Watershed mercury TMDLs, respectively. Therefore, it is not surprising that their prey fish mercury concentrations are higher than the other reservoirs. These fish from SoulaJule Reservoir were collected during the bird breeding season and greatly exceed the applicable prey fish mercury WQO.

4 Time Trends in Fish Mercury Concentrations

In this section we compared 2021 fish mercury concentrations to previous years, for available data. The method that we used to evaluate time trends requires developing the linear relationship between total mercury concentration and fish size for a given fish species. For each reservoir investigated, we then can evaluate how this relationship changes through time and compare total mercury tissue concentrations at a standardized fish length (350 mm) across years based on the year-specific concentration vs. size regression relationships.

The first step of the time trends analysis is to confirm that there is a statistically significant (i.e., slope is statistically different from zero) linear relationship between mercury concentration and fish size. A non-significant slope indicates that fish size is not a strong predictor of tissue concentration and that there are other factors determining mercury concentration. Once we have developed the linear relationships between concentration and size, we can then account for the concentration variance with size by comparing mercury concentrations predicted by the regressions at a standardized length of 350 mm.

The concentration versus size regressions reveals three basic ways for differences to appear between fish mercury concentrations at a standardized length. First, the regression slopes can be similar across data sets, but there are different y-intercepts. This would indicate that there is more mercury at the bottom of the food web, but the bioaccumulation with increasing size is similar in the two data sets. Second, the regressions may have similar y-intercepts, but the slopes can be different. This would indicate that the mercury at the bottom of the food web is similar (e.g., across years), but specific features in the food web are different across years and are causing either a more rapid or slower bioaccumulation with increasing size. Third, the regressions could have both different slopes and y-intercepts, indicating differing amounts of mercury at base of the food web as well as different food web properties. By comparing regression slopes and y-intercepts across data sets, we can gain insights into how the food webs may differ, and this information complements the information revealed through the comparison of regression predictions at a standard fish size of 350 mm.

4.1 Sport-size largemouth bass length-to-mercury over time

The STEW program has extensively documented that mercury concentrations in sport-size largemouth bass are positively correlated with age and length. Hence, we provide mercury concentration versus length data plots with superimposed linear regression lines shown by year. These plots facilitate comparison by years over a range of fish sizes.

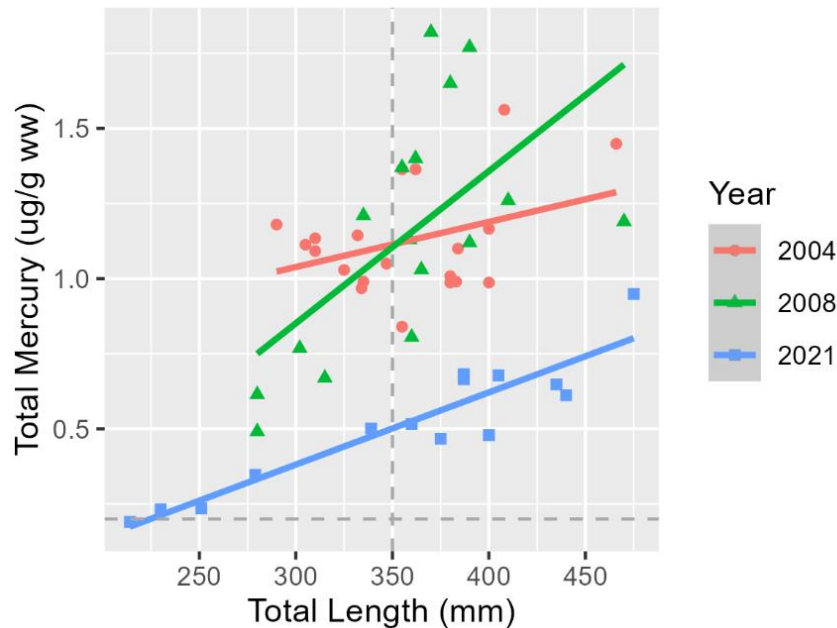


Figure 8. Total Mercury (ug/g ww) versus Total Length (mm) for Sport-size Largemouth Bass in Calero Reservoir

Fish were collected in 3 years (2004, 2008, and 2021) and had markedly lower mercury concentrations in 2021 compared to prior years. The dashed vertical line facilitates comparison at STEW's standardized fish length of 350 mm and the horizontal dashed line shows the statewide sport fish mercury WQO (although this WQO does not apply to Calero or Soulajule Reservoirs).

In 2004, the slope of the linear model was not statistically significant (p -value=0.12, R^2 =0.13). For 2008 (p -value=1.17e-02, R^2 =0.37) and 2021 (p -value=2.01e-06, R^2 =0.86) the slopes of both linear models were statistically significant. However, there are no statistically significant differences when comparing the slopes for the years shown: 2004 and 2008 (p -value=0.072), 2004 and 2021 (p -value=0.33), and 2008 and 2021 (p -value=0.10).

In Calero Reservoir, sport-size largemouth bass had markedly lower mercury concentrations in 2021 compared to prior years (2004 and 2008). A method from Rees and Henry (1988)¹ was used to test the statistical significance (at α =0.05) of the differences between the year-to-year predicted total mercury concentrations at STEW's standardized fish length of 350 mm. When comparing the predicted total mercury concentration at STEW's standardized fish length of 350 mm, the standardized fish total mercury concentration for 2021 (0.5011 ± 0.1885 ug/g ww, predicted

¹ D. G. Rees and C. J. K. Henry. (1988). On Comparing the Predicted Values from Two Simple Linear Regression Lines. *Journal of the Royal Statistical Society. Series D (The Statistician)*. Vol. 37, No. 3 (1988), pp. 299-306.

mercury concentration_{350mm} ± 95% prediction interval²) was lower than both the total mercury concentration for 2008 (1.1046 ± 0.7311 ug/g ww) and 2004 (1.1138 ± 0.3756 ug/g ww). The difference between the predicted total mercury concentrations for 2004 and 2008 was not statistically significant (p-value=0.94), while the differences between the predicted total mercury concentrations for 2004 and 2021 (p-value<.0001) and 2008 and 2021 (p-value<.0001) were both statistically significant. Water Board staff attributes this improvement primarily to cleanup of an upstream mine³.

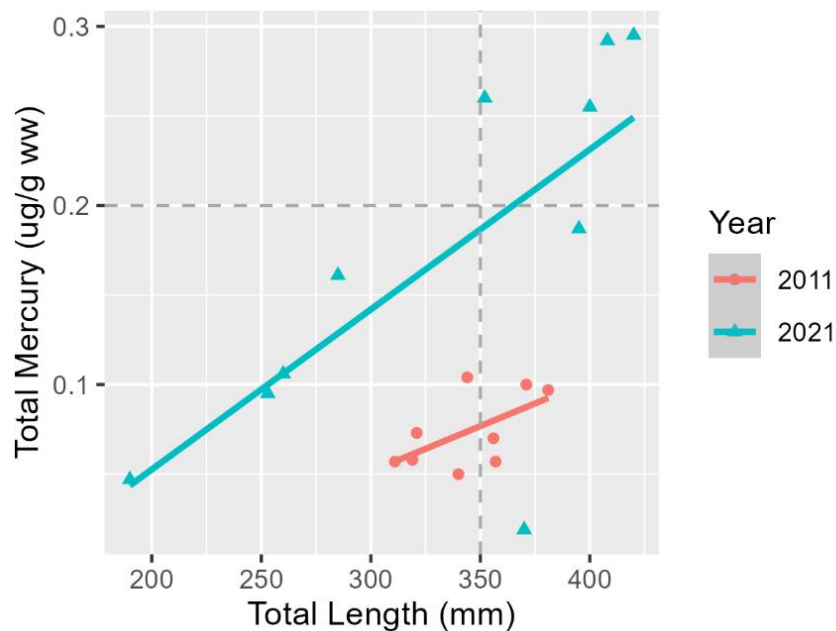


Figure 9. Total Mercury (ug/g ww) versus Total Length (mm) for Sport-size Largemouth Bass in Camden Pond

All fish were collected from “Camden Percolation Pond below Los Gatos Creek Park #3.” Fish were collected in 2011 and 2021. The dashed lines are to facilitate comparison at STEW’s standardized fish length of 350 mm and the statewide sport fish mercury WQO.

In 2011, the slope of the linear model was not statistically significant (p-value=0.1, R²=0.34). For 2021, the slope of the linear model was statistically significant (p-value=0.002, R²=0.49). However, there is no statistically significant difference between the regression slopes for 2011 and 2021 (p=0.67).

² A prediction interval is an estimated range of values that may contain the value of a single new observation, based on previous data. Prediction intervals need to account for the variability within the estimated mean that is present in every prediction and must also account for the estimated variance of the model and the variance of the outcome variable to provide an accurate measure of uncertainty.

³ See report posted to the [Guadalupe Mercury TMDL website](#), “Ten Year Implementation Status of the Guadalupe River Watershed Mercury Total Maximum Daily Load.”

In Camden Pond, sport-size largemouth bass had markedly higher mercury concentrations in 2021 compared to 2011, for unknown reasons. When comparing the predicted total mercury concentration at STEW's standardized fish length of 350 mm, the total standardized fish mercury concentration for 2021 (0.1866 ± 0.1873 ug/g ww) was substantially higher than the total mercury concentration for 2011 (0.0768 ± 0.046 ug/g ww). The difference between these predicted total mercury concentrations was statistically significant (p -value=0.01).

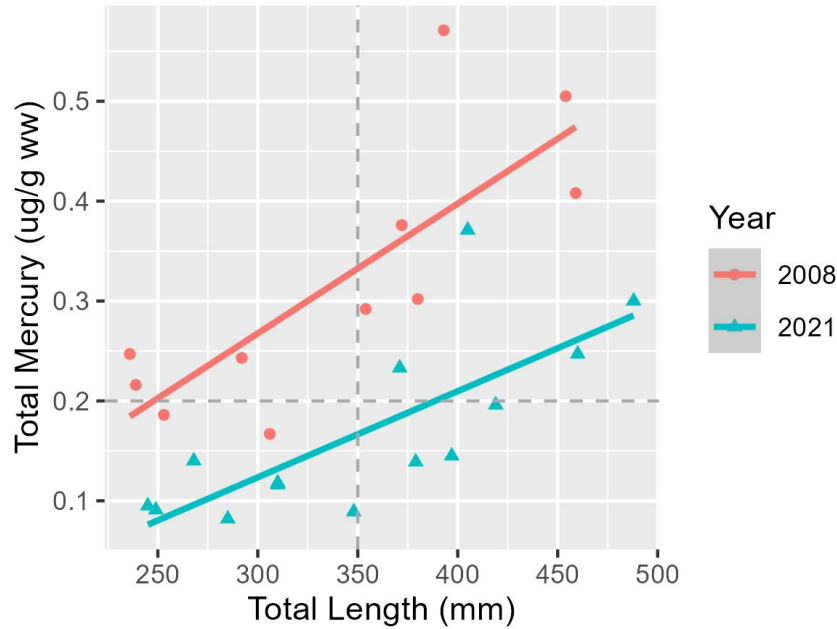


Figure 10. Total Mercury (ug/g ww) versus Total Length (mm) for Sport-size Largemouth Bass in Lafayette Reservoir

Fish were collected in 2008 and 2021. The dashed lines are to facilitate comparison at STEW's standardized fish length of 350 mm and the statewide sport fish mercury WQO.

In Lafayette Reservoir, sport-size largemouth bass had lower mercury concentrations in 2021 compared to 2008, for unknown reasons. For 2008 (p -value=0.003, $R^2=0.63$) and 2021 (p -value=0.002, $R^2=0.57$) the slopes of both linear models were statistically significant. The difference between the regression slopes for 2008 and 2021 is not statistically significant (p -value=0.26). When comparing the predicted total mercury concentration at STEW's standardized fish length of 350 mm, the standardized total mercury concentration for 2021 (0.1666 ± 0.1372 ug/g ww) was substantially lower than the standardized total mercury concentration for 2008 (0.3326 ± 0.1983 ug/g ww). The difference between these predicted total mercury concentrations was statistically significant (p -value=0.001).

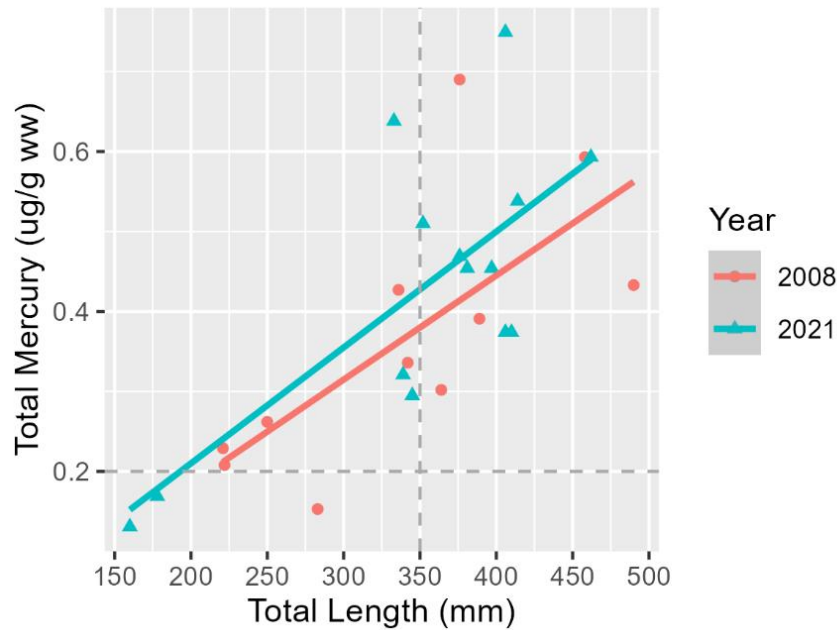


Figure 11. Total Mercury (ug/g ww) versus Total Length (mm) for Sport-size Largemouth Bass in Shadow Cliffs Reservoir

Fish were collected in 2008 and 2021. The dashed lines are to facilitate comparison at STEW's standardized fish length of 350 mm and the statewide sport fish mercury WQO.

In Shadow Cliffs Reservoir, both slopes of the linear models for 2008 (p-value=0.015, R²=0.50) and 2021 (p-value=0.0035, R²=0.52) were statistically significant. The difference between the regression slopes for 2008 and 2021 is not statistically significant (p-value=0.81). When comparing the predicted total mercury concentration at STEW's standardized fish length of 350 mm, the standardized total mercury concentration for 2021 (0.4274 ± 0.2795 ug/g ww) was slightly higher than the standardized total mercury concentration for 2008 (0.3799 ± 0.289 ug/g ww), but the difference was not statistically significant (p-value=0.50).

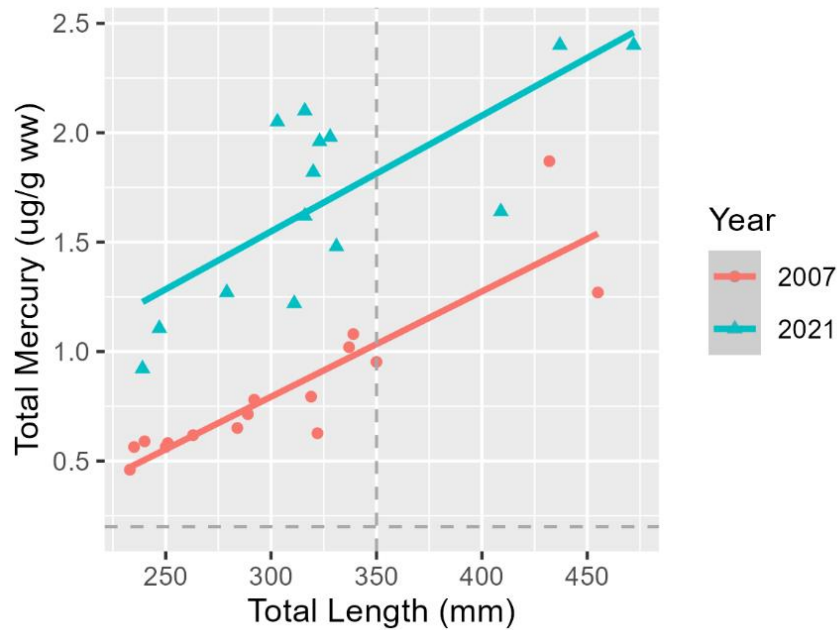


Figure 12. Total Mercury (ug/g ww) versus Total Length (mm) for Sport-size Largemouth Bass in Souljule Reservoir

Fish were collected in 2007 and 2021. The dashed lines are to facilitate comparison at STEW's standardized fish length of 350 mm and the statewide sport fish mercury WQO (although this WQO does not apply to Calero or Souljule Reservoirs).

In Souljule Reservoir, sport-size largemouth bass had markedly higher mercury concentrations in 2021 compared to 2007, for unknown reasons. The slopes of both linear models were statistically significant: 2007 ($p\text{-value} < .0001$, $R^2 = 0.80$), and 2021 ($p\text{-value} = 0.002$, $R^2 = 0.56$). The difference in the regression slopes for 2007 and 2021 is not statistically significant ($p\text{-value} = 0.74$). When comparing the predicted total mercury concentration at STEW's standardized fish length of 350 mm, the standardized total mercury concentration for 2021 (1.8136 ± 0.7303 ug/g ww) was higher than the standardized total mercury concentration for 2007 (1.0342 ± 0.3737 ug/g ww). The difference between these predicted total mercury concentrations was statistically significant ($p\text{-value} = 0.0001$).

4.2 REI fish mercury concentrations over time

Previously, REI fish were only collected from Calero Reservoir.

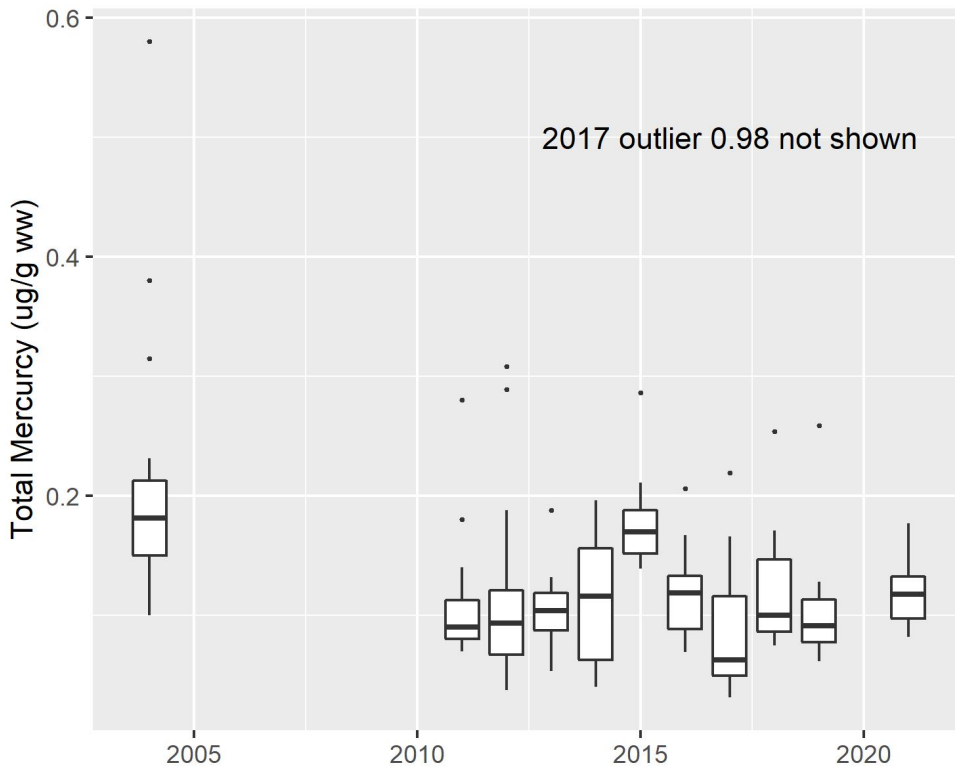


Figure 13. Boxplot of Annual REI Fish Mercury Concentrations in Calero Reservoir

Data from 2004 were collected for the Guadalupe Mercury TMDL Conceptual Model. Data from 2011 to 2019 were collected by Valley Water. 2021 data were collected for the Water Board. This figure omits one extreme value (from 2017 of 0.98 ug/g ww) to facilitate comparison of the boxes.

In Calero Reservoir, when adjusted for the dry season (only considering samples collected between July 15-September 15, not shown here) fish had statistically significantly lower mercury concentrations in 2021 compared to prior years. Water Board staff attribute this improvement to cleanup of an upstream mine. Statistics and further explanation are provided in a separate report⁴.

4.3 Prey fish mercury concentrations over time

Prey fish mercury concentrations at Calero and Soulajule Reservoirs consistently exceed the mercury WQO of 0.05 ug/g ww (Figure 14), as expected because these reservoirs are polluted by mercury mines. The Guadalupe and Walker Creek prey fish WQOs for comparison to 2021 apply

⁴ See section 6.2 in the report posted to the [Guadalupe Mercury TMDL website](#), "Ten Year Implementation Status of the Guadalupe River Watershed Mercury Total Maximum Daily Load."

to trophic level 3 fish. Therefore, largemouth bass are not included in Figure 14 because they are considered trophic level 4 fish.

Prior to 2021, prey fish were not sampled from Camden Pond, Lafayette Reservoir, or Shadow Cliffs Reservoir, therefore time trends could not be evaluated. However, we can investigate concentration patterns across species by comparing the 2021 prey fish data from Lafayette and Shadow Cliffs Reservoirs to the Statewide Prey Fish WQO which applies to all trophic levels of fish (Figure 15). Based on the data available, we are unable to see consistent patterns in mercury concentrations among the different prey species. For Lafayette Reservoir, the single crappie composite was far below the Statewide Prey Fish WQO. For Shadow Cliffs Reservoir, the bluegill composite was slightly above the Statewide Prey Fish WQO, while the Sacramento sucker composite was far below the WQO. In addition, there are a few green sunfish and sculpin that fall above the WQO but there are no consistent concentration patterns. The variation in mercury concentrations among different prey fish species could possibly be explained by different feeding habits. This highlights the importance of collecting the same fish species at each location.

Valley Water provides extensive analysis of prey fish mercury data that accounts for season of collection (they have often collected fish more than once per year) and other factors that influence prey fish mercury concentrations. We have provided Valley Water with the 2021 prey fish data for Calero Reservoir so they can include the results in their long-term trend analysis in their 2022-2023 Biennial Report.

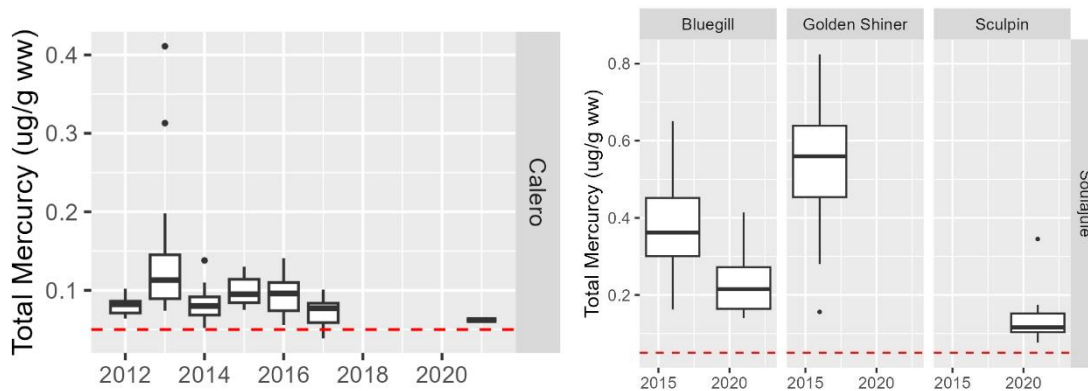


Figure 14. Comparison of Annual Prey Fish Mercury Concentrations in Calero and Soulajule Reservoirs Over Time

Note change in scale of vertical axis between Calero (left) and Soulajule (right) Reservoirs. These data conform to the WQO: trophic level 3 fish species and range of total length from 50 to 150 mm. In Calero, all data are for bluegill except threadfin shad in 2021.

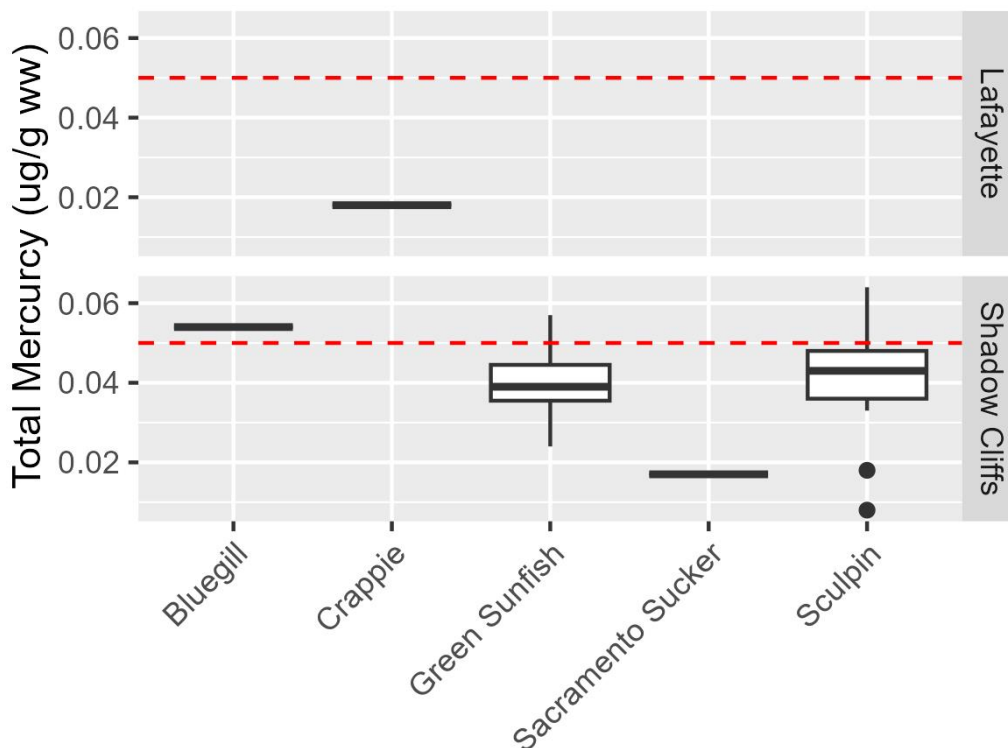


Figure 15. Boxplot of 2021 Prey Fish Mercury Concentrations for Lafayette and Shadow Cliffs Reservoirs (prey fish data prior to 2021 were unavailable)

Notes: For both Lafayette and Shadow Cliffs Reservoirs, there was no prey fish data available prior to 2021. For Lafayette Reservoir, crappie (composite of n=10) has a Hg concentration of 0.018 ug/g ww, which is below [Statewide Prey Fish Mercury](#) WQO of 0.05 ug/g ww (red horizontal line). For Shadow Cliffs Reservoir, there are a few green sunfish and sculpin that fall above the Prey Fish Mercury WQO. Bluegill (composite of n=10) has a mean Hg concentration of 0.054 ug/g ww which is slightly above the Statewide Prey Fish Mercury WQO. Lastly, Sacramento sucker (composite of n=10) has a mean Hg concentration of 0.017 ug/g ww which is far below the Prey Fish Mercury WQO.

5 Discussion and Conclusions

5.1 2021 Sport Fish, REI, and Prey Fish

In 2021, Soulajule Reservoir had much higher mercury concentrations (mean) in sport-size largemouth bass (1.67 ug/g) than the other four reservoirs sampled. The second highest mercury concentrations in sport-size largemouth bass were observed in Calero Reservoir (0.52 ug/g), Shadow Cliffs (0.45 ug/g), Camden (0.19 ug/g), and Lafayette (0.17 ug/g). Although REI fish were intended to be collected at all reservoirs, none were successfully caught in Shadow Cliffs or Soulajule Reservoirs. When comparing mercury concentrations in REI fish (50-150mm largemouth bass), Calero Reservoir had higher mercury concentrations (0.12 ug/g) than Camden (0.04 ug/g) or Lafayette Reservoirs (0.02 ug/g). There were only two reservoirs (i.e., Soulajule and Shadow Cliffs) in which the same prey fish species were collected (i.e., bluegill and sculpin) in 2021. For both prey fish species, Soulajule had higher mercury concentrations (0.19 ug/g) than Shadow Cliffs (0.05 ug/g).

For all 2021 data, either Soulajule or Calero Reservoirs had higher mercury concentrations than the other reservoirs in all the different size categories (sport, REI, and prey). Both Calero and Soulajule Reservoirs are affected by mercury mines, so it is not surprising that their fish mercury concentrations are higher than the other reservoirs included in this report.

5.2 Time Trends

There were no consistent temporal trends in mercury over time across these five reservoirs. The predicted total mercury concentration at STEW's standardized fish length of 350 mm was used to compare mercury concentrations in sport-size largemouth bass at each reservoir. At Camden Pond and Soulajule reservoirs mercury concentrations significantly increased from previous years. In contrast, there was no significant change in mercury sport fish concentrations from Shadow Cliffs Reservoir. These increases in predicted total mercury concentrations at Camden and Soulajule Reservoirs require further investigation.

In contrast, predicted total mercury concentrations in 2021 for Calero and Lafayette Reservoirs were significantly lower than previous years. For Calero Reservoir, the decrease from 2004 to 2021 in predicted total mercury concentration was attributed to cleanup of an upstream mine. In Lafayette Reservoir, the decrease from 2008 to 2021 in predicted total mercury concentration needs further investigation. The large change in baseline conditions of largemouth bass at Lafayette are seen as a limitation in this being a good study site for the Mercury Program.

Lastly, time trend analyses were also conducted for REI and prey fish at each reservoir. However, REI fish were only collected at Calero Reservoir and there were no clear trends from 2004-2021. Regarding prey fish, mercury concentrations consistently exceed the mercury Water Quality Objective in Calero and Soulajule Reservoirs. This is expected because both reservoirs are impacted by mercury mines. Unfortunately, prey fish were not sampled at Camden Pond, Lafayette Reservoir, and Shadow Cliffs Reservoir in the past, therefore time trends could not be evaluated.

5.3 Future Work

The purpose of fish mercury sampling in these five reservoirs was to obtain robust mercury data to support the Mercury Program. Generally, reservoirs impacted by mercury mines (e.g., Calero and Soulajule Reservoirs) continue to have higher mercury concentrations in all fish sizes (sport, REI, and prey) than reservoirs not impacted by mercury mines, meaning that our past decisions to focus TMDL development and implementation at those reservoirs was a good decision. However, one of the largest data gaps that exists when comparing reservoirs impacted by mercury mines to reservoirs without mercury mines, is the extent of the dataset. As shown in this report, a comparison of REI and prey fish mercury concentrations among the various reservoirs was unable to be conducted due to the limited historical data. Despite seeing lower concentrations in reservoirs not impacted by mercury mines, we observed both significant increases and decreases in reservoirs with no known manipulation. We take this result to be evidence of strong interannual variability occurring in sport fish over 5-15 years and thus leads us to conclude that it is imperative to collect multiyear datasets prior to evaluating the effect of any large-scale action to affect mercury bioaccumulation within reservoirs.

In order to continue assembling a robust baseline mercury dataset to support the Mercury Program, additional fish data are needed in all size categories (i.e., sport, REI, and prey) to allow for a better comparison of changes over time. Sport fish data will provide us further information on the risks to humans, while REI and prey fish data are a useful measure of recent changes in methylmercury bioaccumulation. Importantly, successful statistical comparisons will require much

larger datasets with samples sizes of at least 20-30 individual sport fish or REIs. Prey fish composites are difficult to compare statistically because of the low sample size, which is normally 2 per species per sample event). In addition, we observed variation in mercury concentrations among different prey fish species collected from the same site. This highlights the importance of collecting the same suite of fish species across different reservoirs. Future work should aim to target and prioritize fish species based on historical data.

To date, there are twenty-five reservoirs in the San Francisco Bay Area that are listed as impaired for mercury on the 2018/2020 303(d) List. Total Maximum Daily Load regulations for the Guadalupe River watershed in Santa Clara County and Walker Creek watershed in west Marin County address five of these reservoirs through implementation and monitoring actions. In this report fish mercury concentrations for five of the twenty-five reservoirs were examined. Although some trends were clear in sport fish, other trends and comparisons in smaller fish were not as evident. Therefore, additional information is needed to fully understand spatial and temporal trends in fish mercury concentrations to resolve mercury impairment in all twenty-five reservoirs. The Water Board continues to collaborate with reservoir owners and operators to better understand the most important drivers in elevated mercury fish tissue concentrations as well as best management practices to reliably reduce mercury concentrations.

6 References

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Soulajule Reservoir 2016: Soulajule Reservoir and Arroyo Sausal Methylmercury Control Project: Synthesis of Phase 2 Pilot Studies and Prioritization of Reservoir Management Measures, prepared by Stillwater Sciences for Marin Municipal Water District, 2018.