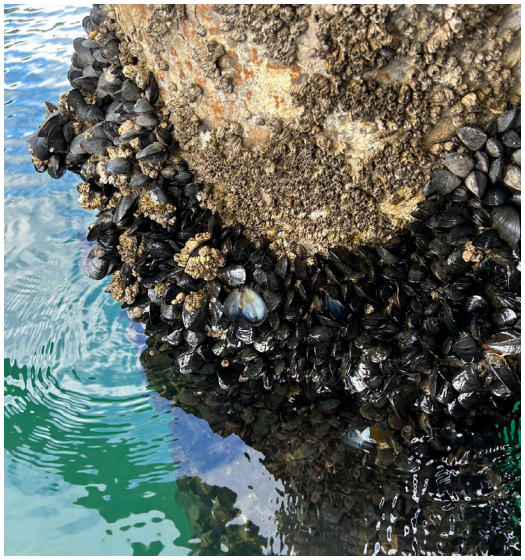
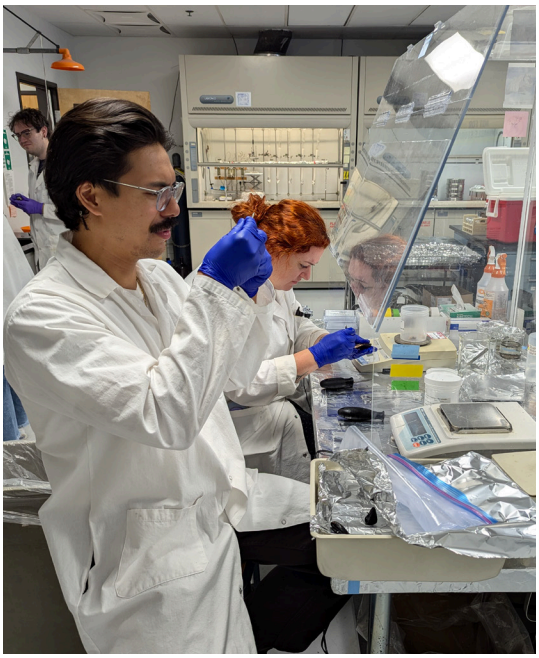
Contaminants in Coastal Bivalves of the Southern California Bight

BIGHT '23





Southern California Bight 2023 Regional Monitoring Program Volume VII

SCCWRP Technical Report 1482

Southern California Bight 2023 Regional Monitoring Program: Volume VII. Spatial and Temporal Distributions of Inorganic and Organic Contaminants in Coastal Bivalves of the Southern California Bight

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ABSTRACT

Urban coastal food webs are commonly impacted by anthropogenic activity. To assess the extent of these impacts, bioaccumulation of chemical contaminants was measured in bivalve tissues along the coast of the Southern California Bight (SCB). Mussels and oysters were collected from multiple sites across three seasons and analyzed for three inorganic elements (arsenic, mercury, and selenium); legacy organochlorine compounds (chlordanes, dichlordiphenyltrichloroethane compounds or DDTs, polychlorinated diphenyls or PCBs), and perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). No clear spatial patterns were observed for arsenic and selenium, consistent with exposure to bivalves predominantly from natural sources. Chlordanes, DDTs, PCBs, and to a lesser extent mercury had greater concentrations at locations impacted by past and/or present urbanization and other anthropogenic activities, such as harbors, bays, and ports, which also generally had increased concentrations of these contaminants in surficial sediments. No clear trends were observed between contaminant concentrations and species, season, and organism size, suggesting that many factors influenced measured chemical residues in SCB bivalves. Concentrations were generally comparable to those observed in bivalves in other urbanized environments worldwide. Current levels of legacy organochlorine compounds were lower than those observed in the 1980s and early 1990s by previous bivalve monitoring efforts in the SCB (e.g., California and NOAA Mussel Watch Programs). There was limited evidence of continued, gradual decreases since the 1990s for some analytes, at scattered locales within the SCB. Only PCBs exceeded the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) Advisory Tissue Levels (ATLs), with 26% of samples above the daily consumption ATL, and 15% above the ATL for no more than three weekly servings. Bivalves with PCB concentrations exceeding OEHHA ATLs were generally found in Los Angeles/Long Beach Harbor and San Diego Bay.

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I. INTRODUCTION

Marine fisheries in California are an important resource economically, socially, and culturally. California leads the country in consumption of seafood; aquaculture in the state in 2023 represented a $200 million industry, ranking 6th in total U.S. production (Wright et al. 2025). Wild bivalve mollusks, such as mussels and clams, have historically provided food for early human populations in the state, are a focus for aquaculture in the state as they make up 30% of the industry (Wright et al. 2025), and are frequently targeted in recreational harvesting (California Department of Fish and Wildlife 2010).

The coastal habitats of the SCB are vulnerable to anthropogenic impacts that can put local fisheries at risk. The coastal areas that form the SCB, from Point Conception in the north to the Mexican border in the south, are among the most densely populated regions of the country, with an estimated population of 17 million in 2025 (State of California 2025). These coasts are impacted by surface runoff from urban and agricultural land uses (Schiff and Tiefenthaler 2011), as well as ocean wastewater outfalls that collectively discharge 4.1 billion L of treated effluent daily (Sutula et al. 2021). As a result of these urban influences, the SCB coastline is impacted by both legacy contaminants as well as constituents of emerging concern (CECs) that may represent a human health risk through consumption of contaminated seafood. Contaminants can remain in coastal waters and sediments for decades and become biomagnified in aquatic food webs (Voutsas et al. 2002, Lavoie et al. 2013), resulting in potential consumption advisories. Accordingly, monitoring for chemical contamination in coastal habitats is important.

Bivalves have long served as a sentinel for such contamination, particularly for bioaccumulative chemicals. In particular, the NOAA Mussel Watch Program has monitored chemical contaminants in bivalves nationwide since 1986, particularly in the SCB (Dodder et al. 2013, Maruya et al. 2014, 2014a). In California, the earlier California Mussel Watch monitored starting in the late 1970s (Melwani et al. 2014). These efforts have found moderate, widespread chemical contamination in bivalves of the SCB (Swam et al. 2023, 2024, 2024a) that exceed human health hazard screening values for some contaminants such as PCBs. In particular, levels have in general not changed appreciably in extent and magnitude in recent decades, particularly for metals and legacy organic contaminants such as PCBs and organochlorine pesticides (Swam et al. 2024, 2024a). However, it is not clear to what extent contaminant levels have changed since the last such survey in 2018, and how this contamination may affect the overall well-being of the SCB.

The Southern California Bight Regional Monitoring Program has assessed the extent and magnitude of chemical contamination in the SCB since its inception in 1994 and its implementation on five-year cycles thereafter. Previous monitoring has entailed evaluation of seabird eggs in Bight ’13 (Clatterbuck et al. 2016), and sport fish in Bight ’18 (McLaughlin et al.

2020) following up on earlier fish monitoring during the Bight ’08 cycle (Davis et al. 2012). As with Mussel Watch, moderate but widespread chemical tissue residues, with greater contaminant burdens in fish found in embayments than in offshore zones (Davis et al. 2012, McLaughlin et al. 2020), and mercury and PCBs exceeding some consumption thresholds and only modest declines in concentrations between 2009 and 2018 (McLaughlin et al. 2020). However, it is unclear if such observations hold true for bivalves in the SCB today.

The goals of this study are threefold. The first goal is to characterize the current extent and magnitude of chemical contaminant bioaccumulation in bivalves in the SCB, in the current monitoring cycle of the Bight Program (Bight ’23). The second is to evaluate spatial and temporal changes, if any, that have occurred since previous monitoring surveys in these shellfish. Long-term monitoring, such as done in the Bight Program, provides a means to document the impact of management actions on regional water quality and the relative rate of these impacts, in this case specifically on sessile marine biota. Finally, these levels are compared to OEHHA’s ATLs (OEHHA 2008) to evaluate what human consumption risks may be, in a manner consistent with those of previous Bight Program biota surveys (McLaughlin et al. 2020).

II. METHODS

Sample Collection

Thirty sites across the SCB were sampled (Figure 1) over three seasons in 2024: winter (January-February), spring (March-May), and summer (August-September). These sites represent a broad gradient of environmental stressors and responses, and thus land use/land cover (agricultural, urban, and open space) that ranged from minimally disturbed reference sites to highly disturbed locations. More information on the site characteristics including land use and population density are provided in Appendix A. Two taxa commonly found in California coastal confluence zones targeted: mussels (*Mytilus californianus* and/or *Mytilus galloprovincialis*) and oysters (*Crassostrea gigas*). Only sites with sufficient shellfish numbers within a 200m radius (e.g., shellfish beds known to be popular for subsistence and recreational harvesting) were sampled. Organisms were collected at low tide, with a minimum of 15 oysters and/or 40 mussels from at least 3 stations composited at each site. A total of 107 composite samples were collected across all sites and all three seasonal collection periods: 74 mussel, 33 oyster. Sixteen field duplicate composite samples (15 mussel, 1 oyster) were collected (six in the winter, five each in spring and summer), for a total of 123 composited bivalve samples.

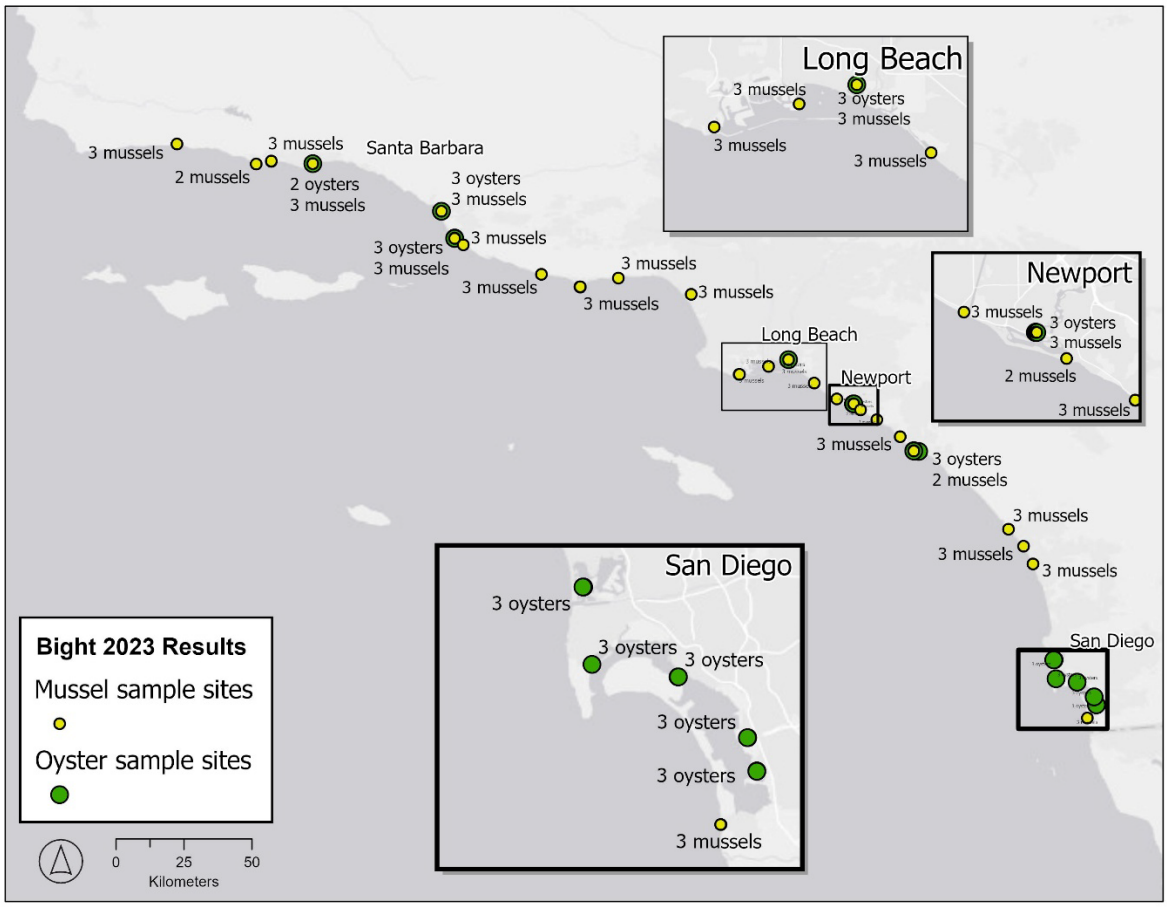

Figure 1: Bivalve sites in Bight '23.

Bivalves were kept cold on ice after collection until shucking within 48 h of collection. At that time, individuals were measured, weighed, and shucked. Edible tissues were composited and homogenized, placed in either sample containers made out of HPDE (for PFAS, 10 g wet weight) or glass (for all other contaminants, 30 g wet weight), then frozen at -20 °C until analysis by participating laboratories (Table 4).

Target Analytes

Three inorganic elements (total arsenic, total mercury, and total selenium) were analyzed, as well as four classes of organic contaminants: five chlordane components (α-chlordane, γ-chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane), 7 DDT compounds (4,4'-DDT, 2,4'-DDT, 4,4'-DDD, 2,4'-DDD, 4,4'-DDE, 2,4'-DDE, and 4,4'-DDMU), 43 PCB congeners (PCBs 8, 18, 28, 37, 44, 49, 52, 66, 70, 74, 77, 81, 87, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 138, 149, 151, 153, 156, 157, 158, 167, 168, 169, 170, 177, 180, 183, 187, 189, 194, 195, 201, 206, and PFAS (PFOS + PFOA). These analytes (Table 5) are similar to those measured in the previous

Bight ’18 cycle for fish (McLaughlin et al. 2020) and include those analyzed in previous bivalve surveys in the SCB (Maruya et al. 2014, Swam et al. 2023, 2024, 2024a).

Analytical Methods

Sample processing and analysis were done by four laboratories that met specified data quality objectives (DQOs) (details in Appendix B) to demonstrate acceptable analytical performance. This included adherence to common quality assurance/quality control (QA/QC) practices, routine analysis of certified reference materials (CRMs), and successful participation in an inter-laboratory calibration study (details in Appendix C) prior to sample analysis.

Sample extraction and analysis

Lipids were determined gravimetrically (e.g., EPA1668C). Tissue samples for arsenic and selenium were digested in acid as per standard methods (e.g., EPA 200.7, EPA 200.8, EPA 3050B). Digestates were diluted with deionized water and analyzed by inductively coupled plasma mass spectrometry or inductively coupled plasma emission spectroscopy, depending on the laboratory. Tissues for mercury analysis were prepared as per EPA Methods 200.8, 245.7, 7471, or 7473, and analyzed with either inductively coupled plasma mass spectrometry or cold vapor atomic absorption spectroscopy as appropriate. Tissues for trace organic compounds were solvent-extracted using one of the following methods: accelerated solvent extraction, Soxhlet, sonication, or liquid solvent extraction with solid-phase extraction cleanup. Gel permeation chromatography was subsequently performed to remove lipids and other high-molecular weight biomolecule interferences, and extracts were further subjected to each laboratory’s own clean-up procedures. PCB congeners and organochlorine pesticides were analyzed using either dual-column gas chromatography (GC) with electron capture detection (GC/ECD), mass spectrometry (GC/MS) in the selected ion monitoring (SIM) mode, or tandem mass spectrometry (GC/MS/MS) using multiple reaction monitoring (MRM). PFAS analytes were analyzed by liquid chromatography-tandem mass spectrometry (LC/MS/MS) using MRM.

Data Analysis

Data below a laboratory’s Method Detection Limit (MDL) values were treated as zero when data were reported, except as specifically indicated. This approach was also adopted for the determination of descriptive statistics, including summation of analyte classes (e.g., the concentration of a non-detected PCB congener was considered zero in calculating total PCBs).

Quantitative spatial analysis was performed using R (R Development Core Team 2015). The 95% confidence intervals about the mean were calculated as 1.96 times the standard error.

Unless otherwise specified, all concentrations are on a wet weight basis. Lipid-normalized concentrations were also evaluated for legacy organic contaminants (i.e., chlordanes, DDTs, and

PCBs), given the propensity of these hydrophobic compounds to bioaccumulate from association with lipid biomolecules (Gobas et al. 1993). For all data analyses, the first laboratory duplicate was selected for use, consistent with procedures for calculating Sediment Quality Objectives (Bay et al. 2021). Values for both field duplicates were included in the data analyses below. Statistical tests for comparisons were performed as indicated below. Statistical significance was at 95% confidence (i.e., $\alpha = 0.05$) throughout, unless otherwise noted. Results for bivalves refer to mussel and oyster results pooled together.

Consumption Risks

Sample concentrations were compared to available advisory tissue levels to determine the number of samples that exceed consumption advisories levels. California OEHHA currently has advisories for five of the chemicals measured in bivalves: DDT, PCB, chlordanes, mercury, and selenium (OEHHA 2008). In addition, the Massachusetts Department of Public Health released tissue-level advisories for several PFAS compounds, including PFOS and PFOA (MA DPH 2023).

III. RESULTS

Concentrations and geographic distributions

With the exception of PFAS compounds, for which only a single detected value was observed for PFOA of 119 samples, chemical analytes were widespread in bivalves (Table 1).

Arsenic and selenium were detected in all bivalves (Table 1). Mercury and total DDTs were detected in over 94% of samples, while total PCBs were detected in roughly three-fourths of samples. Chlordanes were detected in only half of the bivalves.

There were generally two different geographic patterns for chemical residues, indicative of differing sources and accumulation for SCB bivalves, based on mean concentrations across the seasons along the coast (Figure 2) as well as maps of concentrations (Figures 3, 4) and locales with elevated levels (Table X).

The first pattern consists of more or less similar concentrations across the SCB, as was the case for arsenic (Figures 2a, 3a) and selenium (Figures 2c, 3c). As noted, concentrations of arsenic were generally greater in oysters than in mussels at sites where both were found. However, the concentration ranges of both analytes were narrow, varying at most by a factor of about 50: 0.37-17 µg/g for As and 0.27-16 µg/g for Se (Table 1). There were no apparent sites with notably high concentrations for either element in the SCB. These concentrations and spatial distributions are consistent with probable natural sources of arsenic and selenium to bivalves in the SCB.

The second pattern was greater concentrations in bivalves located in areas with greater anthropogenic impacts. Bivalves had greater concentrations of total chlordanes (Figures 2d,

3d), total DDT (Figures 2e, 3e), and total PCBs (Figures 2f, 3f). Concentrations for these analytes at heavily urbanized and industrialized shorelines of the SCB varied (Table 1) by factors of hundreds, compared to the single order of magnitude variation for contaminants likely from natural origins such as As and Se. All three legacy organic analyte classes were elevated in Los Angeles/Long Beach Harbor and Newport Bay. Total PCBs were elevated in bivalves in San Diego Bay, specifically oysters, as mussels were generally not found there. Total chlordanes and total DDT were also elevated also in Channel Islands Harbor and its vicinity (Figures 2d-e, 3d-e). Mercury was also elevated in both species at more impacted sites, although to a lesser degree than for the legacy organic contaminants (Figures 2b, 3b). In addition, mercury levels for both mussels and oysters were greater in Santa Barbara (STBB) compared to other sites.

Distribution of legacy organic contaminants

The abundances of arsenic and selenium in SCB bivalves were significantly and positively correlated with each other (Table 15, Spearman $\rho = 0.51$, $p < 0.001$), as were the two legacy organic pesticide classes of total chlordanes and total DDTs ($\rho = 0.42$, $p < 0.001$), and total chlordanes with total PCBs ($\rho = 0.56$, $p < 0.001$). Mercury was also significantly correlated with total PCBs ($\rho = 0.39$, $p < 0.001$). Other analytes were generally not well correlated, indicating that, for example, greater concentrations of mercury in bivalves at a particular site also did not correspond to greater concentrations of arsenic ($\rho = 0.05$).

The relative distribution of individual legacy organic contaminants (chlordanes, DDTs, and PCBs) varied by site (Figure 7, see Appendix D). The chlorinated cyclodienes were generally dominated by α- and γ-chlordane, with some measurable traces of the metabolite oxychlordane in bivalves of San Diego and Dana Point (Figure 7a). Residues of DDT compounds in bivalves were dominated by 4,4'-DDE, the dehydrodechlorination product of 4,4'-DDT (Figure 7b). Those bivalves in eastern Los Angeles County and alongside Orange County also had measurable levels of 4,4'-DDMU, the dechlorination product of 4,4'-DDE. A small proportion of 4,4'-DDT and 2,4'-DDT were observed in some of these bivalves, with greater proportions of parent DDT compounds at and near Channel Islands Harbor. Considerable proportions of DDD, the reductive dechlorination product of DDT, were also observed in the bivalves around Channel Islands Harbor and particularly further north along the Santa Barbara coast (Figure 7b). The most common PCB congeners observed were recalcitrant congeners, such as PCBs 153, 138, and 180 (Figure 7c). The relative composition varied by site, with greater relative levels of more heavily chlorinated congeners (e.g., PCBs 187, 195, and 206) offshore San Diego northward to Dana Point (Figure 7c). Of the non-*ortho*-substituted PCB congeners, which have the greatest Ah-receptor affinity and hence dioxin-like toxicity (van den Berg 2006) of the PCBs, only PCB 77 (TEQ = 0.0001) was found in 8 samples (6% detection, 0.03-0.85 ng/g, mean 0.26 ng/g wet weight); PCBs 81, 126 (the congener with the greatest dioxin-like toxicity, with TEQ = 0.1), and

169 were not detected. Of the mono-*ortho*-substituted congeners with lower Ah-receptor affinity (TEQ = 0.00003), PCB 118 (TEQ = 0.0001) was most commonly found (44% detection, 0.03-4.9 ng/g wet weight, mean 0.88 ng/g), with PCBs 157 and 189 not detected and all others (PCBs 105, 114, 123, 156, and 167) detected in less than 6% of bivalves, with a maximum concentration of 1.3 ng/g wet weight for PCB 123.

Species and seasonal distributions

Both mussels and oysters were collected at the same time at a number of sites. These paired samples were used to evaluate whether there were systematic differences in concentrations between the two species, as such organisms were subject to the same exposure conditions and levels of chemical contaminants. Only arsenic showed significant differences between species, with concentrations in oysters greater than the corresponding concentrations in mussels (paired t-test, $p = 0.0002$). This result indicates that data for both species, aside from arsenic, can be pooled together for further evaluation, including those for lipid-normalized concentrations of legacy organic compounds.

Based on the paired samples, seasonal differences (one-way ANOVA) across all bivalves of the entire SCB were observed in bivalves for mercury ($p = 0.03$), selenium ($p = 0.049$), and total chlordanes both wet weight ($p = 0.00001$) and lipid-normalized ($p = 0.00002$). However, no seasonal differences were observed for either wet weight or lipid-normalized total DDT ($p > 0.66$) and total PCBs ($p > 0.09$). Mercury concentrations were greater in summer than in winter. Selenium concentrations in spring were greater than they were in the other seasons. Chlordane concentrations were lower in the summer than in other seasons. Seasonal differences were not observed for mussels ($p = 0.71$), but were found for arsenic in oysters ($p = 0.009$), for which concentrations in summer were less than in spring and in winter (Figures 8-9).

The oysters collected were generally physically larger than the mussels, both in terms of weight and length. Because all samples were composites of individual organisms, mean weights and lengths were used to evaluate if linear regressions of organism size were significantly correlated with analyte concentrations (Figures 10-13, Table 16). This was the case throughout for total DDTs on both a wet-weight and lipid-normalized basis, for both species and both size metrics, with a negative correlation for mussels and a positive correlation for oysters. For mussels only, mean size and length were significantly correlated positively for arsenic, and mean weight was correlated negatively for mercury. For total PCBs, mean length but not mean weight was significantly and negatively correlated with wet-weight concentrations in oysters; both size metrics were significantly and negatively correlated with lipid-normalized concentrations in mussels, but not in oysters.

Table 1. Contaminant summary statistics in all bivalves, in mussels, and in oysters (ww = wet weight, N/A = not applicable). Only one detection for PFOS+PFOA was observed.

Analyte	**Species**	**Units**	**mean**	Minimum	**25th percentile**	**Median**	**75th percentile**	**90th percentile**	**Maximum**	**% detection**
Arsenic	All	µg/g ww	1.1	0.37	0.70	1.1	1.4	1.7	2.0	100
Mercury	All	µg/g ww	0.0051	0.0013	0.0029	0.0036	0.0052	0.0091	0.027	95
Selenium	All	µg/g ww	0.50	0.15	0.27	0.36	0.46	0.52	0.72	100
Total Chlordanes	All	ng/g ww	2.3	0.19	0.71	1.5	2.6	6.0	11	51
Total DDT	All	ng/g ww	8.0	0.23	1.6	3.0	7.5	15	130	95
Total PCBs	All	ng/g ww	6.3	0.07	0.75	1.7	10	18	47	73
PFOS+PFOA	All	ng/g ww	0.19	0.19	--	0.19	--	--	0.19	0.84
Lipids	All	% by wt.	0.70	0.08	0.41	0.59	0.93	1.2	2.2	98
Total Chlordanes	All	ng/g lipid	420	16	170	320	480	880	2600	51
Total DDT	All	ng/g lipid	1400	42	190	550	1600	3800	14000	95
Total PCBs	All	ng/g lipid	1200	7.1	130	460	2100	3100	5600	73
Arsenic	Mussels	µg/g ww	1.1	0.37	0.63	1.1	1.5	1.7	1.9	100
Mercury	Mussels	µg/g ww	0.0046	0.0013	0.0028	0.0034	0.0043	0.0070	0.027	98
Selenium	Mussels	µg/g ww	0.39	0.16	0.32	0.39	0.47	0.55	0.72	100
Total Chlordanes	Mussels	ng/g ww	1.2	0.19	0.50	0.98	1.5	2.4	4.4	43
Total DDT	Mussels	ng/g ww	5.1	0.63	2.0	3.0	7.1	11	26	95

Analyte	**Species**	**Units**	**mean**	Minimum	**25th percentile**	**Median**	**75th percentile**	**90th percentile**	**Maximum**	**% detection**
Total PCBs	Mussels	ng/g ww	3.2	0.073	0.65	1.3	3.2	8.8	21	68
PFOS+PFOA	Mussels	ng/g ww	0.19	0.19	--	0.19	--	--	0.19	1.1
Lipids	Mussels	% by wt.	0.65	0.08	0.35	0.54	0.90	1.2	2.2	98
Total Chlordanes	Mussels	ng/g lipid	350	16	140	300	450	700	1300	43
Total DDT	Mussels	ng/g lipid	1300	42	250	600	1500	3400	7600	94
Total PCBs	Mussels	ng/g lipid	800	7.1	120	290	1000	2500	5600	68
Arsenic	Oysters	µg/g ww	1.2	0.50	0.94	1.1	1.4	1.8	2.0	100
Mercury	Oysters	µg/g ww	0.0062	0.0020	0.0041	0.0050	0.0080	0.0094	0.020	97
Selenium	Oysters	µg/g ww	0.30	0.15	0.23	0.26	0.37	0.44	0.49	100
Total Chlordanes	Oysters	ng/g ww	4.0	0.25	1.5	2.6	6.0	9.0	11	73
Total DDT	Oysters	ng/g ww	16	0.23	1.1	2.3	12	43	130	94
Total PCBs	Oysters	ng/g ww	13	0.24	2.4	11	18	29	47	85
PFOS+PFOA	Oysters	ng/g ww	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Lipids	Oysters	% by wt.	0.84	0.18	0.56	0.68	1.1	1.6	2.1	97
Total Chlordanes	Oysters	ng/g lipid	530	65	240	400	690	920	2600	73
Total DDT	Oysters	ng/g lipid	1900	56	150	340	1800	7400	14000	94
Total PCBs	Oysters	ng/g lipid	2000	45	330	1900	3100	4300	5600	85

Figure 2. Mean wet weight concentrations (±σ) of (A) arsenic, (B) mercury, (C) selenium, (D) total chlordanes, (E) total DDTs, and (F) total PCBs across seasons, for Bight '23 mussels and oysters along the Southern California Bight coastline from north to south, grouped by county (SB Santa Barbara, VT Ventura, LA Los Angeles, OC Orange, SD San Diego). Concentrations in µg/g for inorganics, ng/g for organics. OEHHA consumption advisory levels as indicated.

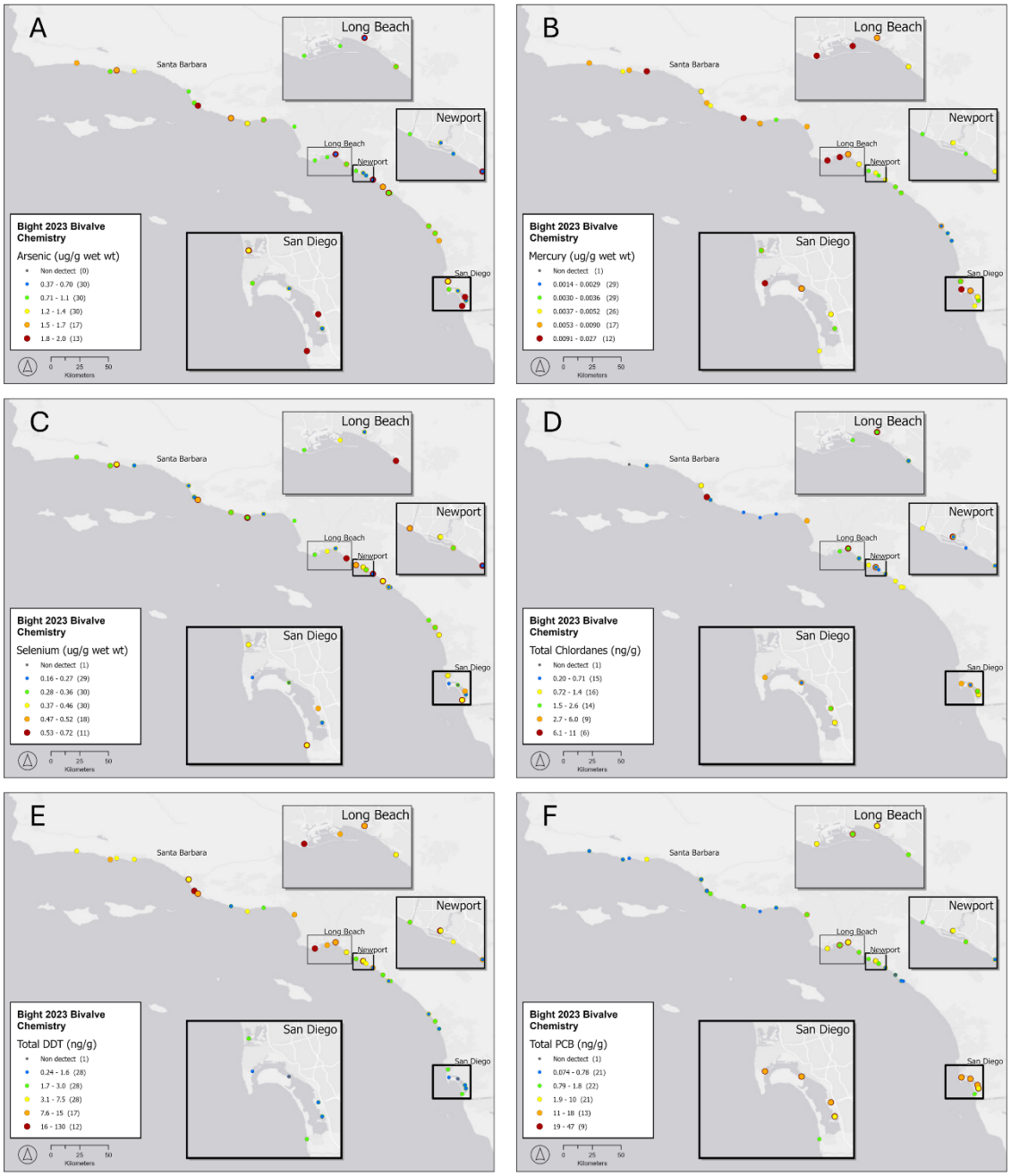

Figure 3. Bight '23 wet weight concentrations of (A) arsenic, (B) mercury, (C) selenium, (D) total chlordanes, (E) total, and (F) total PCBs, categorized as non-detected values (i.e., below the analysis lab's method detection limit), minimum to 25th percentile, 25th percentile to median, median to 75th percentile, 75th percentile to 90th percentile, and 90th percentile to maximum. Numbers in parentheses after the concentration ranges are the number of samples in each bin. Concentrations in µg/g for inorganics, ng/g for organics.

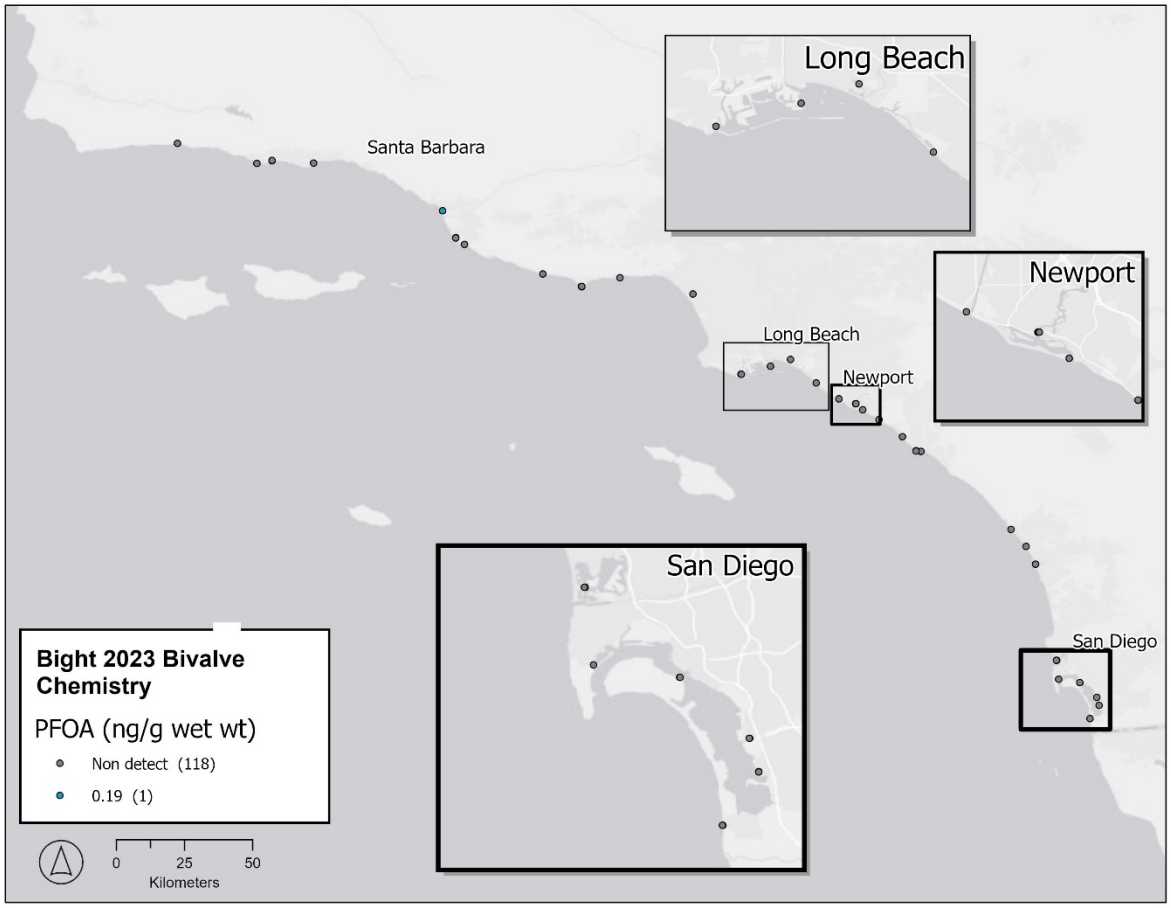

Figure 4. Map of PFOA concentrations (ng/g wet weight) in Bight '23 bivalves. Null values are non-detects.

Consumption advisories

With the exception of PCBs, all bivalve samples from Bight ’23 had chemical contaminant concentrations for seafood (Table 2) below consumption guidelines from OEHHA (2008). These exist for mercury (with separate values for more sensitive populations such as children and women of childbearing age), selenium, chlordanes, DDT, and PCBs. Thresholds range from any consumption at all, as well as lower values for having more than three or seven meals weekly. Roughly one-sixth of Bight ’23 bivalves had PCB concentrations greater than the advisory for three weekly meals, and a quarter of the bivalves had concentrations greater than that for seven weekly meals. No bivalve samples exceeded the “do not consume” advisory. The most contaminated bivalves were generally those located in harbors and bays with documented sediment contamination such as Los Angeles/Long Beach Harbor, Newport Bay, and San Diego Bay (Figures 2, 3) (See Wong et al. 2026 for details on sediment concentrations). These findings are consistent with previous assessments by NOAA Mussel Watch who found bivalve concentrations well below USEPA recommended screening values recreational fishers for

chlordanes, DDTs, and PCBs, but some exceedances for subsistence fishers for DDTs and PCBs (Swam et al. 2024a). While OEHHA does not currently have consumption levels for PFOS and PFOA, the Massachusetts Department of Public Health does have advisory values (see Table 2, MA DPH 2023), which were at least one order of magnitude higher than the levels measured in all Bight '23 bivalve samples.

Table 2. Selected consumption advisories for seafood, and proportion of Bight '23 bivalve samples exceeding these values (N=107). Advisories from OEHHA except for those for PFAS (Massachusetts Department of Public Health).

Analyte class	Advisory: Do not consume (ng/g ww)	Bight '23 bivalves above "do not consume" advisory	Advisory: do not exceed 3 8-oz. weekly meals (ng/g ww)	Bight '23 bivalves above "do not exceed 3 weekly meals" advisory	Advisory: do not exceed 7 8-oz. weekly meals (ng/g ww)	Bight '23 bivalves exceeding "do not exceed 7 weekly meals" advisory
Mercury	440 (women < 45, children)	0%	55	0%	31	0%
Mercury	1310 (women > 45, adult men)	0%	160	0%	94	0%
Selenium	15,000	0%	1,800	0%	1,000	0%
Chlordanes	560	0%	140	0%	80	0%
DDTs	2100	0%	390	0%	220	0%
PCBs	120	0%	16	15%	9	26%
PFOS	3.5	0%	--	--	0.22	0%
PFOA	3.5	0%	--	--	0.22	0%

IV. DISCUSSION

In this discussion, we put the results from the Bight ’23 bivalve bioaccumulation survey into context and perspective. This is done by evaluating seasonal and physiological factors that may affect chemical concentrations, by comparing concentration distributions of Bight ’23 bivalves to similar efforts elsewhere in the world, by evaluating likely sources of contaminant exposure to SCB bivalves, by evaluating bioaccumulation of chemical contaminants in Bight ’23 bivalves with other biota monitored in previous Bight cycles (i.e., Bight ’18 sport fish), and by comparing spatial and temporal distributions of chemical contaminants in bivalves of the SCB from other monitoring programs.

Seasonal and physiological factors affecting bivalve chemical residue levels

There were no strong seasonal effects, nor is it apparent that organism physiology and size affected contaminant residues. Processes that could be seasonal or physiological in nature, such as growth dilution from bivalves growing over time, would result in decreasing concentration with increasing size, while wasting of organisms would do the opposite as concentrations would increase as organisms lose biomass. Both of these processes would affect, in a similar manner, chemicals being bioaccumulated and depurated by passive processes, such as fugacity-driven toxicokinetics affecting hydrophobic organic contaminants such as legacy organochlorine pesticides and PCBs (Gobas et al. 1993). However, there were no systematic trends across analytes in concentrations across either seasons (Figures 8-9) or size (Figures 10-13, Table 16). This observation, along with the fact that there was considerable scatter of concentrations for all analytes across seasons (Figures 8-9), indicates that that season and physiology had, at most, a secondary effect on body residues of bivalves in the SCB, and that other factors, such as location and subsequent exposure to chemical contaminants or feeding strategies, were more likely to influence such concentrations.

Comparison with selected worldwide literature values for bivalves

The levels of metals in Bight ’23 bivalves are in line with those found elsewhere in the world in the recent past (Table 3). Arsenic levels in Bight ’23 ranged from 0.4 to 2 µg/g and averaged 1.1 µg/g for both mussels and bivalves (Table 3), which was similar to values (maximum 4 µg/g, average 2 µg/g) observed in China (Ni et al. 2026), as well as in the Italian Adriatic coast (0.8-22 µg/g, average 2-3 µg/g, Tavoloni et al. 2021) and on Sardinia (1.6-9.6 µg/g, Esposito et al. 2018) (Table 3). Mercury levels in SCB bivalves (0.001-0.027 µg/g, average 0.005 µg/g, Table 1) are also similar to China and Italy (Table 3). Selenium is less commonly measured in bivalves, but concentrations in SCB bivalves were of similar magnitude (average 0.5 µg/g, Table 1) as those found in freshwater bivalves in China (average 2 µg/g, Table 3, Xu et al. 2022). These observations suggest that there were no locally strong sources of these three inorganic

contaminants, whether of natural or anthropogenic origin, that were appreciably different in the SCB compared to other locales.

Legacy organic contaminants in Bight ’23 bivalves are also of comparable magnitude with bivalves elsewhere, with the notable exception of DDT. Concentrations of total chlordane (0.2-11 ng/g, average 2.3 ng/g) were similar to those observed in mussels in Hiroshima Bay, Japan (average 1.7 ng/g, Table 3, Goto et al. 2020). For total PCBs, ranges (0.07-47 ng/g) and average concentrations (6 ng/g) were also similar to those in Hiroshima (2.20-45 ng/g, average 15 ng/g, Table 3, Goto et al. 2020), Spain (max 2.6 ng/g, Rodin et al. 2019) and in Vietnam (1.4-47 ng/g, Thuy et al. 2024), but were greater than those observed in Brazil (0.1-0.5 ng/g, Ferreira et al. 2026) and along the Russian coast of the Sea of Japan (maximum 0.07 ng/g, Borokova et al. 2024).

While average levels of total DDT in Bight ’23 bivalves (8 ng/g, Table 1) were similar to those in Hiroshima (2.4 ng/g, Table 3, Goto et al. 2020), maximum levels in the SCB (130 ng/g) were greater than those elsewhere (0.2-33 ng/g, Table 3, Thuy et al. 2024). DDT contamination is particularly acute in the SCB given that the largest U.S. manufacturer of DDT, Montrose Chemical Corporation, discharged on the order of 1,000 metric tons of technical grade DDT wastes from the 1950s to 1971 through wastewater systems to the Palos Verdes Shelf, which is now designated a Superfund site (USEPA 2024). Approximately the same amount of DDT in acidic wastes was barged out and dumped further offshore (Kivenson et al. 2019, Wu et al. 2025) from 1947 to 1961.

For PFOA, the single detection of 0.19 ng/g observed in Bight ’23 bivalves (Table 1) is comparable to levels elsewhere (Table 3). These would include those in China off the Zhejiang Coast (maximum levels 0.3 ng/g, Ni et al. 2026) and Poyang Lake (maximum levels 0.1 ng/g, Xu et al. 2022), in Delaware bay (maximum levels 0.3 ng/g, Jones et al. 2025), and in Tokyo Bay (0.7 ng/g, So et al. 2006). Bight ’23 levels were lower than maximum levels observed for PFOA in oysters of the Florida coast (1.1 ng/g, Lemos et al. 2022).

Table 3. Selected reported mean and maximum (in parentheses) bivalve wet weight concentrations of contaminants (inorganic in µg/g, organic in ng/g) in the Southern California Bight (SCB) and elsewhere. - = not applicable, ND = not detected, *=calculated from reported lipid-normalized weight with average lipid weight reported (0.33%), **=calculated from dry weight assuming 85% moisture.

Location (study period)	Species	As	Hg	Se	chlordanes	DDTs	PCBs	PFOA	Reference
SCB, CA (2024)	**Overall**	**1.2 (17)**	**0.0013 (0.027)**	**0.5 (16)**	**2.3 (11)**	**7.9 (130)**	**6.3 (47)**	**0.19**	**This study**
SCB, CA, US (2024)	***Mytilus* spp.**	**1.3 (17)**	**0.0013 (0.027)**	**0.57 (16)**	**1.2 (4.4)**	**5.1 (26)**	**3.1 (21)**	**0.19**	**This study**
SCB, CA, US (2024)	***Crassostrea gigas***	**1.2 (2)**	**0.0062 (0.02)**	**0.3 (0.49)**	**4 (11)**	**16 (130)**	**13 (47)**	**ND**	**This study**
SCB (2009-2010)	*Mytilus* spp.	1.5	0.015	--	1.5	67.5	5.2	--	Edwards et al. (2014)
SCB (1997-2010)	*Mytilus californianus*	--	--	--	--	(1500)	(1500)	--	Melwani et al. (2014)
SCB (1986-2009)	*Mytilus* spp.	--	--	--	--	3.2 (42)	--	--	Sericano et al. (2014)
Adriatic Sea, Italy (2008-2018)	*Chamelea gallina*	2.4 (3.7)	<0.025	--	--	--	--	--	Tavoloni et al. (2021)
Adriatic Sea, Italy (2008-2018)	*Mytilus galloprovincialis*	3.5 (7.0)	<0.025	--	--	--	--	--	Tavoloni et al. (2021)
Europe (1993-2018)	*Chamelea gallina*	--	(0.19)	--	--	--	--	--	Tavoloni et al. (2021)
Europe (1993-2018)	*Mytilus galloprovincialis*	(22)	(0.16)	--	--	--	--	--	Bian et al. (2025)

Location (study period)	Species	As	Hg	Se	chlordanes	DDTs	PCBs	PFOA	Reference
Zhejiang province, China	*Meretrix meretrix, Mytilus edulis, Crassostrea gigas, Scapharca subcrenata, Sinonovacula constricta*	1.9 (4)	0.0073 (0.022)	--	--	--	--	--	Ni et al. (2026)
Zhejiang province, China	*Mytilus* spp.	2 (2.4)	0.005 (0.007)	--	--	--	--	--	Ni et al. (2026)
Zhejiang province, China	*Crassostrea gigas*	1.4 (3.8)	0.01 (0.02)	--	--	--	--	--	Ni et al. (2026)
Poyang Lake, China	*Hyriopsis cumingii*	--	--	2 (4)	--	--	--	--	Xu et al. (2022)
Sardinia, Italy (2016)	*Ruditapes descussatus*	--	(0.047)	(1.6)	--	--	--	--	Esposito et al. (2018)
Naples, Italy (2016-2019)	*Mytilus galloprovincialis*	--	0.07 (0.76)	--	--	--	--	--	Esposito et al. (2020)
Hiroshima Bay, Japan (2012)	*Mytilus galloprovincialis*	--	--	--	0.8 (1.2)	1.8 (7.1)	15 (45)	--	Goto et al. (2020)
Vietnam	*Crassostrea gigas*	--	--	--	--	(33)	(47)	--	Thuy et al. (2024)
Shandong province, China	*Crassostrea gigas*	--	--	--	--	(0.9)	--	--	Thuy et al. (2024)

Location (study period)	Species	As	Hg	Se	chlordanes	DDTs	PCBs	PFOA	Reference
Brazil (2023-2024)	*Crassostrea gigas*	--	--	--	ND	0.3 (2)	(0.5)	--	Ferreira et al. (2026)
Sea of Japan, Russia (2017-2018)	*Mytilus trossulus*	--	--	--	--	0.14 (0.16)	0.05 (0.07)	--	Borokova et al. (2024)*
Spain (2012-2013)	*Mytilus galloprovincialis, Cerestoderma edule, Ruditapes descussatus*	--	--	--	--	--	(2.6)	--	Rodil et al. (2019)**
Florida, US (2020-2021)	*Crassostrea virginica*	--	--	--	--	--	--	(1.1)	Lemos et al. (2022)
Delaware Bay, US (2021-2022)	*Crassostrea virginica*	--	--	--	--	--	--	(0.25)	Jones et al. (2025)
Delaware Bay, US (2021-2022)	*Geukensia demissa*	--	--	--	--	--	--	(0.12)	Jones et al. (2025)
Scheldt Estuary, Belgium (2023)	*Mytilus edulis, Corbicula fluminea*	--	--	--	--	--	--	(2)	Bonso et al. (2026)
Tokyo Bay, Japan (2004)	*Crassostrea gigas*	--	--	--	--	--	--	(0.66)	So et al. (2006)

Likely contaminant sources to bivalves

Distributions of arsenic and selenium in bivalves are consistent with exposure of these elements from natural sources. Both elements had similar concentrations in bivalves all along the SCB coastline (Figures 2a,c, 3a,c), in a relatively narrow range of 0.5-2 μg/g for arsenic and 0.2-0.6 μg/g for selenium, compared with those of other analytes (e.g., up to 130 ng/g for total DDT). As a result, levels of the two elements correlated in bivalves (Table 14, $\rho = 0.51$), and neither correlated with mercury or the organic contaminants. These levels are consistent with the analogous spatial distributions in SCB surficial sediments, to which bivalves may be exposed. There were some elevated concentrations of arsenic in surface sediments in Los Angeles/Long Beach Harbor and in San Diego Bay; however, these concentrations were not dissimilar to those along the coast (Wong et al. 2026), and were often lower, as was the case of offshore selenium being greater in sediments than along shorelines. Both elements can be released from anthropogenic activities such as refining and fossil fuel combustion; arsenic was common for wood preservation, and selenium is found in various consumer, industrial, and agricultural products (Swam et al. 2024). These potential anthropogenic sources can explain some of the increased concentrations observed in embayments. That said, both elements are naturally present, and arsenic in particular is highly prevalent in the bedrock of the SCB (Swam et al. 2024).

Mercury's distribution in bivalves is consistent with both exposure from natural and anthropogenic sources, which include mining and power plant emissions (GESAMP 1986, Gribble et al. 2016). Most of the SCB had bivalve concentrations on the order of 0.0025 to 0.005 μg/g wet weight (Figures 2b, 3b), which may reflect natural ambient concentrations (Swam et al. 2024). Somewhat higher concentrations were observed in bivalves of San Diego Bay (Figures 2c, 3c). The two sites in San Diego Bay with the greatest concentrations (means at SDKB and SDFL of 0.0088 and 0.0095 μg/g wet weight, respectively) are matched by elevated levels in surficial sediments. These sediment sites (Figure 14) are either nearby (1 km or less) and/or at locations that may influence levels at the bivalve locales e.g., fine sediments that may be resuspended by currents and tides. Such sediments had mercury concentrations from 0.05 to 2.29 μg/g dry weight (Figure 13), which are median and maximum concentrations, respectively, in Bight '23 sediments (Wong et al. 2026). Bivalves in Los Angeles/Long Beach harbors and in Santa Barbara also had elevated mercury levels (Figures 2c, 3c) but there were no corresponding nearby Bight '23 surficial sites (Figure 14). The idea that mercury exposure to bivalves was from both natural and anthropogenic sources is consistent with the lack of correlation of mercury to arsenic and selenium (Table 15), exposure to which were likely from natural origins as noted above.

The organic contaminants measured in Bight '23 have no known natural origins, and greater concentrations were found at areas more heavily impacted by anthropogenic activities which have likely been altered from the original contaminant mixtures that were discharged. This is reflected in the correlation of total chlordanes with total DDTs (Table 15, $\rho = 0.42$), likely at least in part from past agricultural and urban use of these insecticides, and the correlation of total chlordanes with total PCBs (Table 15, $\rho = 0.56$) from ubiquitous past use of both. Bivalves had greater proportions of the more recalcitrant nonachlors (Figure 7a) than is present in the original insecticide, technical chlordane, which had roughly 7% trans-nonachlor (Schmitt et al. 1990). This observation suggests that bivalves had either been exposed to chlordanes that had been weathered over time to change the relative distribution of chlordane components, or that bivalves had preferentially transformed or eliminated some more labile chlordane components, or both. Such transformation or elimination processes are consistent with the presence of the metabolite oxychlordane in some SCB bivalves (Figure 7a).

The presence of DDT components in SCB bivalves is also likely from exposure to weathered material. This is reflected by the dominance of DDE, the most common aerobic transformation product of DDT, in bivalves (Figure 7b). Interestingly, total DDTs correlated poorly with total PCBs (Table 15, $\rho = 0.11$). This observation is likely due to the heavy past regional discharge of DDTs through wastewater offshore Palos Verdes (USEPA 2024), and ocean dumping of wastes (Kivenson et al. 2019, Wu et al. 2025) resulting in high sediment levels of DDT offshore (Kivenson et al. 2019, USEPA 2024, Wu et al. 2025, Wong et al. 2026) compared to high sediment levels of chlordanes and PCBs in embayments (Wong et al. 2026). The influence of these offshore DDT residues, which have been weathered over time by microbial transformation to produce some DDMU (Wu et al. 2025) is reflected by the presence of DDMU in bivalves along the coast from Alamitos Bay to Dana Point (Figure 7b). This observation suggests that such bivalves may have at least some exposure to weathered DDT residues from offshore, as DDMU is at most a trace component of technical DDT, the original source material (Kivenson et al. 2019). While the possibility of in vivo transformation of legacy organochlorine compounds by bivalves cannot be ruled out (Wong et al. 2001), such transformation in bivalves along the SCB could result in measurable DDMU in bivalves all along the coast, which was not observed (Figure 7b).

The areas of the SCB with elevated levels of organic contaminants (Figures 2d-f, 3d-f, Table 14) included Los Angeles/Long Beach Harbor, Newport Bay, San Diego Bay, and Channel Islands Harbor. These areas are also locations at which contamination of surficial sediments from anthropogenic activities was also observed (Wong et al. 2026). In Los Angeles/Long Beach Harbor, elevated levels of total chlordanes, total DDTs, and total PCBs were observed in both bivalves (Figures 2d-f, 3d-f), and in surficial sediments for which some of the highest concentrations of all three analyte classes were found (Wong et al. 2026). In Newport Bay, high

concentrations of chlordanes were present in bivalves at up to 8 ng/g wet weight or above 90th percentile, as well as in nearby surficial sediments (Figure 15) at 1.7 to 7.4 ng/g dry weight, which were above the median and the 90th percentile, respectively. The same was true for total DDT in bivalves at 7-43 ng/g wet weight (75th percentile to above the 90th percentile) and sediments (Figure 16) at 11-28 ng/g dry weight (between the median and 75th percentile), and total PCBs (2-16 ng/g wet weight, median to 90th percentile) and sediments (up to 7.6 ng/g dry weight, above the median value, Figure 16). In San Diego Bay, total PCBs in bivalves (8-37 ng/g wet weight, a bit below 75th percentile to above 90th percentile) corresponded with mean concentrations of 8.3 ng/g dry weight (Figure 17), above median B'23 sediment values (Wong et al. 2026). Elevated levels of PCB in San Diego Bay are consistent with known contamination there (Zeng et al. 2002, Wong et al. 2026) and with the presence there of heavier PCB congeners in bivalves than elsewhere (Figure 7c), suggestive of localized sources. Finally, Channel Islands Harbor had bivalves with high levels of total chlordanes (Figures 9d, 10d), at 1.2 to 11 ng/g wet weight or roughly the median to the maximum observed value, Table 8), as well as total DDT (Figures 8e, 9e), at 5 to 130 ng/g wet weight, which were above the median to the maximum observed value, Table 8). Nearby surficial sediment sites also had high levels of these pesticides in the SCB: 7.4 ng/g dry weight or above the 90th percentile for total chlordanes (Figure 15), and 95 ng/g dry weight or 90th percentile for total DDT (Figure 16, Wong et al. 2026). These residues may be likely due to past agricultural activity and use of the two legacy insecticides in this region. This may be particularly true for DDTs, given the presence of fresh DDT in bivalves at and near Channel Islands Harbor, and the greater proportion of the reductive dichlorination product DDD there and in bivalves of Santa Barbara County (Figure 7b). These observations suggest the potential of a localized source of DDTs along the coastline of Santa Barbara County and Channel Islands Harbor, other than the large regional sources of the Palos Verdes Superfund site and the offshore dumpsites.

The low detections of PFOS and PFOA in SCB bivalves (Figure 4) suggests that such contamination in embayment surficial sediments was not likely a major source to mussels and bivalves. Bight '23 sediments in Los Angeles/Long Beach Harbor, Newport Harbor, and San Diego Harbor had levels of PFOS+PFOA ranging from 0.8 to 68 ng/g dry weight (Wong et al. 2026). However, PFOA was only detected in bivalves at one site, in Ventura Harbor, and then only at a very low level of 0.19 ng/g. Further discussion of potential PFAS sources to bivalves will be noted in our evaluation of temporal trends below.

Comparison with Bight '18 sport fish

Contaminant levels in Bight '23 bivalves were generally lower than those observed in biota targeted in Bight '18, specifically sport fish. The mean total DDT bivalve levels (8 ng/g) were considerably less than those of Bight '18 fish species (means up to 50 ng/g), as were levels of

total DDT (mean of 6 ng/g in bivalves, means of 25-50 ng/g in fish), and of mercury (means of 0.005 µg/g in bivalves, and means of 0.1 µg/g in fish) (McLaughlin et al. 2020), although there is considerable scatter in concentrations of all species. Sport fish species are generally higher in trophic level than bivalves, which are filter feeders consuming phytoplankton and zooplankton. Thus, bioaccumulative contaminants would biomagnify to a greater degree in the former than in the latter, which would be consistent with the differences in contaminant levels observed. Both selenium and arsenic had similar levels in both bivalves (mean concentrations of 0.5 and 1 µg/g, respectively) and fish (mean concentrations of 0.35 to 1.5 µg/g, respectively), suggesting that exposure, likely from natural origins as previously discussed, affected these aquatic species to similar extents.

Of those contaminants measured in Bight '23 bivalves, only PCBs exceeded the OEHHA threshold of not consuming more than 3 or 7 servings weekly, with 15% and 26% of samples respectively (Table 2). This was also the case for sport fish in the previous Bight '18 cycle, in which a quarter of the composites exceeded this same threshold (McLaughlin et al. 2020). However, 71% of Bight '18 fish composites also exceeded OEHHA thresholds for mercury for the least restrictive threshold of 7 weekly servings, and over half (54%) exceeded thresholds of 3 weekly servings (McLaughlin et al. 2020). The greater exceedances observed in Bight '18 sport fish, compared to bivalves, are consistent with these species being present at a greater trophic level than bivalves, which would make them more susceptible to biomagnification of bioaccumulative contaminants.

Comparison to previous bivalve monitoring in the SCB

Bight '23 is the latest monitoring program for bivalves in the SCB. Considerable monitoring has been done in the past, most notably by NOAA's Mussel Watch Program, which has been evaluating chemical contaminants in bivalves since its inception in 1986 (Sericano et al. 2014). Prior to this national-level Mussel Watch Program was the California Mussel Watch, which has monitored bivalves since 1977 (Melwani et al. 2014).

In general, contaminant concentrations in Bight '23 bivalves were considerably lower than those at the start of other SCB bivalve monitoring programs, which coincided with periods over which sources for many of these contaminants were curtailed. California Mussel Watch, at its inception in 1977, found SCB mussel concentrations on the order of 10,000 to 100,000 ng/g lipid weight for DDTs and PCBs (Melwani et al. 2014), values that dwarf the mean lipid-normalized concentrations today (1400 and 800 ng/g for DDTs and PCBs, respectively, Table 1). Even maximum concentrations observed today (14,000 ng/g and 5,600 ng/g lipid, respectively) are on the lower end of the scale previously observed (Melwani et al. 2014). Concentrations of both PCBs and DDTs decreased between the late '70s and early '80s and in 2010. By that time, lipid-normalized bivalve concentrations in the SCB were 1,000 to 10,000 ng/g for DDTs and 500

to 10,000 ng/g for PCBs; similar decreases over this time period were also observed for chlordanes (Melwani et al. 2014). These decreases are consistent with environmental half-lives for DDT in bivalves of 10-14 years nationally between 1986-2009, based on NOAA Mussel Watch (Sericano et al. 2014), and are likely due to source control measures that started in the 1970s and 1980s. These occurred both nationally, such as the banning of PCBs in 1979 under the Toxic Substances Control Act, as well as regionally, such as the closure of the Montrose DDT production plant in 1982 and subsequent investigations that led to the declaration of Superfund status for the Palos Verdes Shelf, USEPA 2024. The magnitude of these decreases is in keeping with those observed in other biomonitoring programs over time, such as the 16-87% decrease in legacy organochlorine contaminants observed in Great Lakes herring gulls between the 1970s, the same time period for which these legacy contaminants were phased out, and the 1990s (Hebert et al. 1999, Fox et al. 2002)

A more in-depth evaluation of spatial and temporal trends of bivalve contaminant levels, at least since the mid- to late-1980s, can be evaluated by comparing the readily available values reported from NOAA Mussel Watch over time with results from Bight ’23. For this comparison, NOAA Mussel Watch data (NCCOS 2026) was obtained for all available years along the mainland coast of the SCB, for the target analytes analyzed by Bight ’23. For this temporal comparison, total DDT is defined as the sum of 2,4’- and 4,4’-DDD, DDE, and DDT across all datasets, as DDMU, analyzed by Bight ’23, was not analyzed by Mussel Watch prior to 2018 (Swam et al. 2024). As well, total PCBs for both datasets are defined in this temporal discussion as the sum total of the core PCBs analyzed in all Mussel Watch cycles. These consist of 18 congener groupings including coeluting congeners, corresponding to 18 chromatographic peaks, and provide for the most consistent comparisons across the decades as feasible: PCBs 8+5, 18, 28+31, 44, 52, 66+80, 101+84+90, 105+127, 118+108, 128+167, 138+164+163, 153+132+168, 170+190, 180+193, 187+182, 195+208, 206, and 209 (Swam et al. 2024). The only one of these Mussel Watch groupings not measured by the Bight program is PCB 209; other PCBs reported include co-eluting congeners (e.g., Bight ’23 PCB 153 is 153+132+168).

Bight-wide concentrations of the inorganic target analytes suggests that while some decreases have occurred since the 1980s, both across the SCB as a whole and at specific locales within the SCB, concentrations have generally not appreciably changed from at least the 1990s to today. For arsenic and selenium, the two inorganic analytes for which residues in bivalves are likely from natural sources, there were decreases in concentration from the mid-1980s to the early 1990s, as visualized by a three-point moving average (Swam et al. 2024) of the annual means of all sites sampled within that year (Figure 18). That said, there were no apparent temporal trends in concentration distributions across the SCB as a whole (Figure 5a,c), as evidenced by non-significant Spearman correlations over time (Table 17). These observations are consistent with previous observations by Mussel Watch. In 2010, concentrations of arsenic were 10 ng/g

dry weight (Edwards et al. 2014) or about 1.5 ng/g wet weight, based on a typical 80-85% moisture content for mussels (Moniruzzaman et al. 2021, Chiefa et al. 2025). These values are comparable with currently observed values (Table 1, Figures 5a and 6a). Both elements appeared to have marginally greater concentrations in 2018 than historically found in the SCB (Swam et al. 2024). Bivalve concentrations of both arsenic and selenium were lower in Bight '23 than they were in the 1980s by approximately 2-3-fold, particularly in Santa Barbara and Ventura Counties (Figure 6a,c). However, this amount was not significant in the Channel Islands Harbor region (Table 18) and is also within the range in concentrations across the SCB for both elements then and now (Figure 6a,c). Accordingly, it is unclear if these changes represent decreases over the last four decades, or if they are part of the variability associated with these measurements. Mercury had some elevated levels in the anthropogenically impacted harbors of Los Angeles/Long Beach and San Diego, as noted (Figures 2b, 3b) but otherwise had similar temporal trends (e.g., 0.1 ng/g dry weight or ca. 0.015 ng/g wet weight in 2010, Edwards et al. 2014) as the other two elements, aside from not having elevated levels in 2018 (Figure 5b). These observations are consistent with mercury having local point sources in the SCB (Swam et al. 2024), natural or anthropogenic, with the fact that these harbors have heavy human impacts suggesting the latter. Mercury levels in Bight '23 were up to an order of magnitude lower than those observed in the 1980s in Santa Barbara and Ventura Counties, and at scattered locations in Los Angeles/Long Beach Harbors and San Diego (Figure 6b). These observations are consistent with the decrease in concentrations observed between 1987 and 1995 (Swam et al. 2024), and with significant decreases observed for mercury since the 1980s (ρ = -0.36, $p < 0.001$) and continuing since 1995 (ρ = -0.25, $p < 0.05$) in San Diego County (Table 18). The general lack of temporal trends both Bight-wide (Figure 5) and outside the areas noted above (Figure 6) suggests that bioavailable arsenic, mercury, and selenium at the SCB shoreline have remained more or less constant since at least the mid-1990s, despite significant increases in selenium levels in Los Angeles/Long Beach Harbor, Newport Bay, and San Diego County from mid-1980s to mid-1990s (Table 18).

All three classes of legacy organochlorine contaminants had significant decreases Bight-wide, particularly since the 1980s (Spearman ρ values from -0.42 to -0.55, $p < 0.03$, Table 17), but only limited evidence of decreases since then, and only in specific locales (Table 18). As with the inorganic analytes, some decreases from the mid-1980s through the 1990s can be visualized (Swam et al. 2024a) with three-point moving averages (Figure 18). Median chlordane concentrations decreased from 0.9 ng/g wet weight to 0.3 ng/g wet weight from 1998 to 2018 (Figure 5d), consistent with a slight decreasing trend over this time period (Melwani et al. 2014, Swam et al. 2024a). Bight '23 median concentrations were 1.5 ng/g wet weight, which is on par with observations in 2010 of 10 ng/g dry weight or approximately 1.5 ng/g wet weight (Edwards et al. 2014), and the overlap in the range of distributions (Figures 6b) suggests that differences

between Bight ‘23 bivalve levels and older data is likely due to intrinsic variability in the annual datasets of these studies. Median total DDT concentrations dropped from 4 to 1 ng/g wet weight from 1988 and 1997 (Figure 5e), an approximate four-fold decrease as noted for that time period in the last Mussel Watch assessment (Swam et al. 2024a). This decrease is consistent with DDT control measures adopted in the 1970s and early 1980s (Sericano et al. 2014). However, there was little evidence of further decreases from 1995 to Bight ‘23 (Figure 5e). In 2010, West Coast mussel DDT levels ranged from 1-283 ng/g dry weight and averaged 21.5 ng/g dry weight (Edwards et al. 2014, Melwani et al. 2014), corresponding to a wet weight of 0.2 to 42 ng/g and an average of approximately 3 ng/g, on par with Bight ’23 observations (Figure 5e). This contrasted with the decreases of DDTs in some SCB fish species between 2009 and 2022 (McLaughlin et al. 2020, USEPA 2024); however, it should be noted that fish live and move within the water column and may thus be exposed to bioavailable PCBs in the pelagic and/or benthic zones (McGill et al. 2024), which may include extremely high concentrations from the sediments of the Palos Verdes Superfund site (USEPA 2024) and the dumpsites further offshore (Kivenson et al. 2019, Wu et al. 2025). For the former, at least, decreases in surficial sediment concentration from burial since at least 2009 are apparent (USEPA 2024), suggesting that the decreases in fish concentrations since that time may have been due, at least in part, to decreased exposure of bioavailable DDTs from sediments. Bivalves, sessile at shorelines, would be less coupled to offshore levels of bioaccumulative contaminants in the water column and sediments, and may not necessarily be affected by changes in concentration over time. As noted above, concentrations of contaminants in bivalves were generally lower than that in fish offshore, consistent with lower exposure to DDTs at shorelines. There were no apparent temporal trends in total PCB concentrations since 1988, which was consistent with Mussel Watch observations in 2010 (Edwards et al. 2014, Melwani et al. 2014) and in 2018 (Swam et al. 2024a). As with DDTs, PCBs have also generally declined in SCB fish since 2009 (McLaughlin et al. 2020), likely for the same reason as for DDTs given that both classes of compounds bioaccumulate in a similar manner (Gobas et al. 1993).

There is some evidence that bivalves in some parts of the SCB have lower concentrations of some legacy organochlorine contaminants now than in the 1980s. Chlordanes were greater in the 1980s than they were in Bight ‘23 by an order of magnitude at a single site in Ventura County (Figure 6d), but were generally similar elsewhere; no significant changes were observed there (Table 18). Both Los Angeles/Long Beach Harbor and San Diego County had significantly decreasing concentrations of DDTs since the mid-1980s, which continued in San Diego since the mid-1990s. For these locales, concentrations changed by order-of-magnitude differences for DDTs (Figure 6e); this was also observed significantly (Table 18) for PCBs between the 1980s and now. These observations are consistent with the Bight-wide decreases previously discussed. Newport Bay also showed decreases for PCBs (Table 18), both since the mid-1980s (ρ

= -0.57, $p < 0.01$) and since the mid-1990s ($\rho = -0.68$, $p < 0.01$). Interestingly, Channel Islands Harbor, which had the highest concentration observed in Bight ’23 bivalves (Figures 2e, 3e, 6e) is near Point Mugu Lagoon, site of elevated concentrations of DDTs (ca. 10 ng/g wet weight) from 1990 to 2018 (Swam et al. 2024a) at levels on par with the closest Bight ’23 site, ORBH (Figures 2e, 3e). This observation supports localized sources of DDTs in this locale.

The fact that PFOS was not detected, and PFOA was only detected in 1 bivalve sample in Bight ’23 (Figure 4), is consistent with past surveys of the SCB, in which PFAS was detected infrequently and at low concentrations with little correlation to sediment levels. NOAA Mussel Watch ’18 also only found a single detectable value for PFOS+PFOA (Swam et al. 2023). In that case, PFOS was measured at 0.4 ng/g wet weight at Point Mugu Lagoon, which is not far either in concentration or in geography from the single detection of PFOA at 0.19 ng/g in Ventura Harbor. Scattered residues of *N*-ethylperfluorooctanesulfonamidoethanol (N-EtFOSE), perfluorooctanesulfonamide (PFOSA), and the long-chain carboxylic acids perfluorododecanoic acid (PFDoA), perfluorotridecanoic acid (PFTrDA), perfluorotetradecanoic acid (PFTeDA), and were also detected, with an overall detection frequency for PFAS of approximately 6%. Only scattered residues of PFAS compounds were observed in paired sediment samples by Mussel Watch ’18; at the three sites where PFAS was detected, PFAS was also found in bivalves; however, other sites with detected PFAS in bivalves did not have detectable PFAS in paired sediment sites (Swam et al. 2023). It is possible that PFAS levels in SCB bivalves are controlled by surface water concentrations rather than those of nearby sediments, which cannot be evaluated in the current Bight cycle. This is consistent with the observation that PCB congener levels in some SCB bivalves differed from those observed in nearby sediments (Otim 2026), indicating that bivalve exposure was less coupled to contaminants in sediments and likely more coupled to that in waters in which they filter-feed.

The levels of PFAS compounds observed in Bight ’23 are also consistent with surveys a decade previous (2009-2010), in which Mussel Watch found only detectable PFDoDA and perfluoroundecanoic acid (PfUnDA) sporadically (28% and 11% detection frequency), with mean concentrations of 0.2 and 1.8 ng/g dry weight (Maruya et al. 2014a), values comparable to the 2018 and Bight ‘23 measurements. The PFAS measurements across all three surveys (Mussel Watch 2009-2010, Mussel Watch 2018, and Bight ’23) indicate that PFAS levels in SCB bivalves are intermittent and have remained at the same low level for at least the last decade and a half.

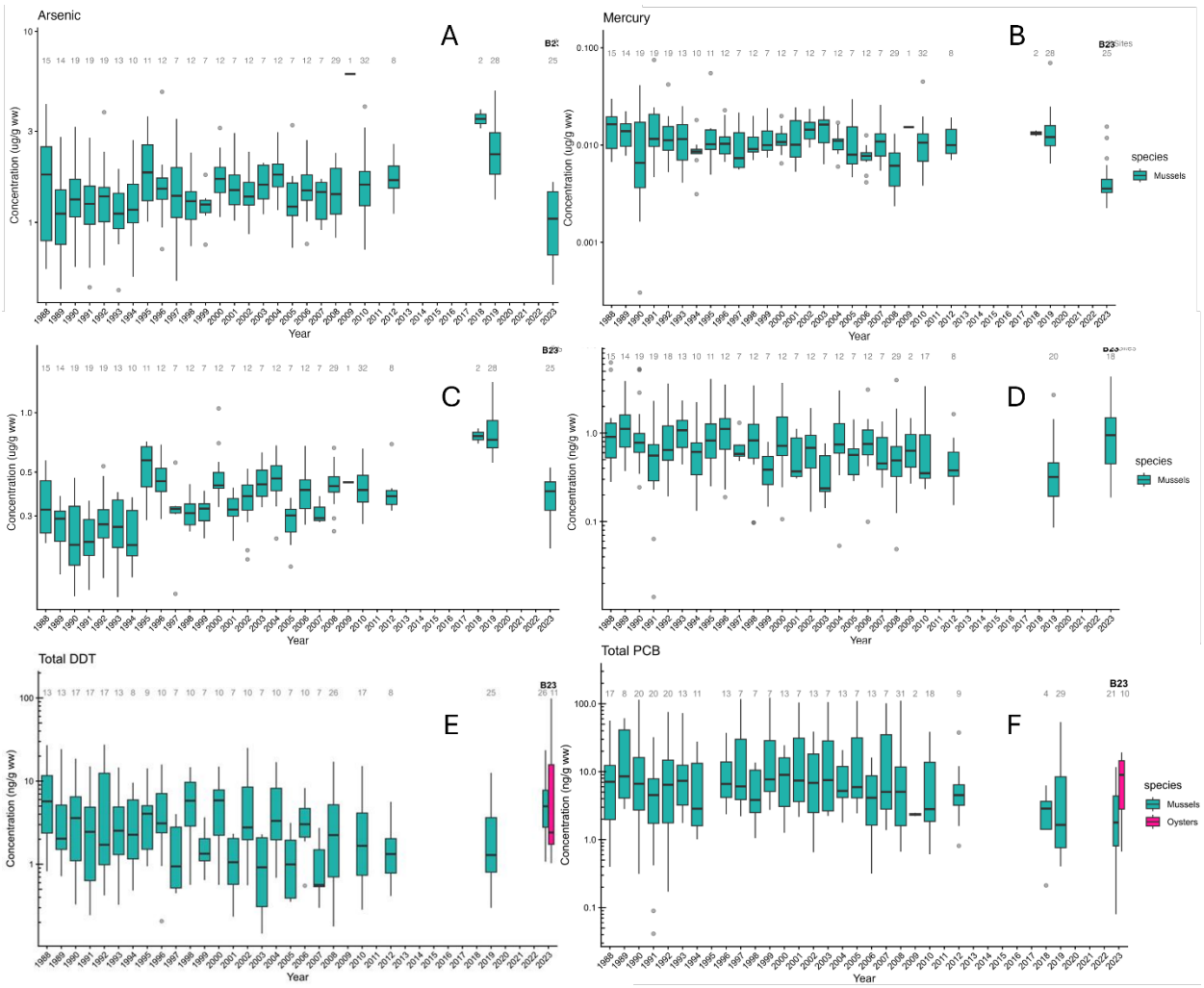

Figure 5. Box plots of bivalve wet weight concentrations for (A) arsenic, (B) mercury, (C) selenium, (D) total chlordanes, (E) total DDT, and (F) total PCBs from the Southern California Bight mainland coast over time, from Bight '23 and NOAA Mussel Watch. Numbers of samples in datasets available for each year indicated above each box plot.

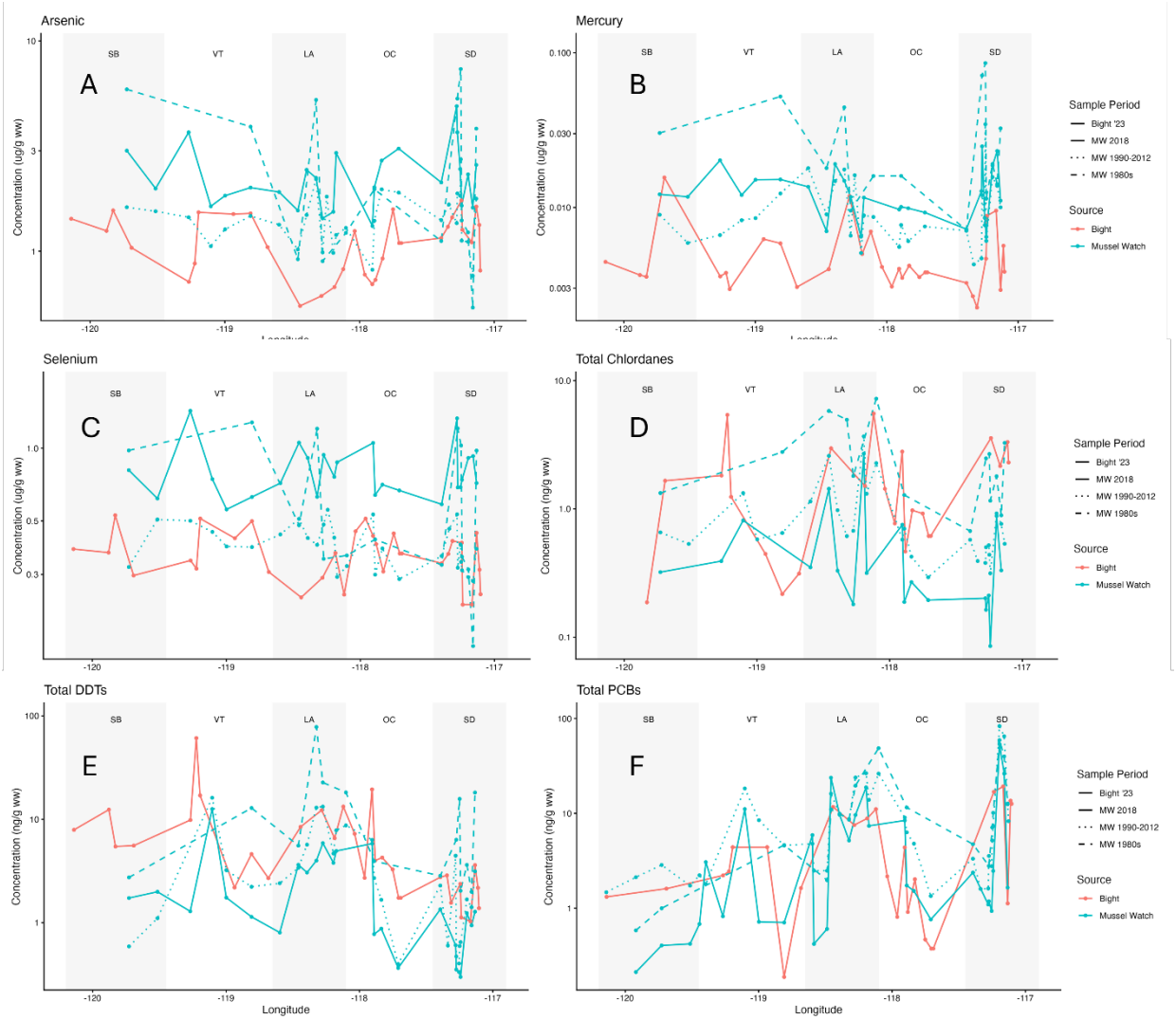

Figure 6. Mean wet weight bivalve concentrations of (A) arsenic, (B) mercury, (C) selenium, (D) total chlordanes, (E) total DDT, and (F) total PCBs from the Southern California Bight mainland coast as a function of longitude, from Bight '23 and NOAA Mussel Watch (surveys from 1980s, 1990-2012, and 2018-2019).

V. CONCLUSIONS

The Bight '23 Program provided a regional assessment of the Southern California Bight's bivalve chemistry through analysis of multiple chemical constituents. Based on the results of this survey, the Chemistry Technical Committee had several conclusions, as follows:

<u>Bivalve concentrations were consistently greater in more embayments than along the open coast.</u>

Bivalves in Bight '23 had greater concentrations of many anthropogenic contaminants (e.g., mercury and organic compounds) at embayment sites subjected to greater urbanization and/or

anthropogenic activity, such as Marina del Rey, Los Angeles/Long Beach Harbor, Newport Bay, and San Diego Bay. Some contaminants, such as DDT, were also elevated at sites impacted by previous activity, such as potential agricultural inputs in Channel Islands Harbor. In contrast, some inorganic contaminants (i.e., selenium, and to a lesser extent arsenic), which are not generated by industrial activities in the SCB and also have natural origins, had more consistent concentrations spatially in bivalves.

Bivalve concentrations were consistent with known historical data.

The spatial distributions of bivalve chemical contamination in Bight ’23 were similar to those observed in previous regional bivalve monitoring efforts e.g., NOAA’s Mussel Watch Program. For decades, Mussel Watch also observed greater concentrations of metals, legacy organic contaminants, and CECs in bivalves at areas more impacted by urbanization and anthropogenic activity, including in the SCB. Concentrations measured in Bight ’23 were also similar to concentrations measured by Mussel Watch over the last few decades, consistent with previous assessments that concentrations of many contaminants have leveled off over time. There is clear evidence of concentration decreases since the 1980s, and limited evidence of some more gradual decreases for some analytes at specific locales since the 1990s.

None of the bivalve samples collected in Bight ‘23 exceeded the OEHHA “do not consume” consumption guidelines.

Even the bivalves with the greatest chemical residues could be safely eaten. Of the analytes measured in Bight ’23, only PCBs exceeded current OEHHA human guidelines for consumption of seafood, at shoreline areas known to have high concentrations of PCBs (i.e., San Diego Bay, Los Angeles/Long Beach Harbors, Newport Bay). Non-*ortho* and mono-*ortho* PCB congeners, which have the greatest Ah-receptor affinity and hence dioxin-like toxicity, were typically rarely detected, and at low concentrations when observed. Mercury, selenium, chlordanes, and DDT were present at concentrations below OEHHA advisory levels. While OEHHA currently does not have advisory levels for PFAS, very little PFAS was detected in Bight ’23 bivalves, and detected values were below advisory levels set in other jurisdictions. These conclusions are consistent with similar findings from past bivalve monitoring in the SCB, i.e., those of the Mussel Watch Program.

VI. RECOMMENDATIONS

Based on the efforts from Bight ’23, both the Chemistry Technical Committee and the Sediment Quality Planning Committee agree on the following recommendations to follow up on current survey results, or to improve future implementations of the regional survey (e.g., Bight ’28).

Recommendation 1: Use proxies for chemicals in the aqueous phase, including bivalves, in future Bight cycles.

The goal of Bight chemistry is to evaluate occurrence and exposure to chemical stressors. This is typically done through monitoring of environmental media integrating such exposure, which for many hydrophobic and legacy chemicals are sediments and biotic tissues. However, Bight '23 has found that some chemical analytes are more likely to be present in the aqueous phase, not just in the environmental phases monitored, and perhaps more so. These include PFAS, tire-wear compounds, and neonicotinoid insecticides, as observed in Bight '23 surficial sediments (Wong et al. 2026). Concentrations of analytes in the water column may affect those in other environmental media, including biota. For example, Bight '23 bivalves had little PFAS, despite the presence of PFOS and PFOA in impacted bays, marinas, and ports. Such sediment contamination is unlikely to be a source of PFAS to bivalves, as those along embayment shorelines likely accumulated contaminants in the water and suspended particulate matter in contact with them. Our bivalve data suggests that water column levels of PFAS right along embayment shorelines are low, and perhaps different than those overlying the contaminated surficial sediments. Thus, integrators of aqueous-phase contaminants are valuable to understand exposure levels to the SCB, particularly for trace-level contaminants for which collecting and measuring in the water itself can be time-consuming and difficult.

Accordingly, further monitoring of water column integrators in future Bight cycles is recommended. Such integrators can take several forms. The first would be suitable organisms such as bivalves. These provide complementary information to the monitoring of chemical contaminants in fish. Both types of seafood are consumed, and continued monitoring of both would provide long-term baselines of levels and potential exposure risks. In addition, the two types of biota monitor contamination in different parts of the SCB, and thus evaluation of them provides further complementary data with regards to coastal chemical contamination exposure. Bivalves are exposed to contamination right along the coast in sediments and particularly surface waters, given the lack of correlation observed for bivalve contaminant residues with nearby Bight sediment contaminants. On the other hand, fish are exposed where they are found and where they move. Such regions may be further offshore, and be depth-dependent (e.g., benthic and demersal fish would be more exposed to sediment-borne contaminants than pelagic fish). Exposure may differ between the two areas. Indeed, caged bivalves could be deployed offshore to integrate chemical concentrations in the water column. Finally, bivalves offer an opportunity to evaluate long-term spatial and temporal trends of contamination as we have previously noted, given the decades of monitoring for them in the SCB. Biota monitoring could take place in alternating cycles, with fish monitoring done in one cycle and bivalve monitoring in the next, depending on logistics and the needs of the program.

The second type of water-column integrator would be passive samplers. These would provide time-weighted average dissolved-phase concentrations, without the complications of keeping transplanted biota alive. For some analytes such as DDT and PCBs, a timeline of chemical exposure in the water column can be established (Zeng et al. 1999, Zeng et al. 2002, Zeng et al. 2005, Fernandez et al. 2012, Fernandez et al. 2014, Lohmann et al. 2023, USEPA 2024) that can provide insights into temporal changes, if any, of such chemicals in southern California coastal waters. It may also be able to identify possible additional sources of contaminants in the region, as suggested for DDTs at and near Channel Islands Harbor based on sediment and bivalve contaminant levels and compositions now and historically.

Decisions for monitoring SCB environmental media also include analyte choice, e.g., OEHHA has promulgated seafood consumption guidelines for cadmium, which is measured in surficial sediments in the Bight Program (Wong et al. 2026) but not in biota. The Bight Program analyzes a smaller number of chemical contaminants than does NOAA Mussel Watch. The choice of analytes to be monitored is subject to the needs of the program, budgetary and logistical constraints, and suitable prioritization, as discussed in the next recommendation below.

Recommendation 2: Incorporate risk-based CEC prioritization process for future Bight cycles.

The Bight Program is an opportunity to see if CEC occurrence in the region may be a potential issue. However, it is not necessarily clear *a priori* which CECs are of greatest concern to human or ecosystem health, and therefore should be monitored. The other side of that coin is also true, in that it is not clear what CECs can be de-prioritized.

Risk-based categorization and prioritization can be used to address such issues. A risk-based approach for CECs was recommended and adopted by the State of California. These were initiated by the State Water Board's first CEC Expert Panel for aquatic ecosystems in 2012 (Anderson et al. 2012), for which strategies can be incorporated to calculate risk and guide prioritization (Drewes et al. 2023). The goal of such frameworks is to rank CECs based on occurrence and risks to human and ecosystem health, using a consistent prioritization framework to develop monitoring and management recommendations. Such frameworks are intended to be periodically updated, as new knowledge, techniques, and CECs come into play (Drewes et al. 2023). Similar approaches have been taken regionally, such as in the San Francisco Bay (Sutton et al. 2024). A current effort is underway to develop a prioritization framework for prioritizing and managing CECs for Southern California, to address specific regional specific issues and needs. This joint project between SCCWRP and its member agency Commission's Technical Advisory Group (CTAG) began in fall 2025 and is slated to report in spring 2027. Recommendations from risk-based categorization and prioritization should be considered in future Bight cycles. This has been recommended for monitoring of Bight

sediments (Wong et al. 2026), and can also be extended for analogous monitoring of biota including bivalves.

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APPENDIX A. CHARACTERISTICS OF THE SAMPLING SITES

Description of the sites where mussels and oysters were collected, including embayment type, population density and percentage of land use. Counties are Santa Barbara (SB), Ventura (VT), Los Angeles (LA), Orange (OC) and San Diego (SD).

County	Site Name	Location Class	Total area (sq km)	Population per sq km	Developed (%)	Forest (%)	Open (%)	Wetlands (%)	Open water (%)
SB	Arroyo Hondo	open coast	185.42	340.5	5.02	41.26	53.42	0.21	0.09
SB	Goleta Slough	open coast	313.9	136853.2	39.67	31.63	27.44	0.94	0.32
SB	Santa Barbara	enclosed	208.66	101851	45.95	34.23	19.09	0.33	0.41
SB	Dev Slough	open coast	161.42	25673.6	11.49	41.88	45.58	0.6	0.44
VT	Ventura Harbor	enclosed	71.21	32903.2	35.95	1.87	61.9	0.21	0.07
VT	Channel Islands Harbor	open coast	109.27	188301.8	75.9	0	21.65	1.93	0.53
VT	Ormond Beach	open coast	142.64	18294.3	22.62	0.26	67.01	8.79	1.32
VT	Leo Carrillo	open coast	132.21	1622.5	9.27	1.25	88.93	0.32	0.22
LA	Malibu Beach	open coast	249.65	223556	44.49	4.15	50.68	0.57	0.11
LA	Point Dume	open coast	156.1	10382.4	20.34	6.89	72.1	0.59	0.08
LA	Marina Del Rey	enclosed	167.57	216843.1	54.96	2.72	41.72	0.49	0.12
LA	Alamitos Bay	enclosed	183.84	407595.1	98.58	0	1.25	0.05	0.12
LA	LA River	open coast	31.81	72371.8	93.28	0	2.53	0.14	4.05
LA	Cabrillo Beach	open coast	31.81	72371.8	93.28	0	2.53	0.14	4.05
LA	Bolsa Chica	enclosed	321.98	699862.4	90.53	0.01	6.13	2.23	1.09
OC	Huntington Beach Wetland	enclosed	9.24	14252.7	78.88	0	11.01	7.51	2.61
OC	Newport Bay	enclosed	274.13	475943.5	82.43	0.01	15.66	1.27	0.63
OC	Newport Beach	enclosed	274.13	475943.5	82.43	0.01	15.66	1.27	0.63
OC	Crystal Cove	open coast	141.92	90174.8	50.08	0.41	48.58	0.72	0.21
OC	Aliso Creek	open coast	234.55	230997.4	59.59	0.79	38.7	0.79	0.14
OC	Dana Point	enclosed	111.29	76916.6	49.99	0.45	48.99	0.44	0.13

OC	Oceanside	open coast	149.61	87015.3	50.53	0.59	46.56	2.09	0.23
OC	Agua Hedionda	enclosed	109.94	76247	70.92	0.22	25.84	1.52	1.49
OC	Batiquitos	enclosed	198.14	165417	65.48	0.42	32.35	0.71	1.05
SD	Mission Bay	enclosed	83.39	142386	89.01	0.11	8.77	0.39	1.72
SD	SD Bay Kellogg Beach	enclosed	557.76	980134.9	77.78	0.07	20.5	1.12	0.52
SD	SD Bay Ferry Landing	enclosed	557.76	980134.9	77.78	0.07	20.5	1.12	0.52
SD	SD Bay Pepper Park	enclosed	557.76	980134.9	77.78	0.07	20.5	1.12	0.52
SD	SD Bay Chula Vista	enclosed	557.76	980134.9	77.78	0.07	20.5	1.12	0.52
SD	Imperial Beach	open coast	70.11	70815.9	84.4	0.34	12.01	2.45	0.79

APPENDIX B. LABORATORY QUALITY ASSURANCE/QUALITY CONTROL

Four laboratories performed sample extraction and analysis of Bight ’23 bivalves (Table 4) for targeted analytes (Table 5). To ensure that bivalve chemistry data generated among the study participants was comparable and complete, a performance-based approach to QA/QC was adopted, as used in previous regional surveys (Gossett et al. 2003) including for chemical analysis in biota (McLaughlin et al. 2020) adapted for bivalves. This approach, carried out in accordance with the Bight ’23 Quality Assurance Manual (Bight ’23 Sediment Quality Committee 2023), aimed to meet common DQOs for target analytes with regards to sensitivity, accuracy, and precision, yet allowed for flexibility by each participating laboratory to utilize its own protocols. Participating laboratories adhered to common quality assurance/quality control (QA/QC) practices, performed routine analysis of certified reference materials (CRMs), and participated in an inter-laboratory calibration study prior to analysis.

Based on the QA/QC results detailed below, the Bight ‘23 Chemistry Technical Committee accepted data, as most QC criteria were met and deviations were deemed not to impart additional and meaningful uncertainty in measurements. No data was removed, excluded, or rejected from the study and its database. However, deviations from QC criteria were flagged by the analyzing laboratory in the study database for users to make their own decisions regarding data quality.

Table 4. Bivalve chemistry laboratory effort for Bight '23. Laboratory name abbreviations: CLAEMD = City of Los Angeles, Environmental Monitoring Division; CSD = City of San Diego; OC San = Orange County Sanitation District.

Parameter	CLAEMD	CSD	OC San	Physis	Total sample number
Lipid	35	27	26	35	123
Metals	35	27	26	35	123
Polychlorinated biphenyls (PCBs)	35	27	26	35	123
Organochlorine pesticides (OCs)	35	27	26	35	123
Per- and polyfluorinated alkyl substances (PFAS)	0	0	0	122	122
Total number of samples	140	108	104	262	614

Table 5. Bivalve chemistry target analytes for Bight '23.

Target analyte group	Number of analytes	Target analytes
Inorganics	3	Arsenic (As), Mercury (Hg), Selenium (Se)
Polychlorinated biphenyls (PCBs)	43	PCB congeners 8, 18, 28, 37, 44, 49, 52, 66, 70, 74, 77, 81, 87, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 138, 149, 151, 153, 156, 157, 158, 167, 168, 169, 170, 177, 180, 183, 187, 189, 194, 195, 201, 206
Organochlorine pesticides (OCs)	12	4,4'-DDT, 2,4'-DDT, 4,4'-DDD, 2,4'-DDD, 4,4'-DDE, 2,4'-DDE, 4,4'-DDMU, α-chlordane, γ-chlordane, *cis*-nonachlor, *trans*-nonachlor, oxychlordane
Per- and polyfluorinated alkyl substances (PFAS)	2	perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA)
Other parameters	1	Lipid content

Reporting Limits

To achieve study goals, minimum target reporting limits (RL) for each analyte (Table 6) were set forth in the Bight '23 Quality Assurance Manual.

Participant-specific minimum RLs were lower than or comparable to the targets with only minor exceptions, as discussed below. This observation is consistent with the fact that all laboratory blanks were non-detects. Therefore, the analyses were performed with adequate sensitivity, as most of the data met target RLs (Table 3).

Exceptions are as follows. The higher reporting limits for PCBs were only for one laboratory, and then only for a single congener, PCB 8, due to the presence of an interference. Reporting limits greater than the Bight-wide RL for organochlorine compounds affected only one laboratory, and only for cyclodiene compounds. This laboratory reported instrumental issues with the first samples to come in that were later corrected. Those for PFAS affected only a single batch of samples.

The RLs among the laboratories generally varied by an order of magnitude, except for mercury (Table 3). Some laboratories elected to use the required RL, even if they were capable of improved sensitivity. Other laboratories, however, elected to use the lowest RL they could achieve. Since the data from the laboratories are combined, there should ideally be a narrower

range of RLs. One future option is to require laboratories to report data only using the current RL (to not utilize lower RLs). This has the advantage of straightforward comparison to historical data acquired with similar RLs, but has the potential disadvantage that such censored data may confound further analysis and interpretation efforts. Alternatively, in a coordinated effort all laboratories could utilize lower RLs. This has the advantage of keeping methods state-of-the-art and continuing to detect and quantify legacy contaminants as they decrease in environmental concentration.

It should be noted that for PFAS, field and equipment blanks were not possible for bivalves, unlike the case for sediments (Wong et al. 2026). For sediment samples in Bight '23, field blanks were sealed jars of water certified to be PFAS-free from the vendor, and equipment blanks consisted of rinsate of such water onto collection equipment as per the Bight '23 Field Manual. This was done to determine if potential exposure to PFAS-bearing materials, which are common, during sample collection, would affect results. No evidence was found in sediments for such contamination (Wong et al. 2026). However, there was no realistic way to implement such blanks for bivalve collection. Bivalves were shut during collection and depuration, prior to shucking, and homogenization of soft tissues to create composite samples were done with non-PTFE-bearing materials. These precautions make it unlikely that contamination by PFAS-bearing materials was a significant factor in bivalve analysis for Bight '23. Future efforts should evaluate the potential for suitable field and equipment blanks for PFAS.

Table 6. Achieved reporting levels in bivalves (wet weight). Percent success is based on the number of samples meeting the required reporting level (RL). N/A=not applicable as a required reporting level was not set. *RL is for each individual analyte.

Analyte (analyte class)	Units	Required reporting level (RL)	Achieved range of RLs	Percent success
Arsenic (inorganic)	µg/g	0.3	0.05-0.28	100%
Mercury (inorganic)	µg/g	0.02	0.00002-0.02	100%
Selenium (inorganic)	µg/g	0.4	0.05-0.37	100%
Polychlorinated biphenyls (PCBs)*	ng/g	1	0.5-6.06	72%
Organochlorine pesticides (OCs)*	ng/g	1	0.5-2.02	80%
Per- and polyfluorinated alkyl substances (PFAS)*	ng/g	1	0.5-15	84%
Lipid content	% by wt.	0.1	N/A	N/A

Interlaboratory Comparison Exercises

Prior to analysis of field samples, reference bivalve samples were selected and prepared, and analyzed by all participating labs to assess the inter-laboratory comparability of analytical results. Metals and organic measurements were each evaluated using two types of reference materials: certified reference materials with assigned certified or reference values, and a reference material generated from bivalve tissues with regionally relevant matrices and ranges of expected target analyte concentrations. Reference materials were analyzed in triplicate. As noted below, PFAS was measured and assessed only using field reference materials due to the unavailability of certified reference materials for these analyte classes, and the resulting intercalibration results are for informational purposes only. Some laboratories participated in the intercalibration exercise for their own interests, but did not perform bivalve measurements for Bight ’23. A summary of intercalibration results is in Table 7 with further details in Appendix C, and was considered suitable by the Bight ’23 Chemistry Technical Committee.

Performance-based Quality Control Goals and Success

Quality Control (QC) goals are described in detail in the Bight ’23 Quality Assurance Manual (Bight ’23 Sediment Quality Committee 2023) and summarized along with the results in Table 8. Completeness, defined as the proportion of the expected data that was collected in the measurement process, was 100% for all analyte groups except for PFAS, for which it was 98%. The frequency success of running method blank and reference material QC samples was 100% throughout. The accuracy and precision success of the QC samples was typically 86% to 100% with two exceptions, both for organochlorine pesticides. The first was matrix spike accuracy at 73%, and the second was reference material accuracy at 45%. These were addressed by the Sediment Chemistry Technical Committee as described below, and data from the affected sample batches were accordingly accepted. Overall, most of the QC criteria were met. Deviations did not impart additional, meaningful uncertainty in measurements. Consequently, no data was removed, excluded, or rejected from the study and its database. However, deviations from QC criteria were flagged by the analyzing laboratory in the study database for users to make their own decisions regarding data quality, and are discussed in detail below.

Inorganics

NIST SRM 2976 Trace Elements and Methylmercury in Mussel Tissue (Freeze-Dried) was used to test method accuracy. Laboratories were required to obtain concentrations within 30% of the certified or reference value for all analytes. Blank spikes and duplicates into pure laboratory water were used to assess precision. Complete 100% success was achieved, as all QC parameters were met (Table 7).

Organics

NIST SRM 1974c Organics in Mussel Tissue (*Mytilus edulis*) was used for organics to evaluate method accuracy for those analytes with certified or reference values: organochlorine pesticides and PCBs. Laboratories are required to obtain concentrations within 50% of the certified or reference value for 70% of the compounds of each of these classes. As no certified values for PFAS analytes are available in reference bivalve tissues at the current time, blank and matrix spikes were used to assess accuracy and precision for this analyte class in Bight '23.

Success rates for PCBs were 100% for all QA parameters (Table 8), as was also the case for PFAS aside from the 86% success rates each for blank spike accuracy and precision, and for matrix spike accuracy. This demonstrates that PCB and PFAS measurements for bivalves were of sufficient quality for Bight '23. Full success was also achieved for organochlorine compounds, with two exceptions as noted above: accuracy for both matrix spikes (73%) and reference materials (45%). Matrix spike recovery issues affected only one laboratory, which achieved DQOs for matrix spike accuracy for 63% of organochlorine compounds, just under the 70% DQO. However, the overall success rate was reasonable. This observation contrasted with the much lower apparent success rate for reference material accuracy. This issue affected data from two laboratories, one of which had 35 samples (28% of the dataset), and the other had 26 samples (21% of the dataset). However, each laboratory only had a single analyte that did not meet the reference material accuracy DQO: α-chlordane for the first laboratory, and 4,4'-DDD for the second laboratory. Thus, it was clear that the issues with reference material accuracy were not systematic, affecting multiple analytes in a class across multiple laboratories, all of which were analyzing bivalve tissues for the first time in the Bight Program. It should also be noted that of the nine organochlorine pesticide analytes with reference values in SRM 1974c, six had values below the Bight-wide RL of 1 ng/g. Of those six analytes, three (2,4'-DDE, 2,4'-DDD, and *cis*-nonachlor) had values below even 50% above the SRM's reference values (i.e., the 50% range for the accuracy DQO in the Bight Program). Analytes for which the reference value was lower than the Bight-wide RL were excluded in DQO evaluation.

While not a formal QC measure, data from field duplicates (Table 9) also provided an additional measure of precision. Overall, the precision in field duplicate concentrations had RPDs ranging from 16 to 23%. These are within the DQOs of 30% for inorganics and 50% for organics (Table 8). Such DQOs can be considered guidelines for evaluating field duplicate precision, in lieu of formal QC requirements, and suggest that measured concentrations had reasonable precision based on field duplicates. Some field duplicates did have much greater RPDs that exceeded such guidelines, such as mercury, DDT, chlordanes, and PCBs, which had maximum RPDs of 76%, 65%, 79%, and 108% (Table 6). However, it should be noted that measured concentrations in the field duplicate samples that exceeded the precision DQO guidelines also tended to be

samples with low concentrations, often below the Bight-wide RL (Table 6). Such samples would inherently have lower precision. Thus, the precision observed for bivalve field duplicates is on par with the precision QA DQOs for this matrix for Bight ’23.

Table 7. Summary of overall bivalve chemistry intercalibration results (percent success). Laboratory name abbreviations: CLAEMD = City of Los Angeles, Environmental Monitoring Division; CSD = City of San Diego; OC San = Orange County Sanitation District. PCB = polychlorinated biphenyls, OC = organochlorine pesticides, PFAS = per- and polyfluorinated alkyl substances. *For informational purposes only. N/A=not applicable.

Reference material	Analyte class	Criteria	CLAEMD	CSD	OC San	Physis	Weck	Pass rate
SRM 2976	Individual metals	±30% target value for 2 of 3 analytes	100	67	67	100	N/A	4/4
SRM 1974c	Individual PCBs	±50% target value for 70+% analytes	88	82	94	100	N/A	4/4
SRM 1974c	Individual OCs	±50% target value for 70+% analytes	100	100	89	100	N/A	3/4
Metals FRM	Total PAHs	Lab mean ±30% of grand mean for 2 of 3 analytes	83	100	100	100	N/A	4/4
Organics FRM	Total PCBs	Lab mean ±50% grand mean	100	100	100	96	N/A	3/4
Organics FRM	Total OCs	Lab mean ±50% grand mean	100	100	100	100	N/A	4/5
Organics FRM	PFAS	Lab mean ±50% grand mean for both analytes	N/A	N/A	N/A	--	100	½*

Table 8. Summary of performance-based sediment quality control (QA) criteria and project success (%) for inorganic (arsenic, mercury, selenium) and organic compounds: organochlorine (OC) pesticides, polychlorinated biphenyls (PCBs), and per- and polyfluorinated alkyl substances (PFAS). N/A = not applicable.

QC parameter	Data quality objective (DQO)	Inorganics	OC pesticides	PCBs	PFAS
Completeness	90%	100	100	100	98
Method blank frequency	1/batch	100	100	100	100
Method blank limit	<MDL or <5% of measured concentration in samples (inorganics); <10×MDL for all analytes (organics)	100	100	100	100
Reference material frequency	1/batch	100	100	100	N/A
Reference material accuracy	Within ±30% of certified value for all analytes (inorganics); within ±50% of the specified value for ≥70% analytes (organics)	100	45	100	N/A
Blank spike and duplicate frequency	1/batch	100	N/A	N/A	100
Blank spike and duplicate accuracy	Within ±25% true value for at least one blank spike per batch (inorganics); 50-150% recovery of spiked amount (PFAS)	100	N/A	N/A	86
Blank spike duplicate precision	RPD <25% (inorganics); RPD < 30% (PFAS)	100	N/A	N/A	86
Matrix spike and duplicate frequency	1/batch	N/A	100	100	100
Matrix spike and duplicate accuracy	50-150% recovery of spiked amount for >70% of analytes	N/A	73	100	86
Matrix spike duplicate precision	RPD <50% for >70% of analytes	N/A	100	100	100

Table 9. Precision (%RPD) in field duplicates, and concentration ranges as a multiple of the analyte class's reporting limit (RL) for those field duplicates with RPDs exceeding Bight-wide Data Quality Objectives (30% for inorganics, 50% for organics). n = number of field duplicates.

Analyte class	RPD range (%) in field duplicates (n)	Concentration range (mean) in field duplicates
Arsenic	0.8-40 (15)	4.7-4.9× RL (4.8×)
Mercury	0-76 (15)	0.1-0.2× RL (0.15×)
Selenium	0.2-36 (15)	1.2× RL (1.2×)
Chlordanes	0-79 (21)	0.3-0.9× RL (0.6×)
DDTs	0-65 (33)	2.1-4.8× RL (4.9×)
PCBs	0-108 (108)	0.1-4.9× RL (0.6×)

Holding Times

Holding times were compliant with QC goals for all analytes (Table 7), except for PFAS. Success rates for PFAS holding times were low, as the laboratory had logistical issues with regards to their analysis that were disclosed to the Chemistry Technical Committee ahead of time. This is unlikely to affect results given the recalcitrance of PFOS and PFOA. The intercalibration results are in keeping with this, as losses of PFAS due to long holding times are not reflected in the success rates observed (Table 5).

Table 10. Achieved holding times. Percent success is based on the number of samples meeting the required holding time.

Analyte class	**Required holding time (days)**	**Holding time range (days)**	**Success (%)**
Inorganics (As, Hg, Se)	365	36-320	100
Organochlorine pesticides	365	24-321	100
PCBs	365	24-322	100
PFAS	365	39-485	35

Analyte class	Required holding time (days)	Holding time range (days)	Success (%)
Lipids	N/A	20-320	--

APPENDIX C. BIVALVE CHEMISTRY INTERCALIBRATION EXERCISE

A key point of all Bight surveys is a substantial effort in the development of analytical comparability. Because such regional programs were conducted in a collaborative manner with multiple analytical laboratories participating, intercalibration studies were critical for analyses of trace metal and trace organic constituents. Although all participating laboratories were certified by the State of California (i.e., by the Environmental Laboratories Accreditation Program) in the analytical methodologies used, there can still be significant discrepancies at times for specific constituents. Therefore, iterative inter-comparison and intercalibration exercises were performed until all laboratories could meet prescribed data quality objectives for inter-laboratory precision. These intercalibrations remain one of the foundational elements of the regional monitoring quality assurance/quality control program.

In the Bight ’23 intercalibration study, both certified reference materials (CRMs) and field reference materials (FRMs) were analyzed by Bight ’23 participating laboratories in triplicate. Assessment of laboratory performance for comparability was as follows. First, for each analyte, the average for each laboratory was computed as the mean of the triplicate samples. Second, a grand mean was calculated as the average across all laboratories. Potential outlier results were identified using the Grubbs Test, and excluded when calculating the grand mean. Finally, depending on the analyte class, 70% of the target analytes must achieve passing results to qualify for Bight ’23 participation for that compound class. All intercalibration results for PFAS are for informational purposes only.

Previous Bight cycles included a criterion that for a given analyte, at least two of three replicates must be within the defined variability of the CRM certified value or FRM grand mean, as appropriate, to pass. This criterion was not applied for Bight ’23.

Laboratories that participated in the intercalibration exercise were required to meet specified performance criteria, which can be found in the Bight ’23 Survey Quality Assurance Plan. Prior to any analysis of the survey samples, laboratories analyzing Bight samples were required to pass the assessment for both CRMs and FRMs.

Overall, all of Bight ’23 participating laboratories passed in both CRM and FRM for the designated analyses (Tables 7 and 11-13).

Intercalibration Certified and Field Reference Materials

One field reference material was used during the intercalibration exercise. Oysters were collected by SCCWRP from Newport Bay (REF?), homogenized, spiked as appropriate, and distributed to laboratories to test both inter- and intra-laboratory precision.

Trace Metals

NIST SRM 2976 Trace Elements and Methylmercury in Mussel Tissue (Freeze-Dried)

SRM 2976 (https://tsapps.nist.gov/srmext/certificates/archives/2976.pdf) tested method accuracy. Laboratories were required to obtain concentrations within 30% of the certified or reference value for 2 of the 3 analytes.

Field Reference Material from Newport Bay

Field reference material tested precision, both inter-laboratory and intra-laboratory. This specific material was similar to tissues collected in Bight '23, and may thus have potential interferences not present in SRM 2976. Laboratories were required to obtain a concentration within 30% of the grand mean value for 2 of 3 analytes.

Organics

NIST SRM 1974c Organics in Mussel Tissue (Mytilus edulis)

SRM 1974c (https://catalog.data.gov/dataset/srm-1974c-organics-in-mussel-tissue-mytilus-edulis-d10c7) tested method accuracy. Laboratories are required to obtain concentrations within 50% of the certified or reference value for 70% of the compounds for PCBs, and for organochlorine pesticides (DDT and chlordane compounds combined). This material was also used to assess lipid content, as reference values are available; this was used in QA for results, but not the intercalibration study.

Field Reference Material from Newport Bay

Field reference material tested precision, both inter-laboratory and intra-laboratory. This is the same material as that used as a field reference material for metals, with potential interferences not present in SRM 1974c. Laboratories were required to obtain a total class concentration within 50% of the grand mean value for PCBs and for OC pesticides, and with 50% of the grand mean value for both PFAS analytes.

Intercalibration Exercise Results

There were a total of three rounds of bivalve intercalibration for Bight '23. Successive rounds beyond the first were necessary to address individual deficiencies in intercalibration.

In the first round (Table 11), OC San did not pass CRM intercalibration for OC pesticides, and Physis did not pass FRM intercalibration for PCBs and PFAS. Other laboratories passed both CRM and FRM intercalibration.

The participating laboratories agreed to conduct a second round of intercalibration (Table 12) to address failed aspects of the first round. In this round, OC San reanalyzed results for SRM 1974c from the first round and passed. Previously reported values for 4,4'-DDD (non-detect), γ-chlordane (non-detect) and *cis*-nonachlor (0.54 ng/g ww) were restudied and reported to be passing values: 0.69 ng/g ww, 0.63 ng/g ww, and 0.34 ng/g ww (from a modified integration algorithm to provide more consistent peak levels at low levels), respectively. However, Physis did not pass FRM tissue intercalibration using the same material, and agreed to conduct a third round.

A third round of FRM intercalibration was done by Physis (Table 13), which analyzed SRM 1974c as an unknown. Results were evaluated against CRM intercalibration data for this material, and a pass result was obtained.

Table 11. Summary of first-round bivalve chemistry intercalibration results. Laboratory name abbreviations: CLAEMD = City of Los Angeles, Environmental Monitoring Division; CSD = City of San Diego; OC San = Orange County Sanitation District. PCB = polychlorinated biphenyls, OC = organochlorine pesticides, PFAS = per- and polyfluorinated alkyl substances. N/A = not applicable.

Reference material	Analyte class	Criteria	CLAEMD	CSD	OC San	Physis	Weck	Pass rate
SRM 2976	Individual metals	±30% target value for 2 of 3 analytes	100	67	67	100	N/A	4/4
SRM 1974c	Individual PCBs	±50% target value for 70+% analytes	88	82	94	100	N/A	4/4
SRM 1974c	Individual OCs	±50% target value for 70+% analytes	100	100	67	100	N/A	3/4
Metals FRM	Total PAHs	Lab mean ±30% of grand mean for 2 of 3 analytes	83	100	100	100	N/A	4/4
Organics FRM	Total PCBs	Lab mean ±50% grand mean	100	100	100	0	N/A	3/4
Organics FRM	Total OCs	Lab mean ±50% grand mean	100	100	100	100	N/A	4/5
Organics FRM	PFAS	Lab mean ±50% grand mean for both analytes	N/A	N/A	N/A	0	100	1/2

Table 12 Summary of second-round bivalve chemistry intercalibration results. Laboratory name abbreviations: CLAEMD = City of Los Angeles, Environmental Monitoring Division; CSD = City of San Diego; OC San = Orange County Sanitation District. PCB = polychlorinated biphenyls. N/A = not applicable.

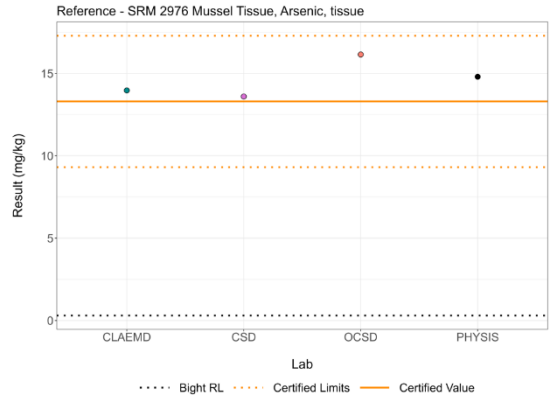
Reference material	Analyte class	Criteria	CLAEMD	CSD	OC San	Physis	Weck	Overall pass rate
SRM 1974c	Individual PCBs	±50% target value for 70+% analytes	--	--	--	0	N/A	3/4
SRM 1974c	Individual OCs	±50% target value for 70+% analytes	--	--	89	--	N/A	4/4

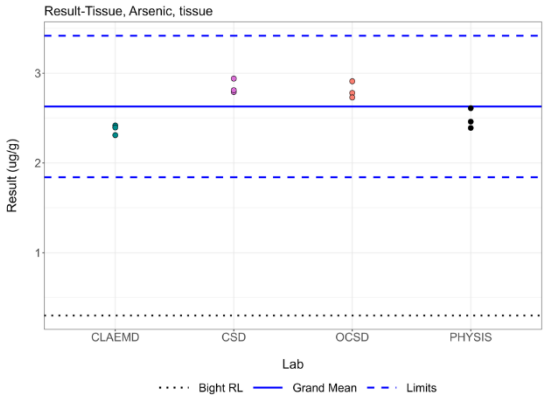
Table 13 Summary of third-round bivalve chemistry intercalibration results. Laboratory name abbreviations: CLAEMD = City of Los Angeles, Environmental Monitoring Division; CSD = City of San Diego; OC San = Orange County Sanitation District. PCB = polychlorinated biphenyls. N/A = not applicable.

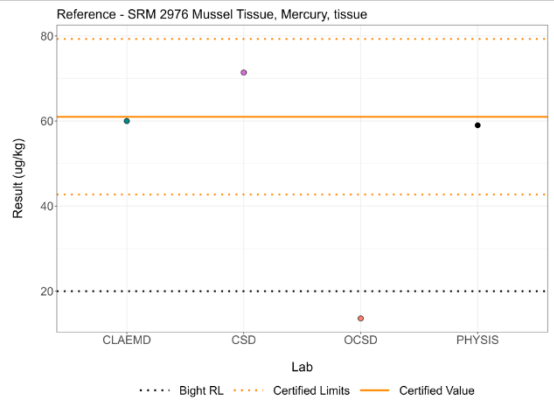
Reference material	Analyte class	Criteria	CLAEMD	CSD	OC San	Physis	Weck	Overall pass rate
SRM 1974c (analyzed as FRM unknown)	Individual PCBs	--	--	--	--	96	N/A	4/4

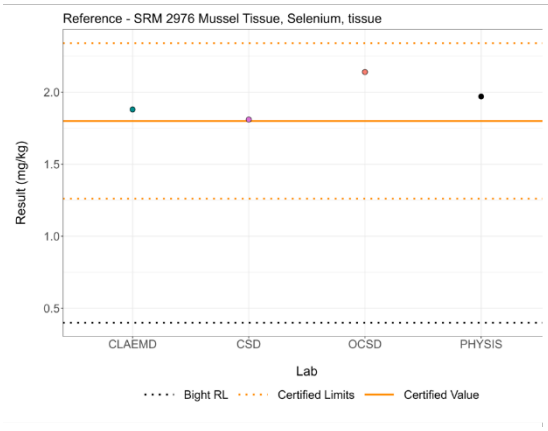
First-Round Intercalibration Results for Core Individual Analytes

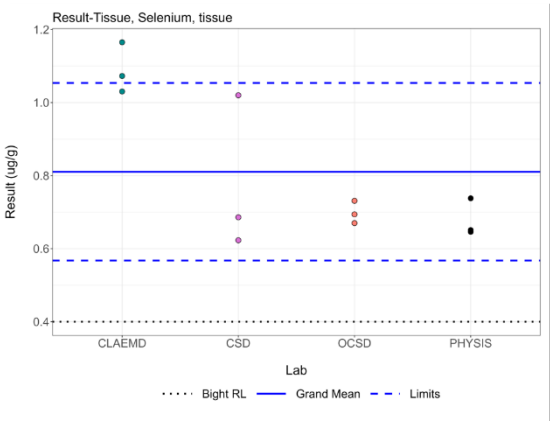
Metals CRM (SRM 2976) and FRM



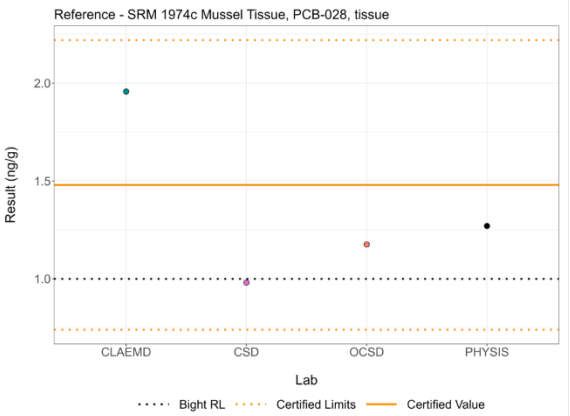


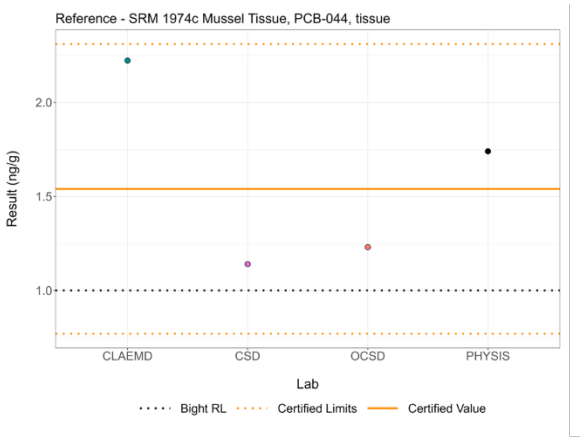


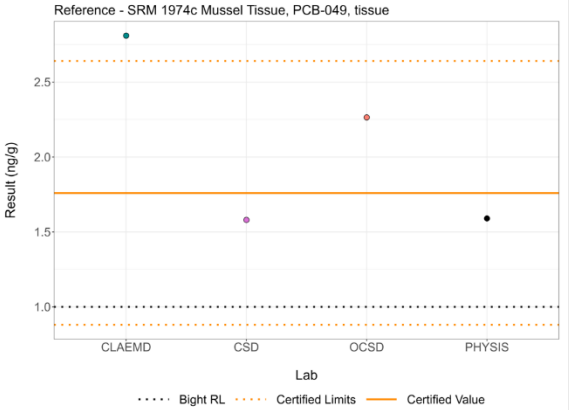


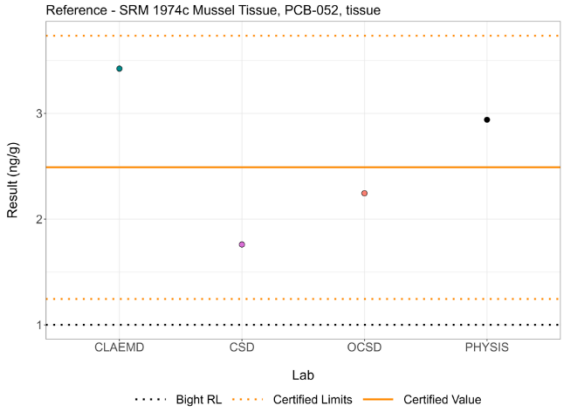


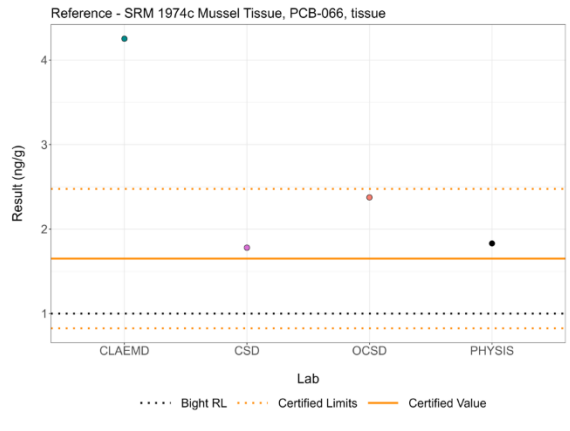
CRM PCBs: SRM 1974c

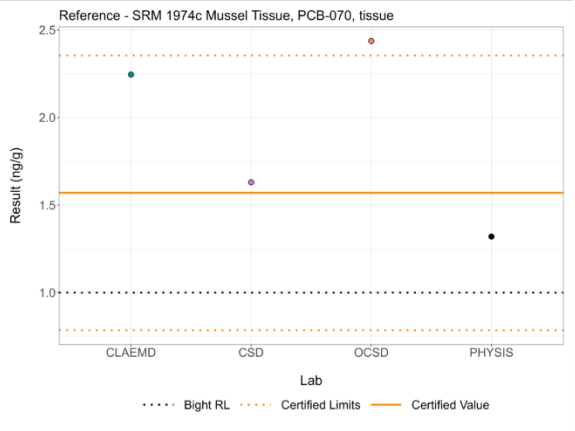


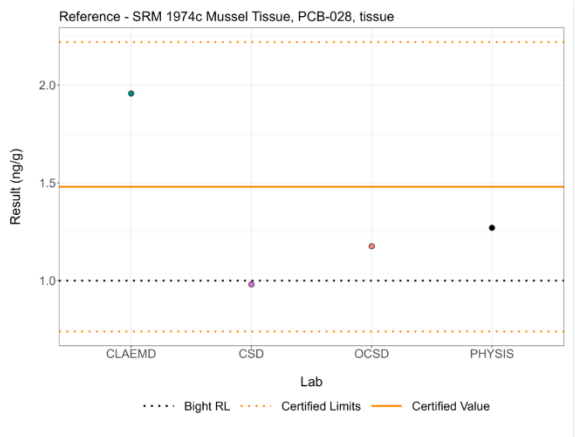


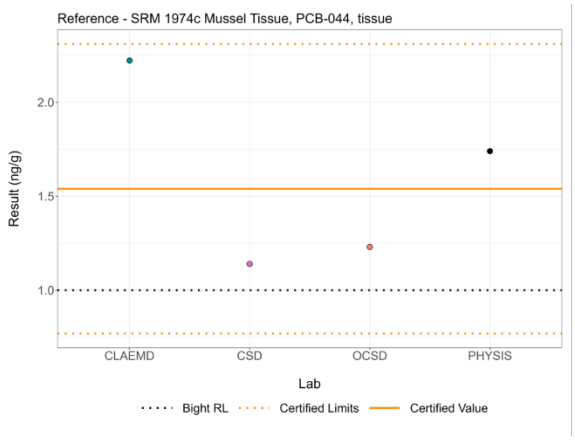


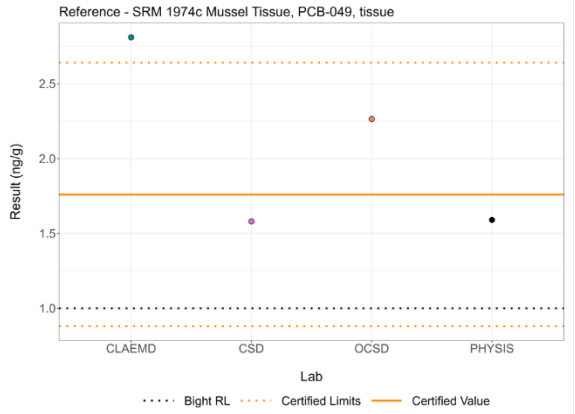


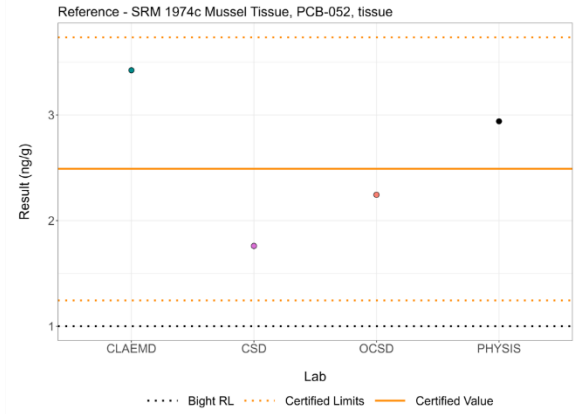


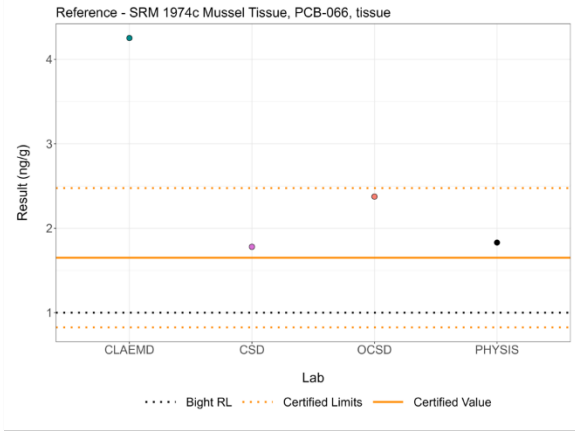


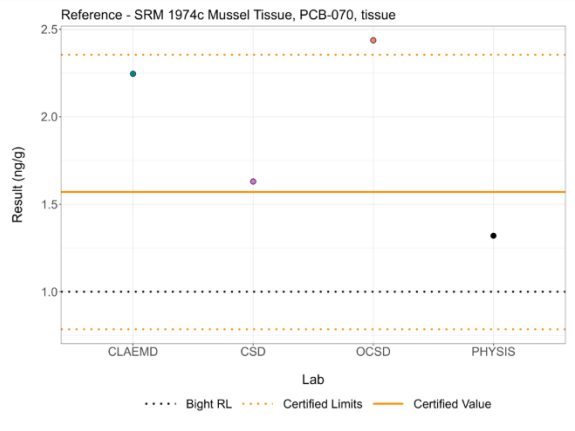

Reference - SRM 1974c Mussel Tissue, PCB-028, tissue
Result (ng/g)
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-044, tissue
Result (ng/g)
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-049, tissue
Result (ng/g)
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-052, tissue
Result (ng/g)
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-066, tissue
Result (ng/g)
4
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-070, tissue
Result (ng/g)
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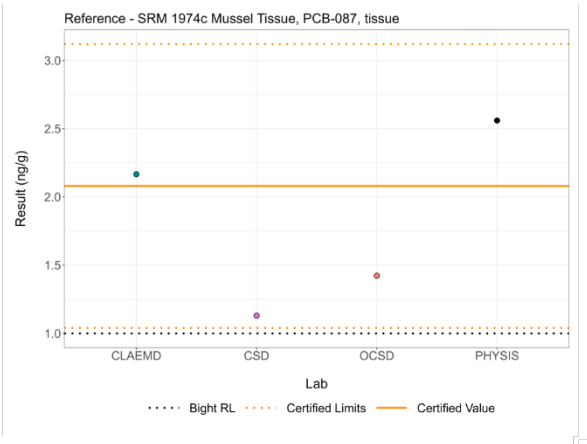
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-087, tissue
Result (ng/g)
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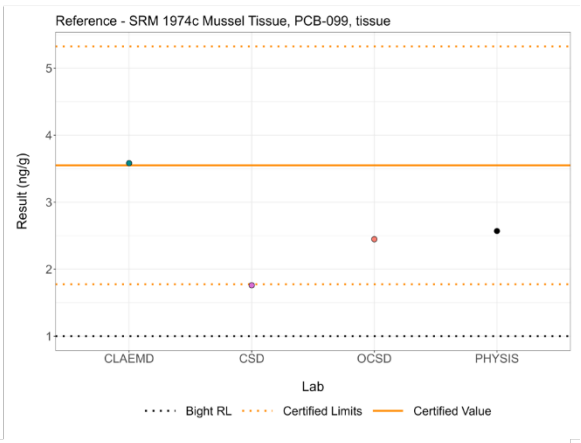
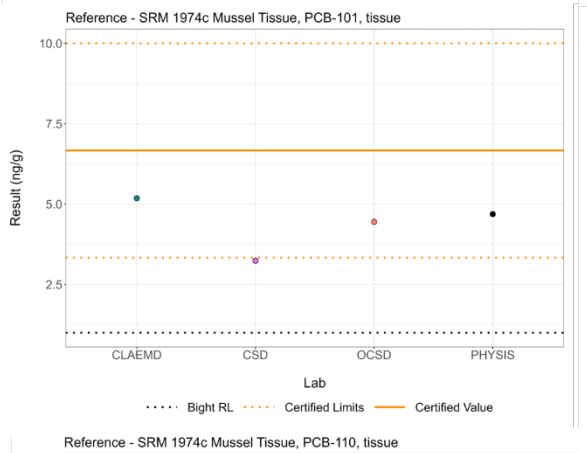
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-099, tissue
Result (ng/g)
5
4
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-101, tissue
Result (ng/g)
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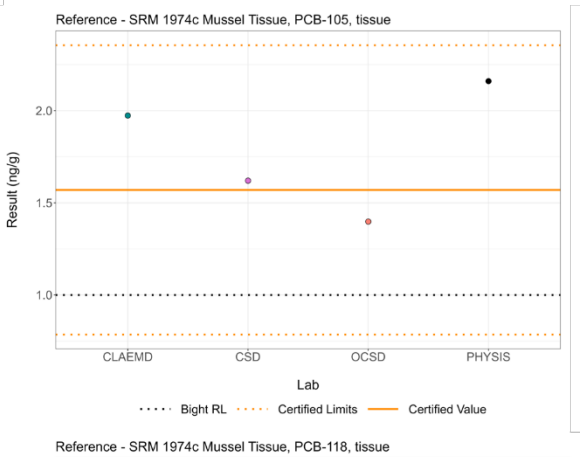
7.5
5.0
2.5
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-105, tissue
Result (ng/g)
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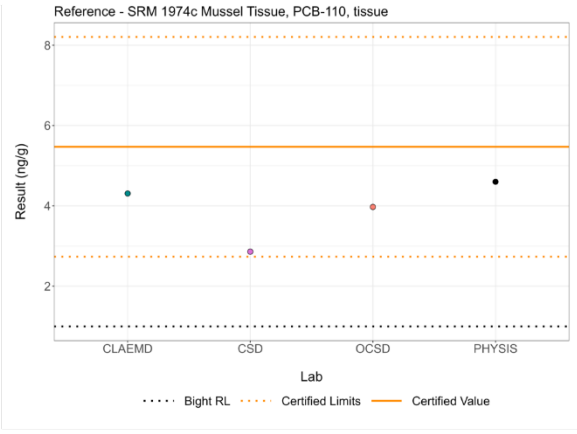
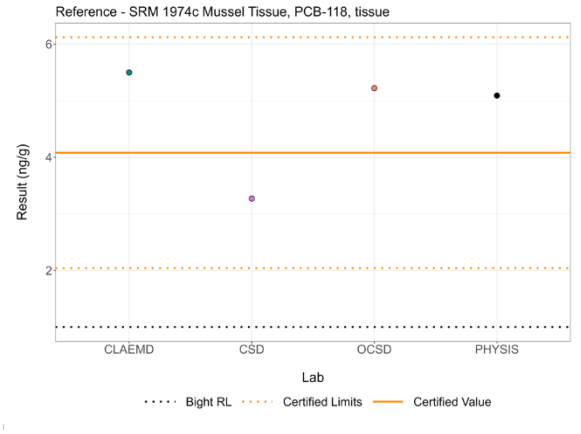
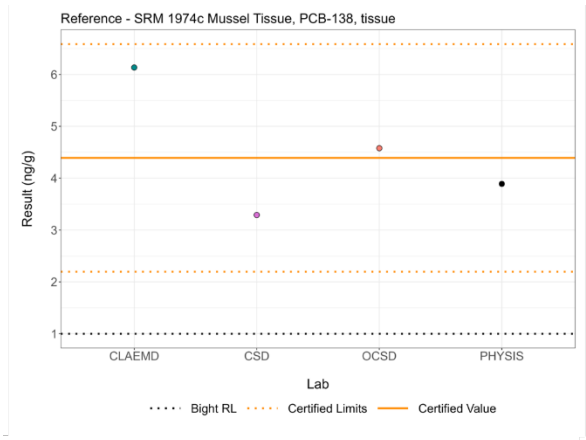
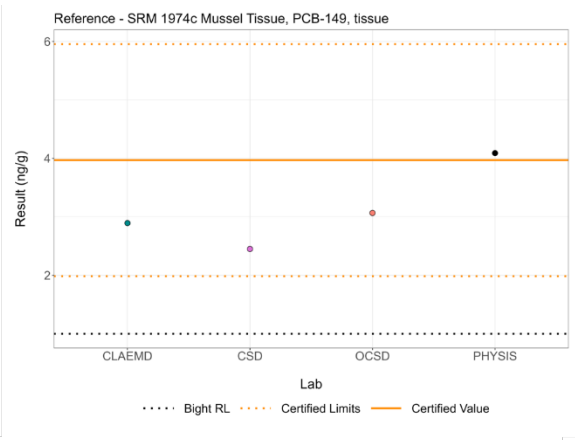
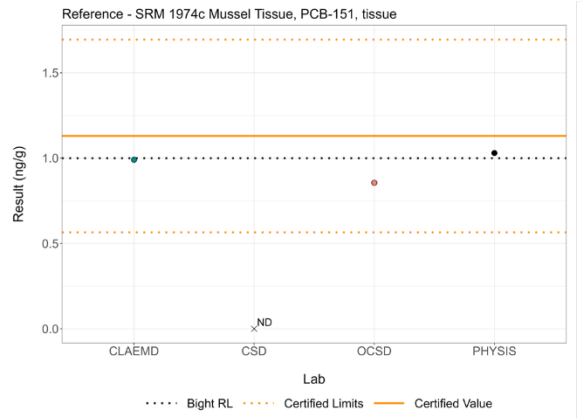
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

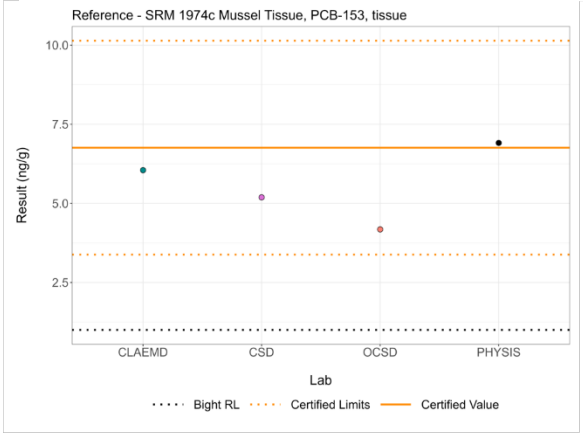

Reference - SRM 1974c Mussel Tissue, PCB-110, tissue
Result (ng/g)
8
6
4
2
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

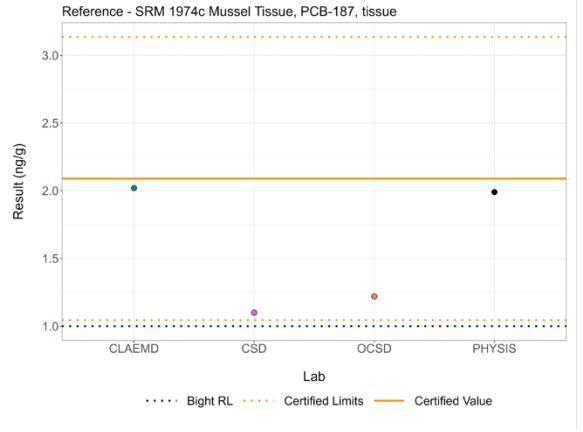

Reference - SRM 1974c Mussel Tissue, PCB-118, tissue
Result (ng/g)
6
4
2
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-138, tissue
Result (ng/g)
6
5
4
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

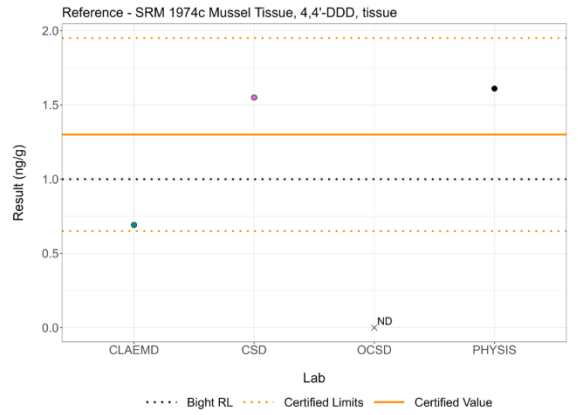

Reference - SRM 1974c Mussel Tissue, PCB-149, tissue
Result (ng/g)
6
4
2
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

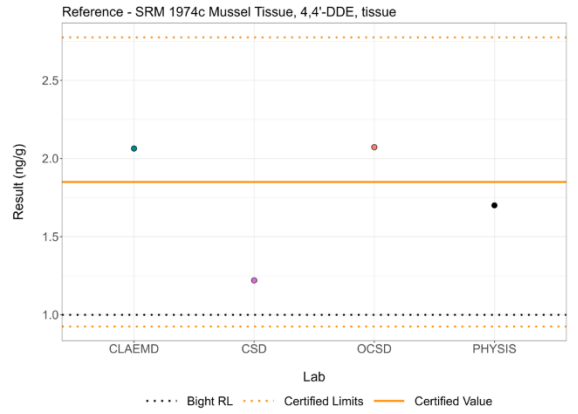

Reference - SRM 1974c Mussel Tissue, PCB-151, tissue
Result (ng/g)
1.5
1.0
0.5
0.0
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

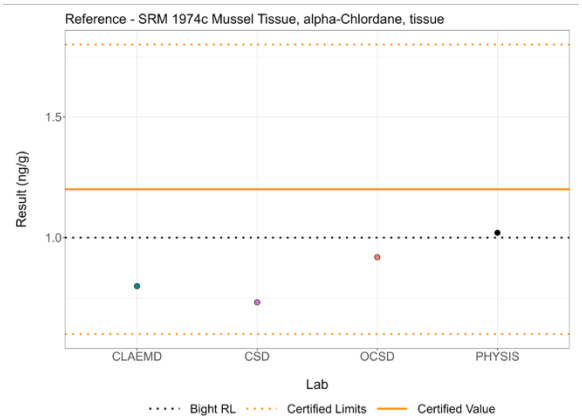

Reference - SRM 1974c Mussel Tissue, PCB-153, tissue
Result (ng/g)
10.0
7.5
5.0
2.5
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value


Reference - SRM 1974c Mussel Tissue, PCB-187, tissue
Result (ng/g)
3.0
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Certified Limits
Certified Value

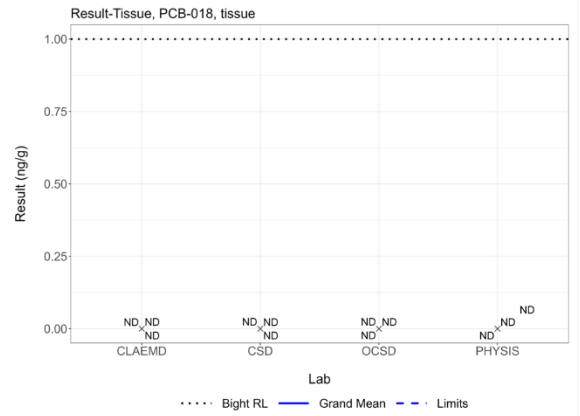
OCs CRM (SRM 1974c)

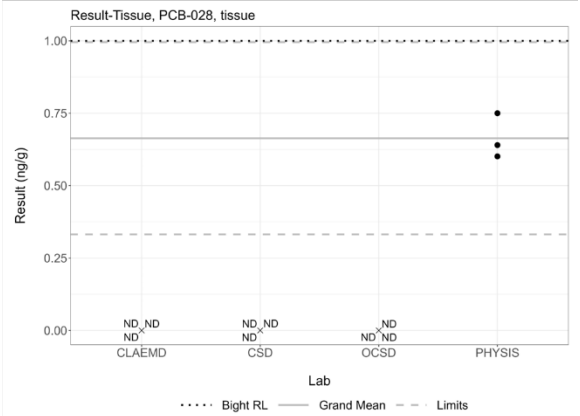


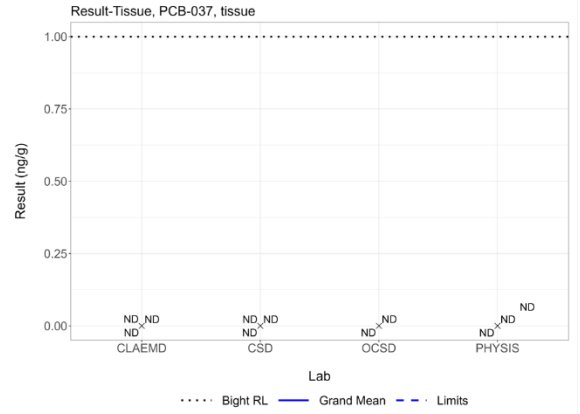


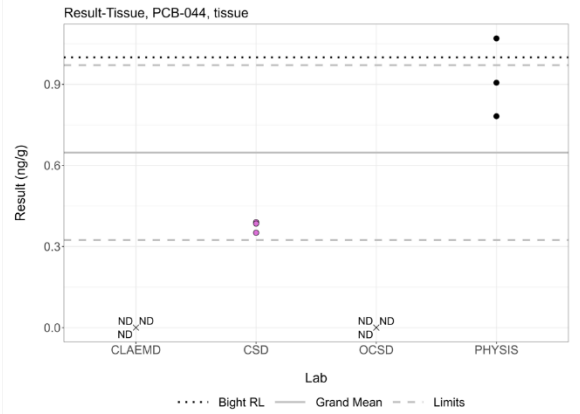


PCBs FRM

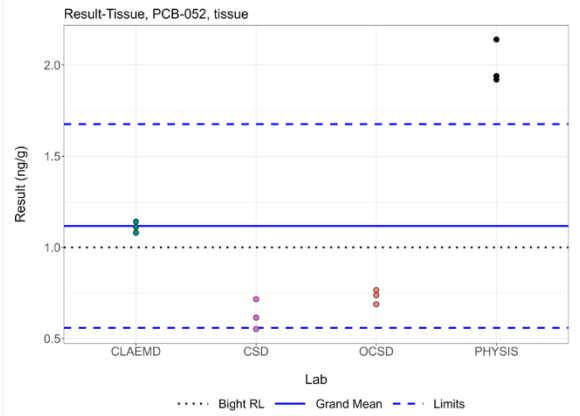

Result-Tissue, PCB-018, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

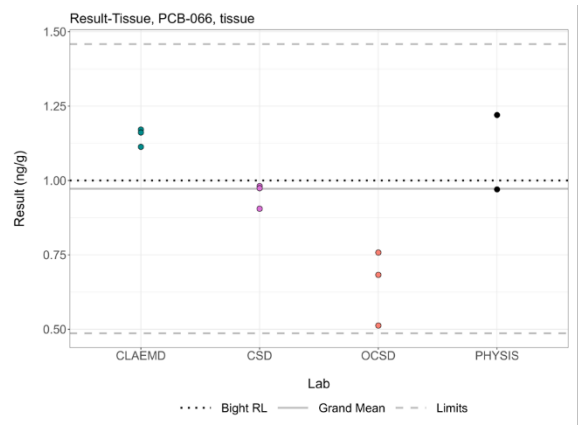

Result-Tissue, PCB-028, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

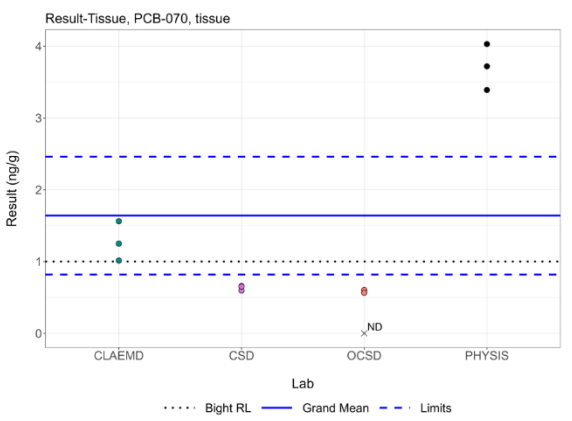

Result-Tissue, PCB-037, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

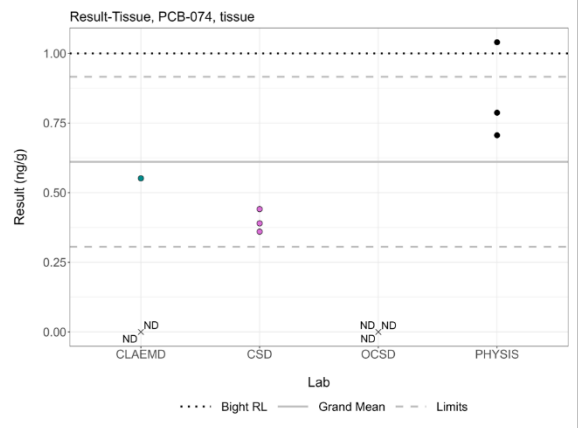

Result-Tissue, PCB-044, tissue
Result (ng/g)
0.9
0.6
0.3
0.0
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

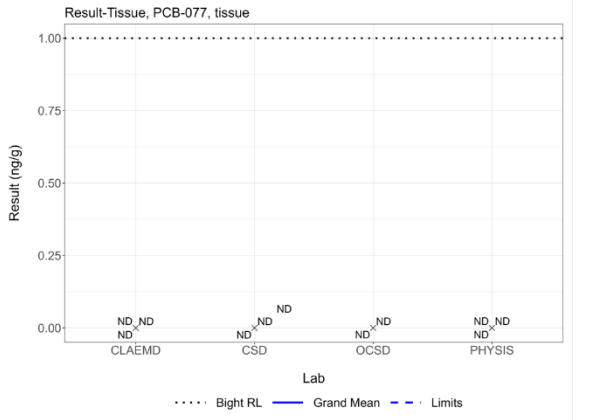

Result-Tissue, PCB-049, tissue
Result (ng/g)
1.75
1.50
1.25
1.00
0.75
0.50
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

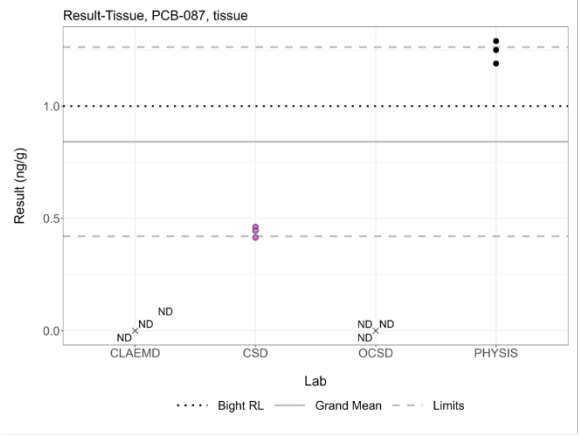

Result-Tissue, PCB-052, tissue
Result (ng/g)
2.0
1.5
1.0
0.5
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

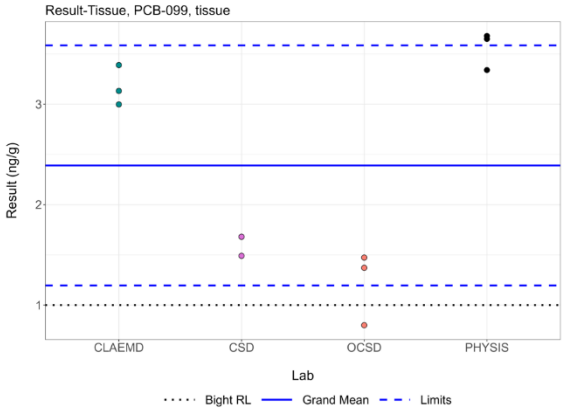

Result-Tissue, PCB-066, tissue
Result (ng/g)
1.50
1.25
1.00
0.75
0.50
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

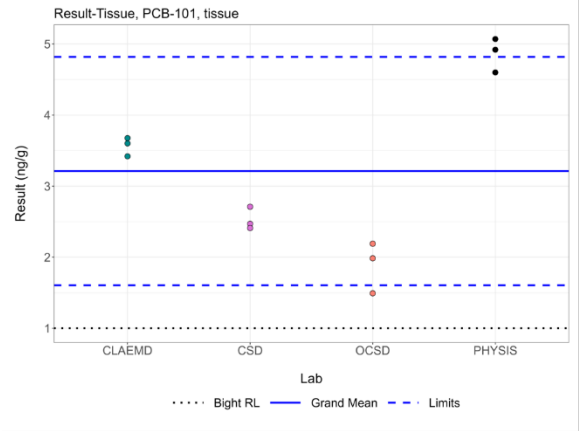

Result-Tissue, PCB-070, tissue
Result (ng/g)
4
3
2
1
0
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

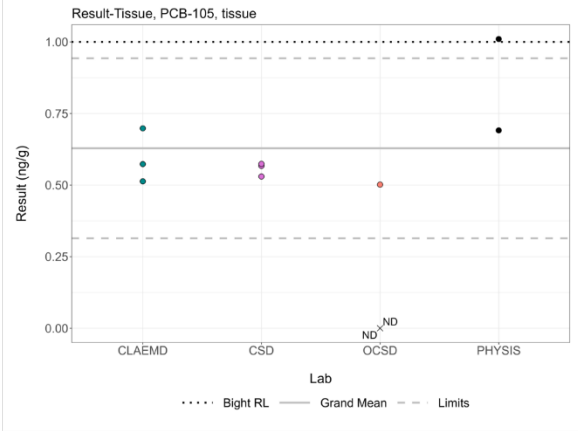

Result-Tissue, PCB-074, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
ND
ND ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

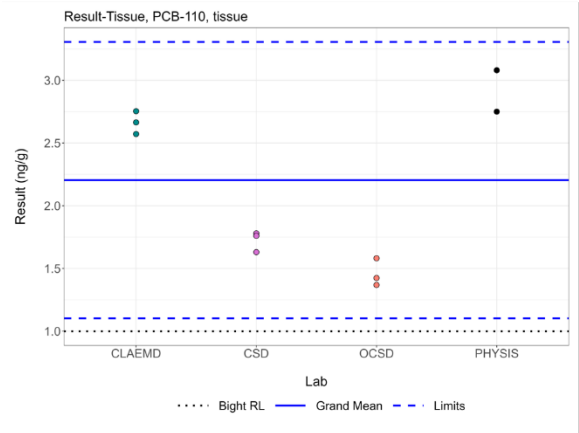

Result-Tissue, PCB-077, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND
ND
ND
ND
ND
ND
ND ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

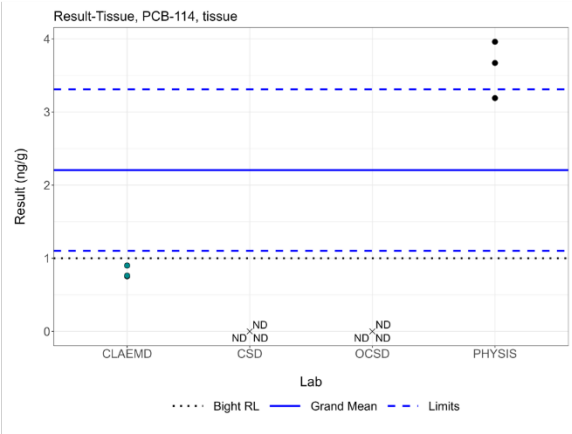

Result-Tissue, PCB-087, tissue
Result (ng/g)
1.0
0.5
0.0
ND
ND
ND
ND ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

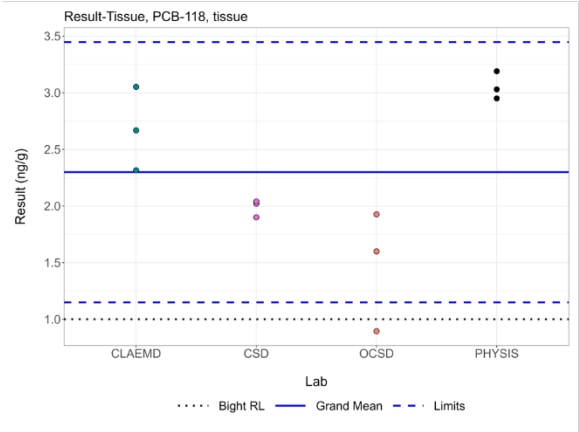

Result-Tissue, PCB-099, tissue
Result (ng/g)
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

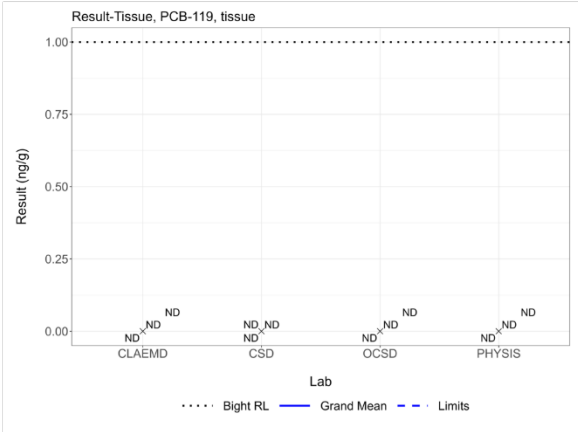

Result-Tissue, PCB-101, tissue
Result (ng/g)
5
4
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

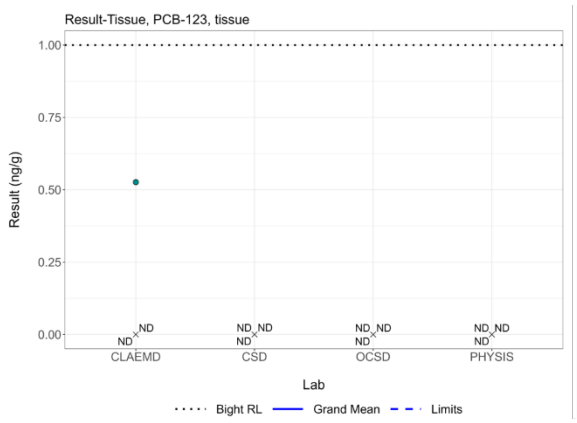

Result-Tissue, PCB-105, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

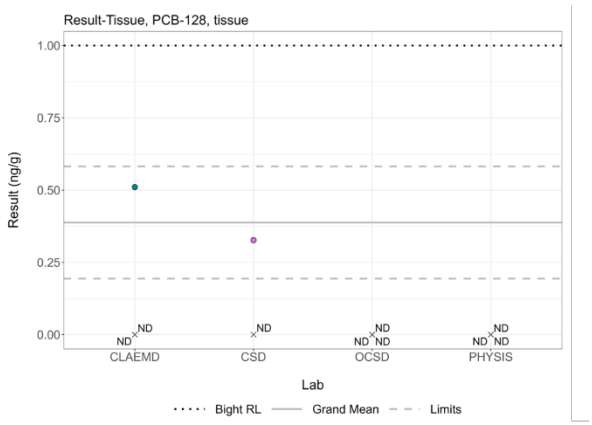

Result-Tissue, PCB-110, tissue
Result (ng/g)
3.0
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

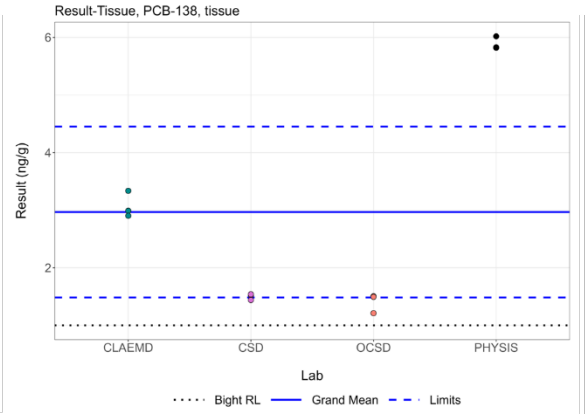

Result-Tissue, PCB-114, tissue
Result (ng/g)
4
3
2
1
0
ND
ND ND
ND
ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

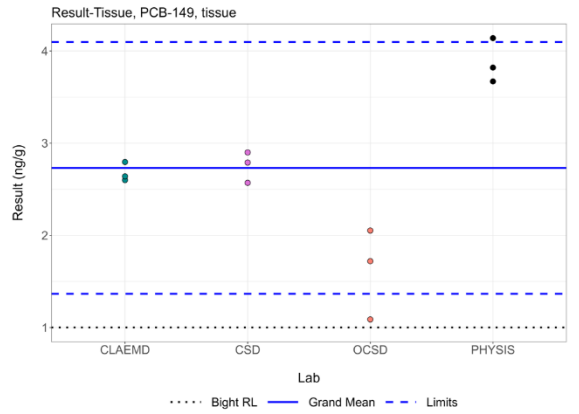

Result-Tissue, PCB-118, tissue
Result (ng/g)
3.5
3.0
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

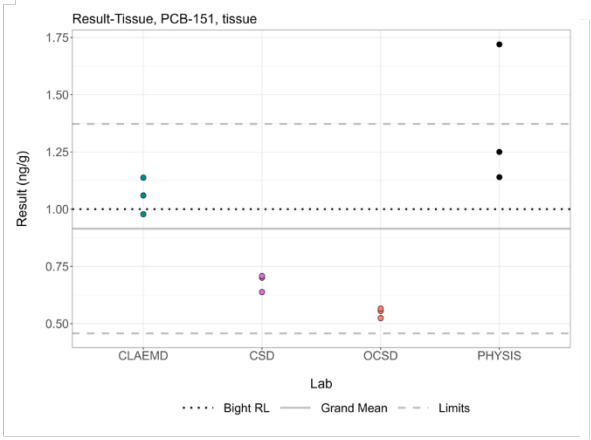

Result-Tissue, PCB-119, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
ND
ND
ND ND
ND
ND
ND
ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

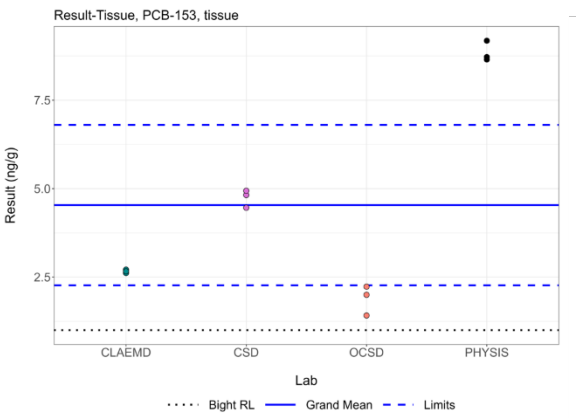

Result-Tissue, PCB-123, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

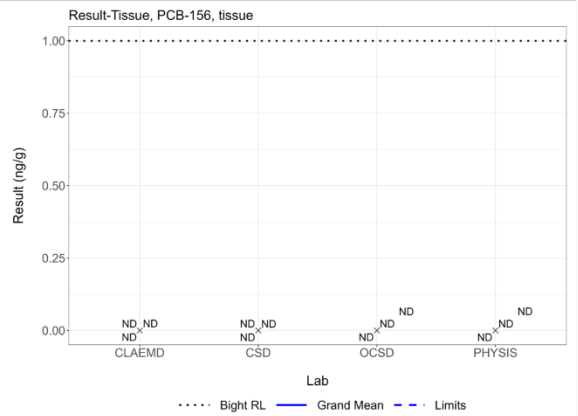

Result-Tissue, PCB-128, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

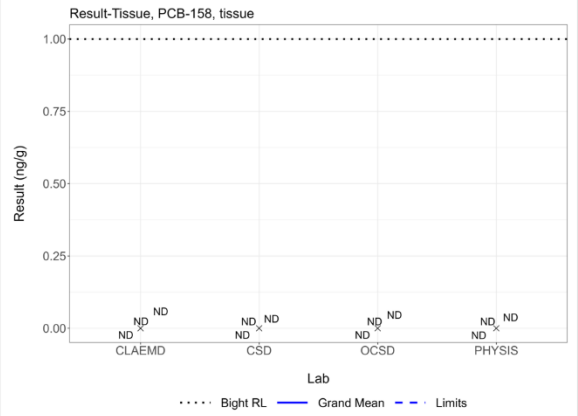

Result-Tissue, PCB-138, tissue
Result (ng/g)
6
4
2
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

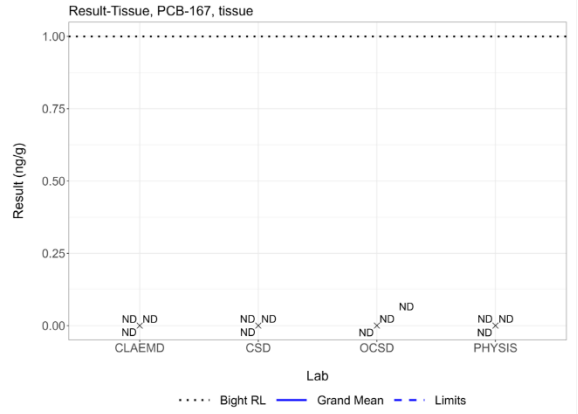

Result-Tissue, PCB-149, tissue
Result (ng/g)
4
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

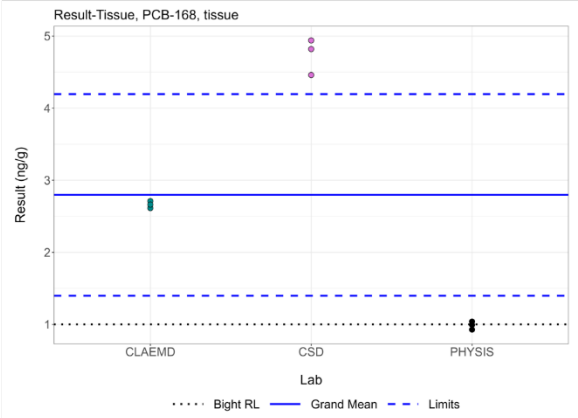

Result-Tissue, PCB-151, tissue
Result (ng/g)
1.75
1.50
1.25
1.00
0.75
0.50
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

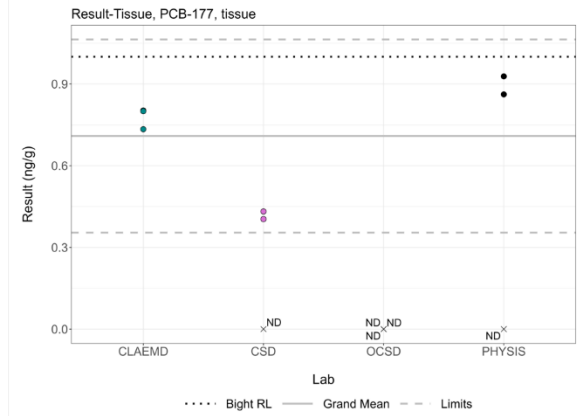

Result-Tissue, PCB-153, tissue
Result (ng/g)
7.5
5.0
2.5
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

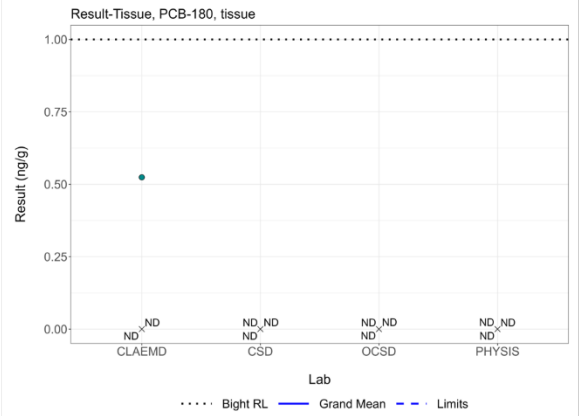

Result-Tissue, PCB-156, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

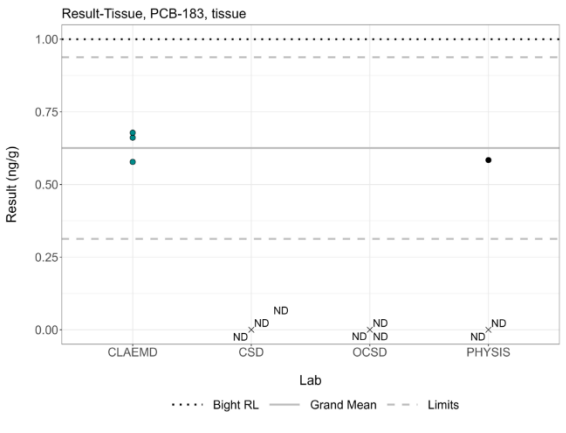

Result-Tissue, PCB-158, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

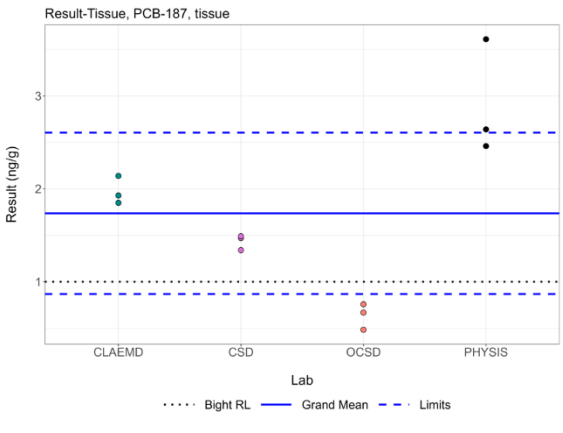

Result-Tissue, PCB-167, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-168, tissue
Result (ng/g)
5
4
3
2
1
CLAEMD
CSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-177, tissue
Result (ng/g)
0.9
0.6
0.3
0.0
ND
ND ND ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

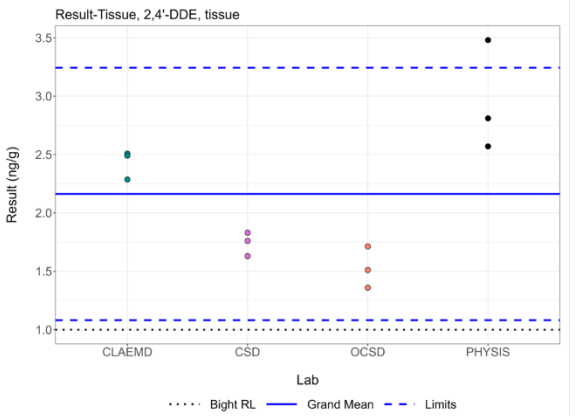

Result-Tissue, PCB-180, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND ND ND
ND ND ND
ND ND ND
ND ND ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

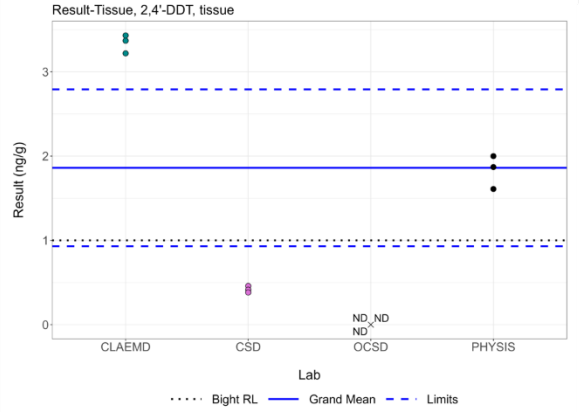

Result-Tissue, PCB-183, tissue
Result (ng/g)
1.00
0.75
0.50
0.25
0.00
ND
ND
ND
ND
ND
ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

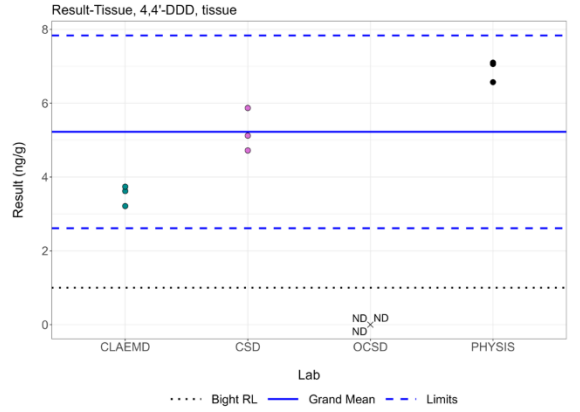

Result-Tissue, PCB-187, tissue
Result (ng/g)
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

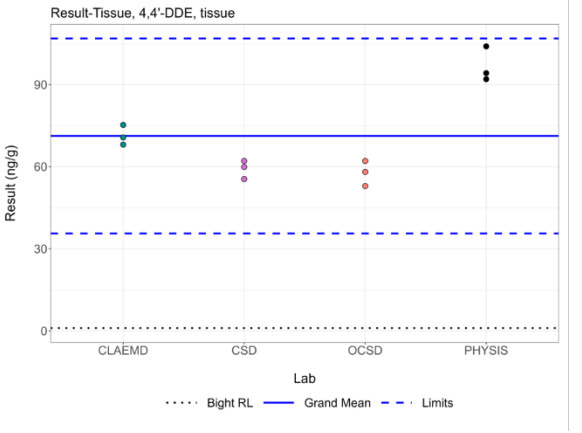
OCs FRM

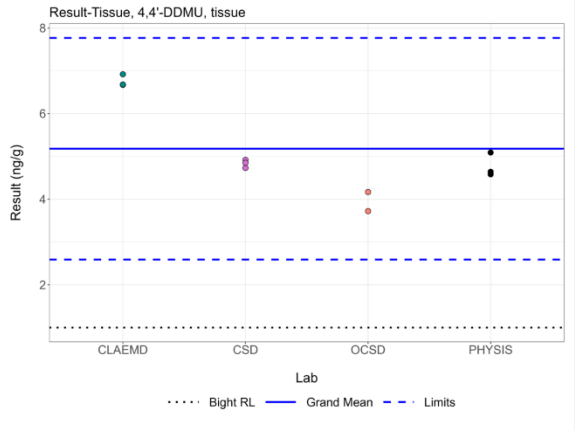

Result-Tissue, 2,4'-DDD, tissue
Result (ng/g)
3
2
1
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

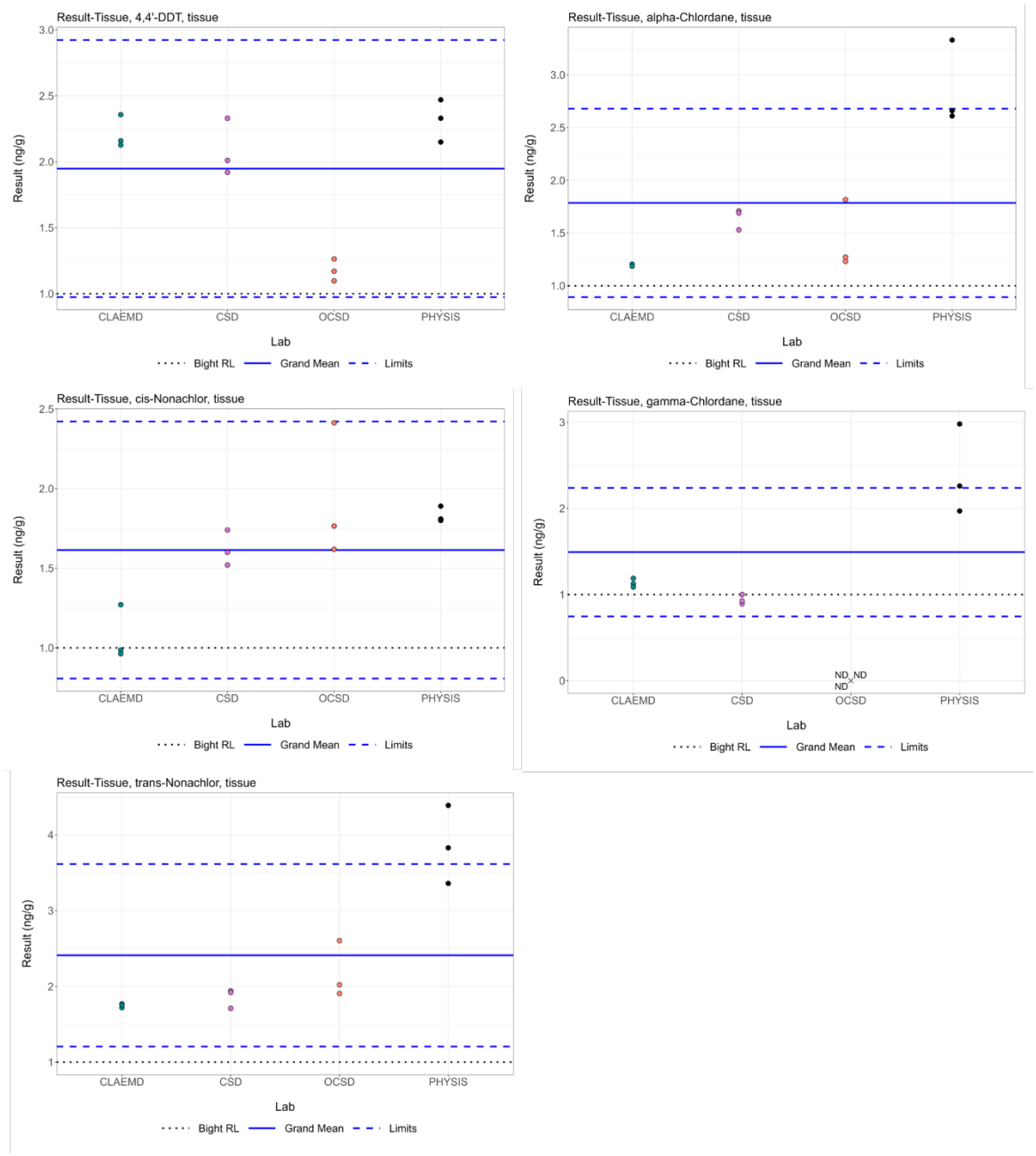

Result-Tissue, 2,4'-DDE, tissue
Result (ng/g)
3.5
3.0
2.5
2.0
1.5
1.0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, 2,4'-DDT, tissue
Result (ng/g)
3
2
1
0
ND
ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, 4,4'-DDD, tissue
Result (ng/g)
8
6
4
2
0
ND
ND
ND
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

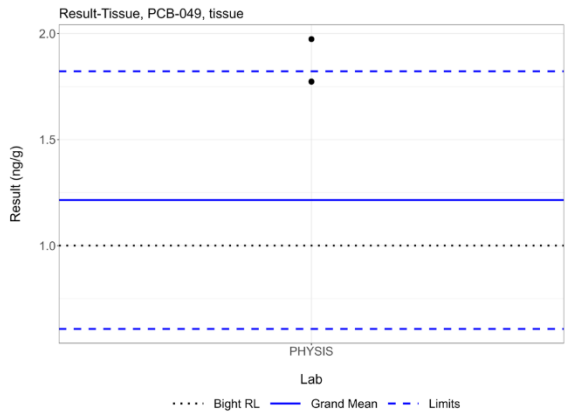

Result-Tissue, 4,4'-DDE, tissue
Result (ng/g)
90
60
30
0
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

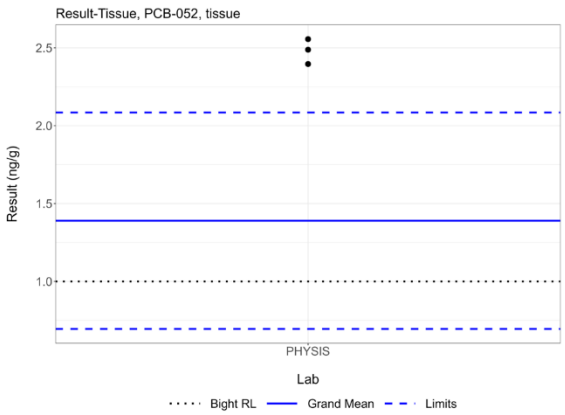

Result-Tissue, 4,4'-DDMU, tissue
Result (ng/g)
8
6
4
2
CLAEMD
CSD
OCSD
PHYSIS
Lab
Bight RL
Grand Mean
Limits

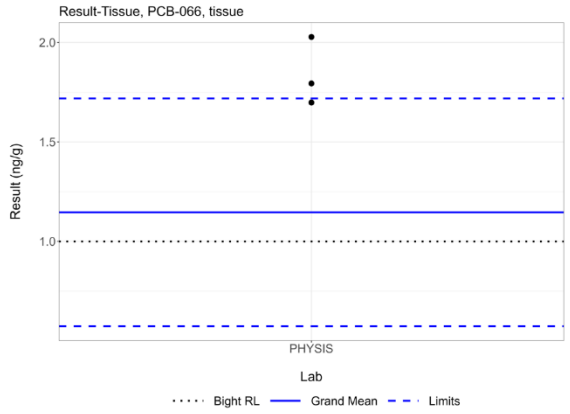


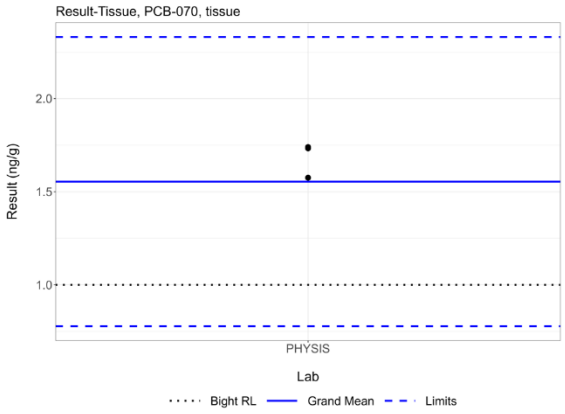
Third-Round Intercalibration Results for Core Individual Analytes

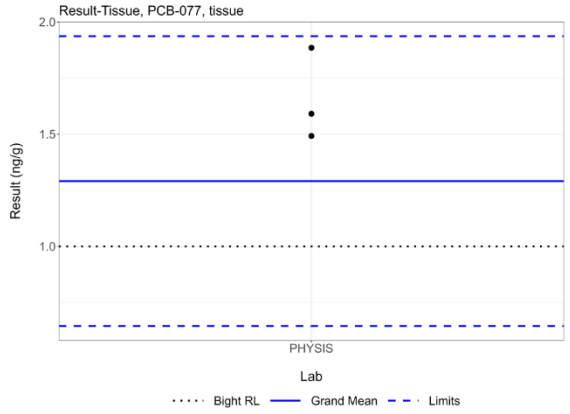
CRM PCBs (SRM 1974c, analyzed as unknown by laboratory)


Result-Tissue, PCB-049, tissue
Result (ng/g)
2.0
1.5
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-052, tissue
Result (ng/g)
2.5
2.0
1.5
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-066, tissue
Result (ng/g)
2.0
1.5
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-070, tissue
Result (ng/g)
2.0
1.5
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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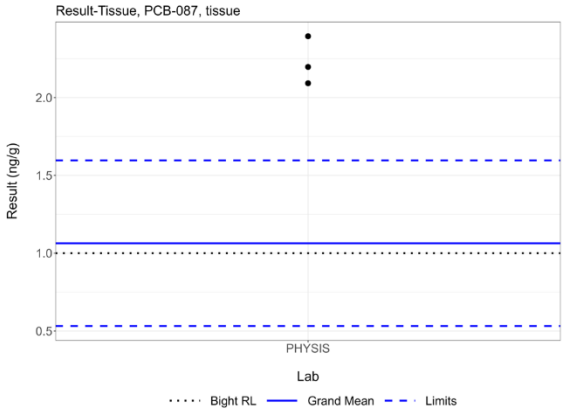
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits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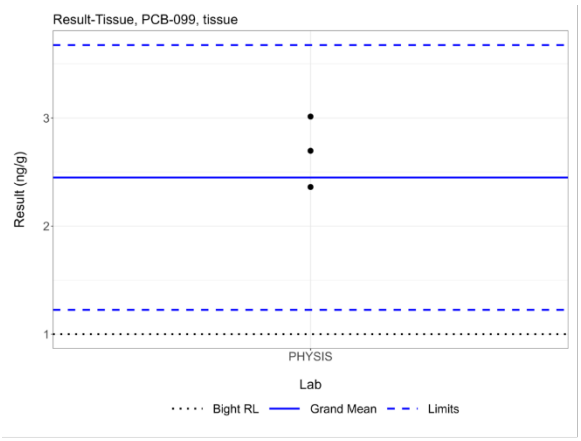
1.0
0.5
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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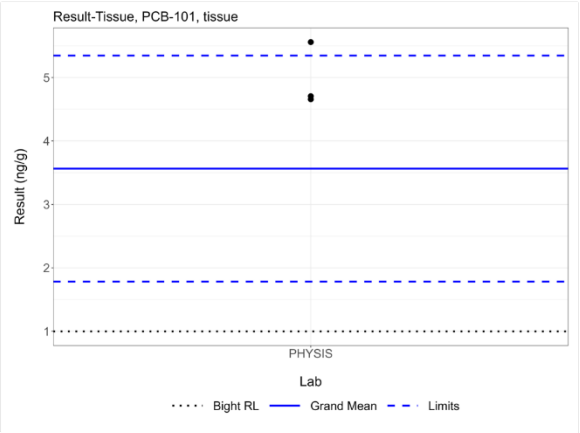
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-101, tissue
Result (ng/g)
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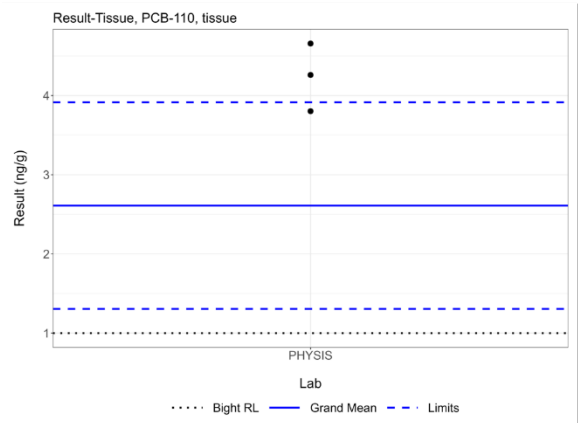
4
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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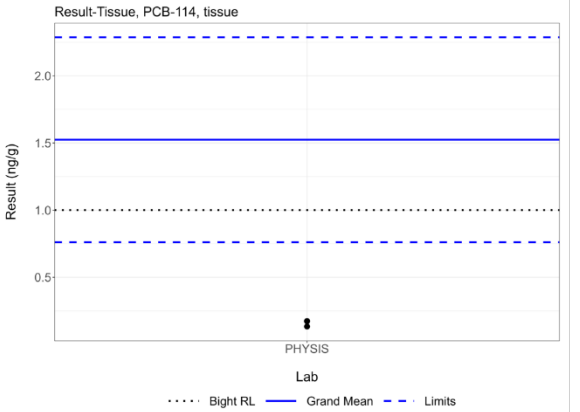
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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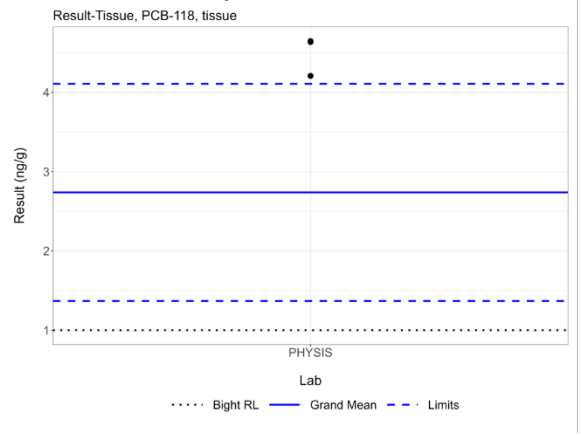
1.5
1.0
0.5
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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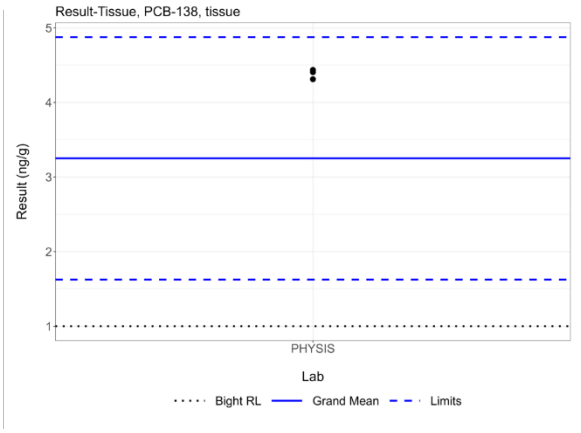
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits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Result (ng/g)
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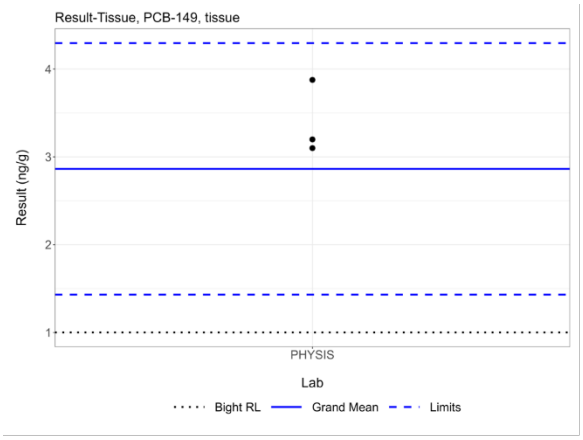
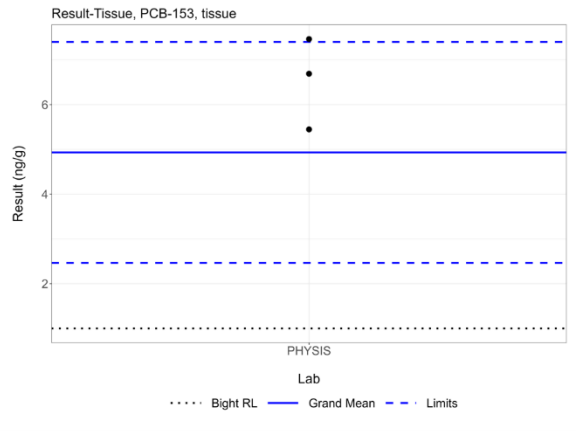
4
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-149, tissue
Result (ng/g)
4
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-153, tissue
Result (ng/g)
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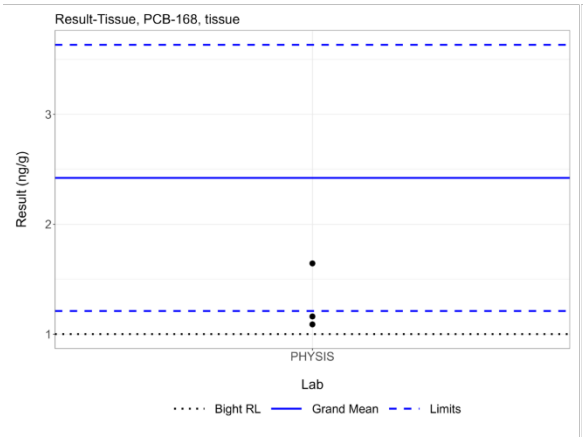
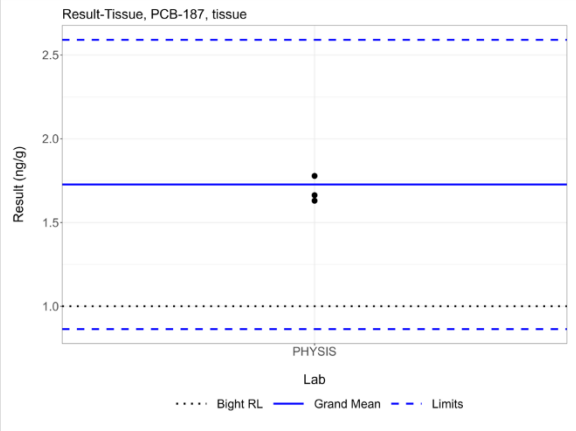
4
2
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-168, tissue
Result (ng/g)
3
2
1
PHYSIS
Lab
Bight RL
Grand Mean
Limits


Result-Tissue, PCB-187, tissue
Result (ng/g)
2.5
2.0
1.5
1.0
PHYSIS
Lab
Bight RL
Grand Mean
Limits

APPENDIX D. SUPPLEMENTAL FIGURES AND TABLES

Table 14. Sites with elevated concentrations of analytes in mussels (M) and oysters (O) in the counties of Santa Barbara (SB), Ventura (VT), Los Angeles (LA), Orange (OC), and San Diego (SD).

County	Site ID	Site name	As	Hg	Se	Total Chlordanes	Total DDT	Total PCBs
SB	AYHD	Arroyo Hondo	M	-	-	-	-	-
SB	GOLS	Goleta Slough	M	-	-	-	-	-
SB	STBB	Santa Barbara	-	M,O	-	-	-	-
SB	DEVS	Dev Slough	-	-	-	-	-	-
VT	VENH	Ventura Harbor	-	-	-	-	-	-
VT	CIHB	Channel Islands Harbor	-	-	-	O	O	-
VT	ORBH	Ormond Beach near Pt. Mugu	M	-	-	-	-	-
VT	LCRO	Leo Carrillo	M	M	-	-	-	-
LA	MALB	Malibu Beach	-	-	-	-	-	-
LA	PTDM	Point Dume	M	-	-	-	-	-
LA	MADR	Marina del Rey	-	-	-	-	-	M
LA	ALAM	Alamitos Bay	-	-	-	O	O	M,O
LA	LARV	Los Angeles River	-	-	-	-	-	M
LA	CABO	Cabrillo Beach	-	M	-	-	-	M
LA	BOLC	Bolsa Chica	-	-	-	-	-	-
OC	HBWT	Huntington Beach Wetland	-	-	-	-	-	-
OC	NPBY	Newport Bay	-	-	-	O	O	O
OC	NPBH	Newport Beach	-	-	-	-	-	-
OC	CRCV	Crystal Cove	-	-	-	-	-	-
OC	ALCK	Aliso Creek	M	-	-	-	-	-
OC	DNPT	Dana Point	-	-	-	-	-	-
OC	OCNS	Oceanside	-	-	-	-	-	-
OC	AGHD	Agua Hedionda	-	-	-	-	-	-
OC	BAQU	Batiquitos	-	-	-	-	-	-
SD	MIBY	Mission Bay	O	-	-	-	-	-
SD	SDKB	San Diego Bay, Kellogg Beach	-	O	-	-	-	O
SD	SDFL	San Diego Bay, Ferry Landing	-	O	-	-	-	O

County	Site ID	Site name	As	Hg	Se	Total Chlordanes	Total DDT	Total PCBs
SD	SDPP	San Diego Bay, Pepper Park	-	-	-	-	-	O
SD	SDCV	San Diego Bay, Chula Vista	-	-	-	-	-	O
SD	IPBH	Imperial Beach	M	-	-	-	-	-

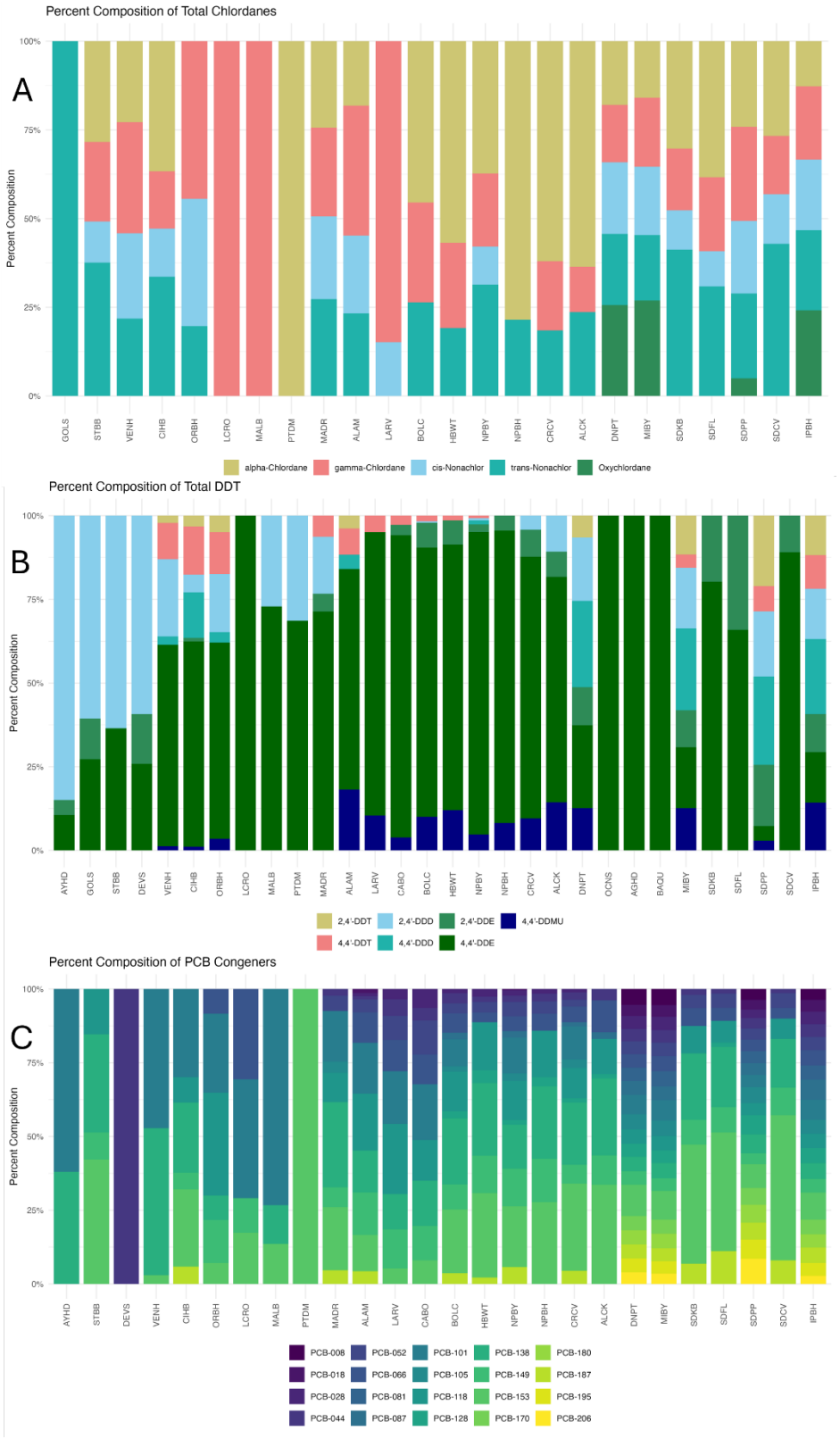


Figure 7. Mean percent composition of chlordanes (A), DDT (B), and PCBs (C) in Bight '23 bivalves along the Southern California Bight coastline from north to south.

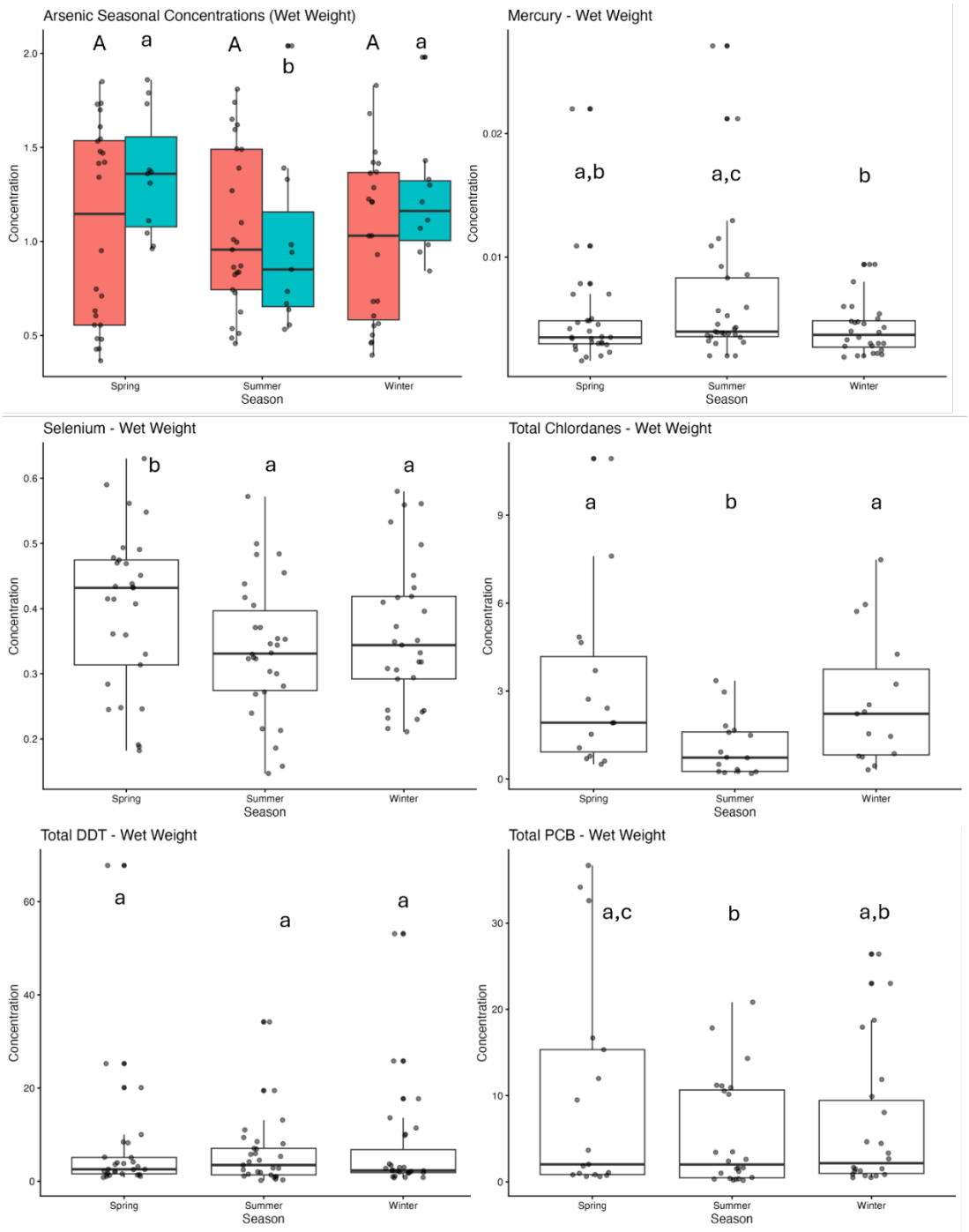


Figure 8. Seasonal distributions of arsenic in Bight '23 mussels (left box plot for each season) and oysters (right box plot), and for all other chemical analyte classes in bivalves (pooled mussels and oysters). Concentrations of inorganics in µg/g and organics in ng/g, both wet weight. Distributions with the same letter are not statistically different (ANOVA, Tukey post-hoc test, overall α=0.05).

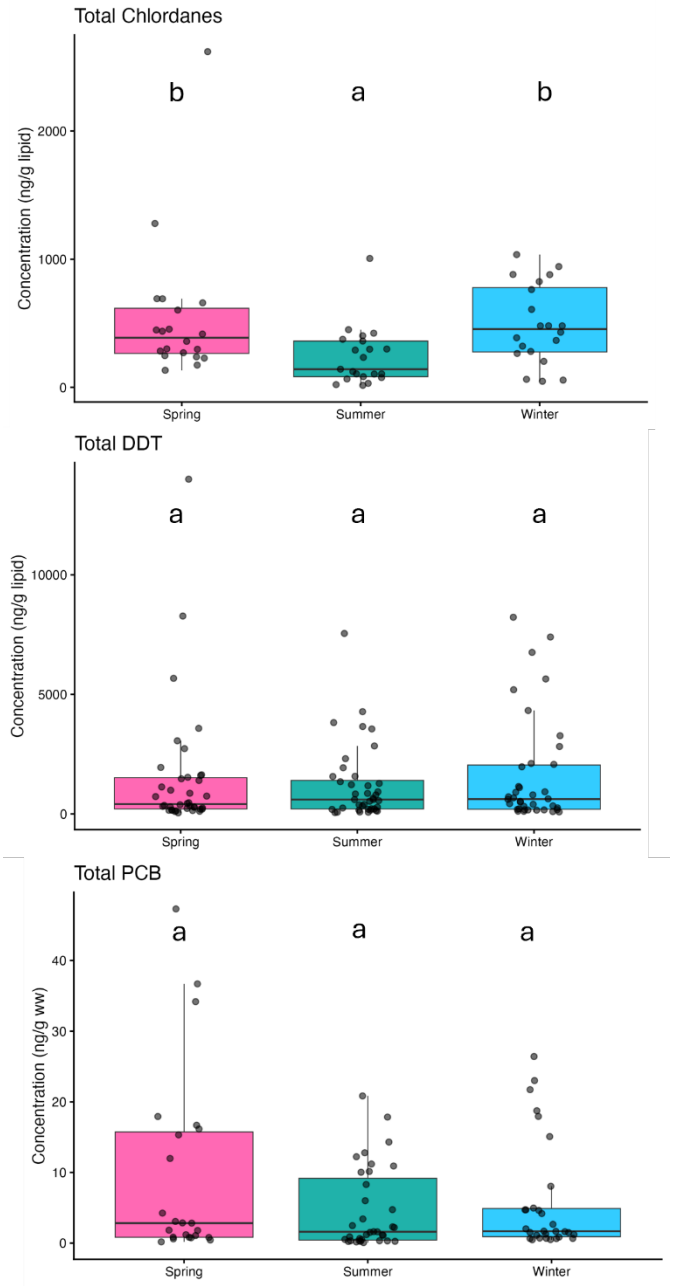


Figure 9. Seasonal lipid-normalized concentration distributions (ng/g lipid) of lipid-normalized total chlordanes, total DDTs, and total PCBs in Bight '23 bivalves (pooled mussels and oysters). Distributions with same letter are not statistically different (ANOVA, Tukey post-hoc test, overall α=0.05).

Table 15. Spearman correlations (ρ) of Bight '23 bivalve analyte classes (arsenic, mercury, selenium, total chlordanes, total DDTs, and total PCBs). Asterisks indicate statistical significance: *p < 0.05, **p < 0.01, and ***p<0.001.

	As	Hg	Se	Chlordanes	DDTs	PCBs
As	**1**	**--**	**--**	**--**	**--**	**--**
Hg	**0.05**	**1**	**--**	**--**	**--**	**--**
Se	**0.51 *****	**-0.24 ****	**1**	**--**	**--**	**--**
Chlordanes	**0.11**	**0.14**	**-0.26 ***	**1**	**--**	**--**
DDTs	**-0.1**	**0.05**	**0.14**	**0.42 *****	**1**	**--**
PCBs	**0.010**	**0.39 *****	**-0.18**	**0.56 *****	**0.12**	**1**

Table 16. P-values and goodness-of-fit (r^2) values for linear regressions between mean weight and mean size and analyte concentrations on a wet weight (ww) and lipid-normalized basis. Asterisks indicate significance at 95% confidence.

Analyte	Species	Conc. basis	weight p-value	r^2 weight vs. conc.	Length p-value	r^2 length vs. conc.
Arsenic	Mussels	ww	0.0000003*	0.272	0.000006*	0.218
Arsenic	Oysters	ww	0.0886	0.094	0.767	0.003
Mercury	Mussels	ww	0.015*	0.073	0.0814	0.038
Mercury	Oysters	ww	0.0794	0.102	0.533	0.014
Selenium	Mussels	ww	0.883	0	0.257	0.015
Selenium	Oysters	ww	0.106	0.085	0.0524	0.12
Total chlordane	Mussels	ww	0.87	0.001	0.685	0.005
Total chlordane	Oysters	ww	0.982	0	0.398	0.034
Total DDTs	Mussels	ww	0.00212*	0.112	0.000772*	0.133
Total DDTs	Oysters	ww	0.01*	0.214	0.00007*	0.437
Total PCBs	Mussels	ww	0.123	0.042	0.0668	0.059

Analyte	Species	Conc. basis	weight p-value	r^2 weight vs. conc.	Length p-value	r^2 length vs. conc.
Total PCBs	Oysters	ww	0.0516	0.143	0.0252*	0.185
Total chlordane	Mussels	lipid	0.552	0.011	0.611	0.008
Total chlordane	Oysters	lipid	0.506	0.021	0.0751	0.143
Total DDTs	Mussels	lipid	0.000488*	0.149	0.00227*	0.116
Total DDTs	Oysters	lipid	0.0023*	0.287	0.00000223*	0.556
Total PCBs	Mussels	lipid	0.0446*	0.073	0.0411*	0.075
Total PCBs	Oysters	lipid	0.136	0.087	0.0949	0.108

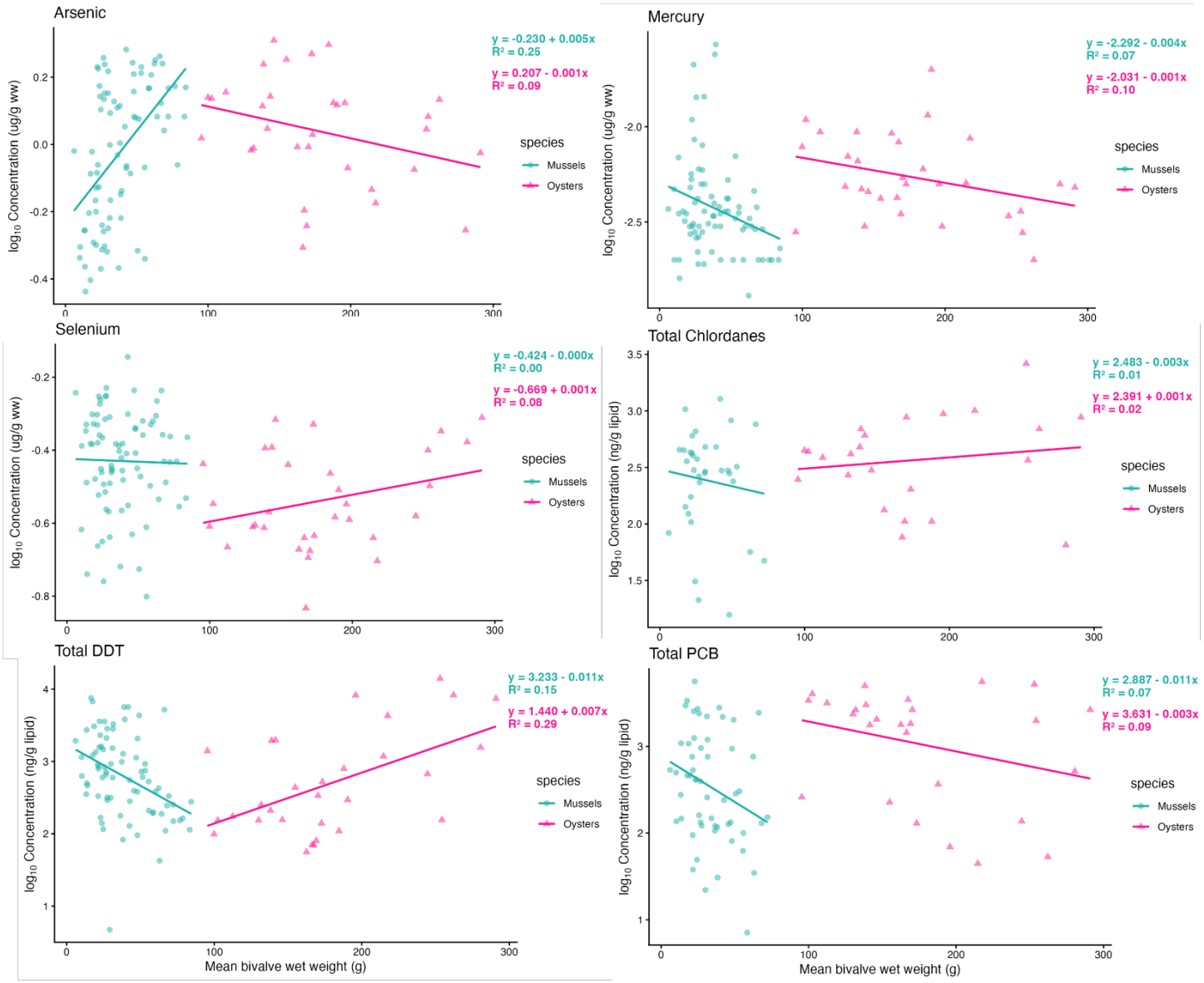


Figure 10. Wet weight concentrations (µg/g for inorganics, ng/g for organics) versus mean weight of mussels and oysters.

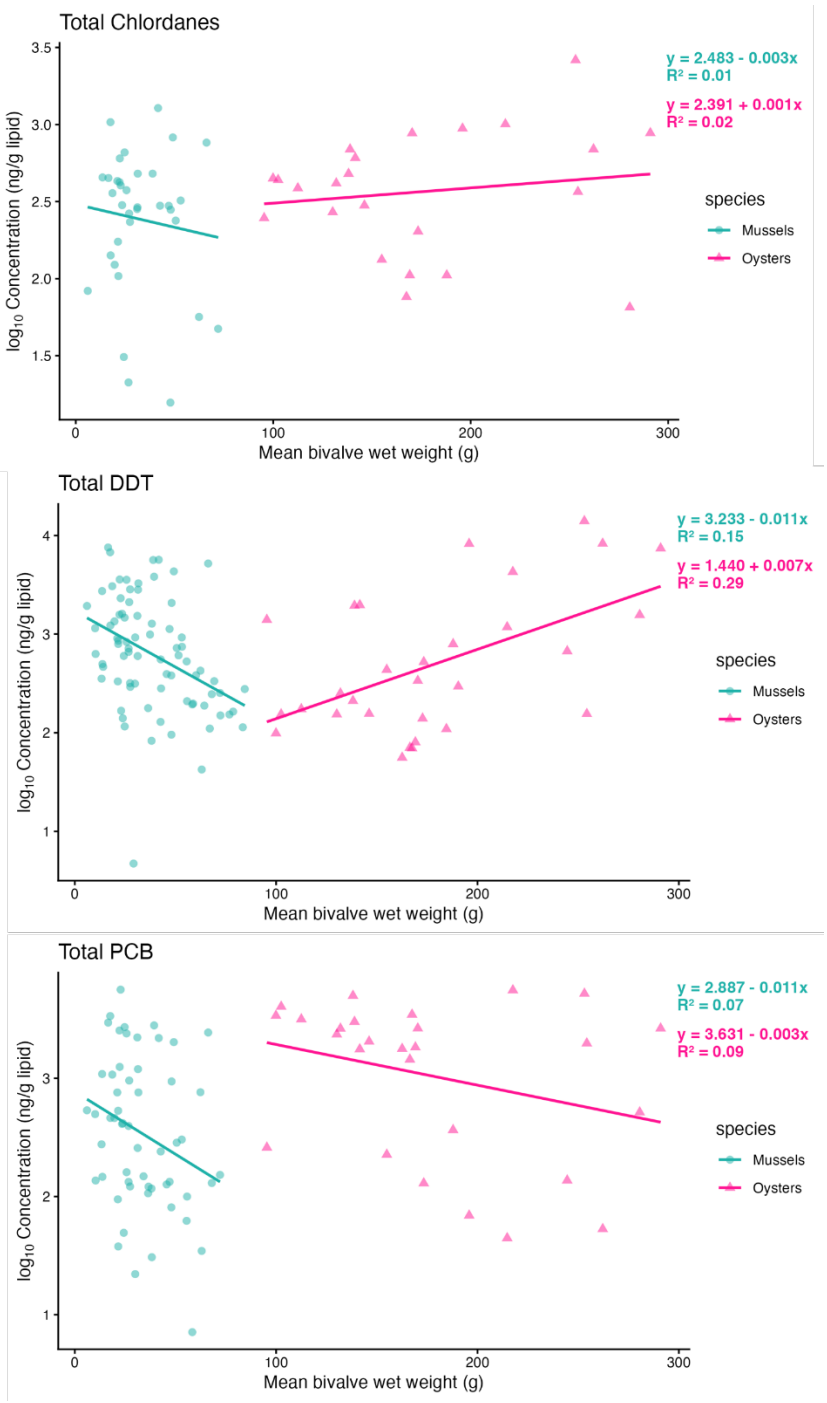


Figure 11. Lipid-normalized concentrations (ng/g) versus mean weight of mussels and oysters.

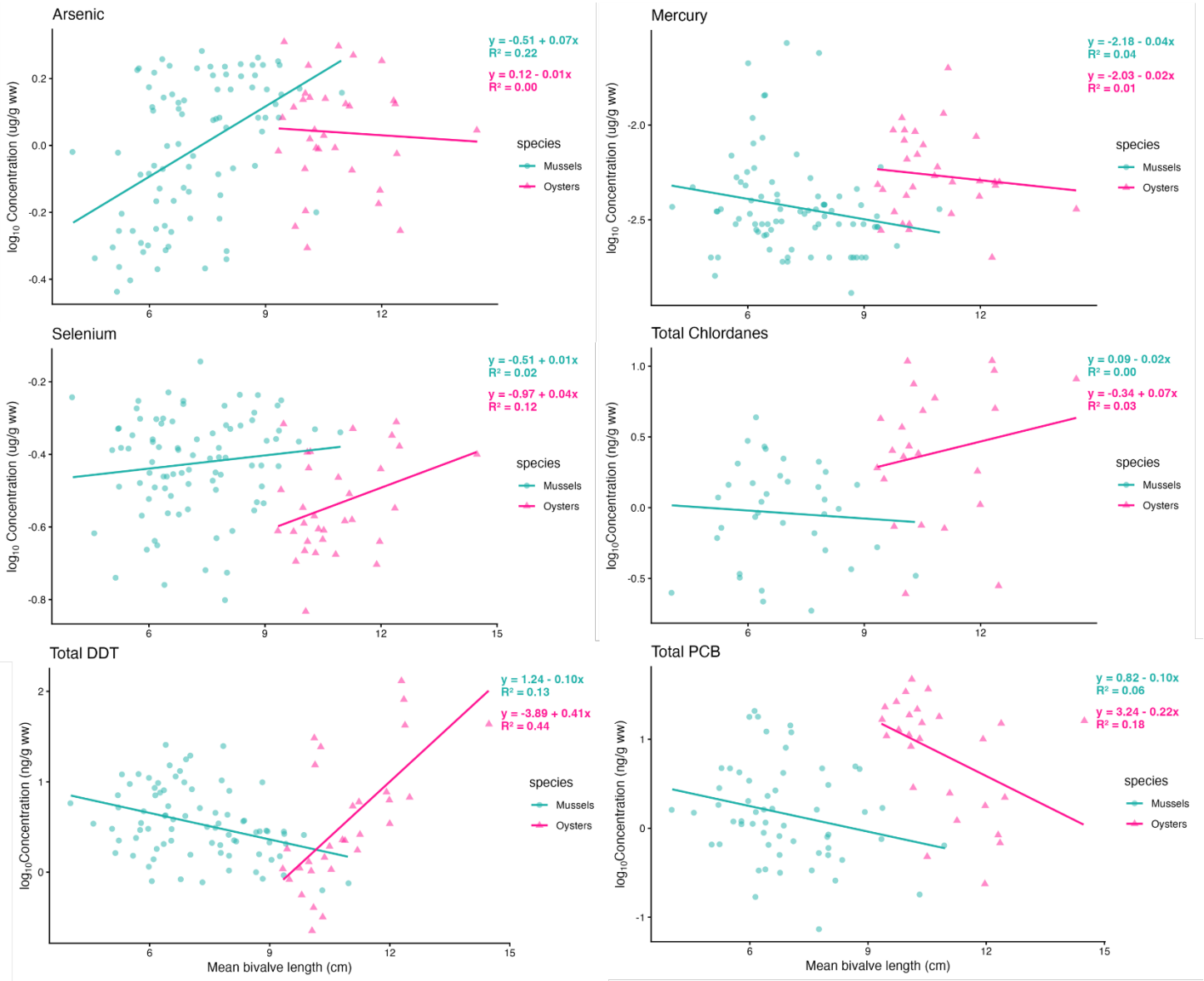


Figure 12. Wet weight concentrations (µg/g for inorganics, ng/g for organics) versus mean length of mussels and oysters.

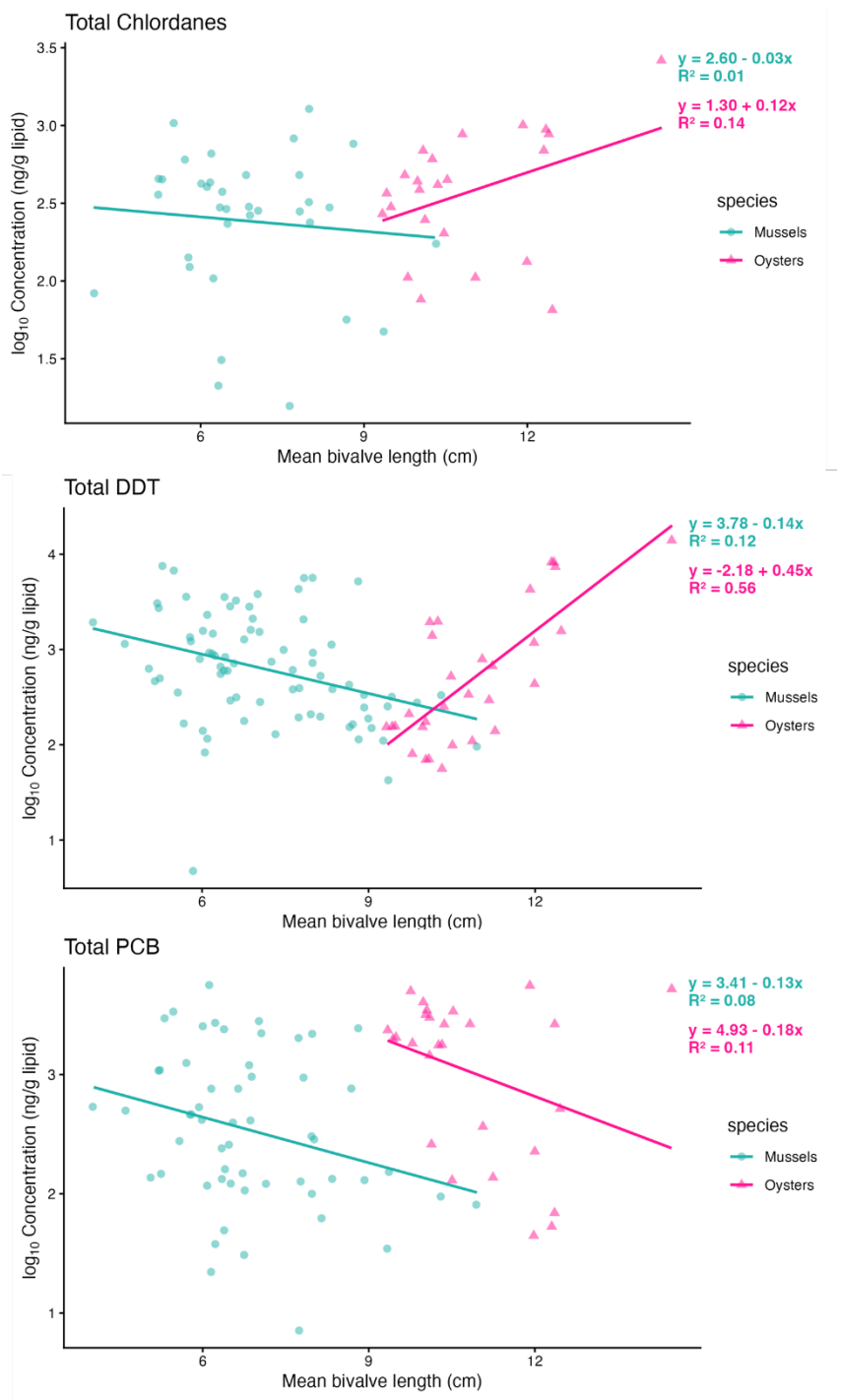


Figure 13. Lipid-normalized concentrations (ng/g) versus mean length of mussels and oysters.

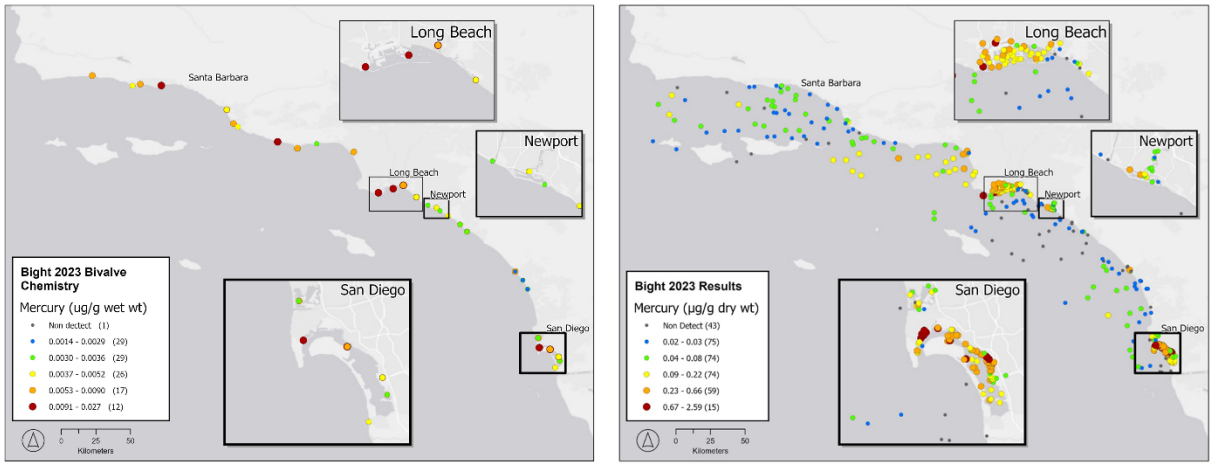


Figure 14. Maps of mercury concentrations in bivalves (left, µg/g wet weight) and surficial sediments (right, ng/g dry weight) in Bight '23. Concentration data is binned into non-detect values, minimum to 25th percentile, 25th percentile to median, median to 75th percentile, 75th percentile to 90th percentile, and 90th percentile to maximum. Numbers in parentheses after concentration ranges are the number of samples in each bin.

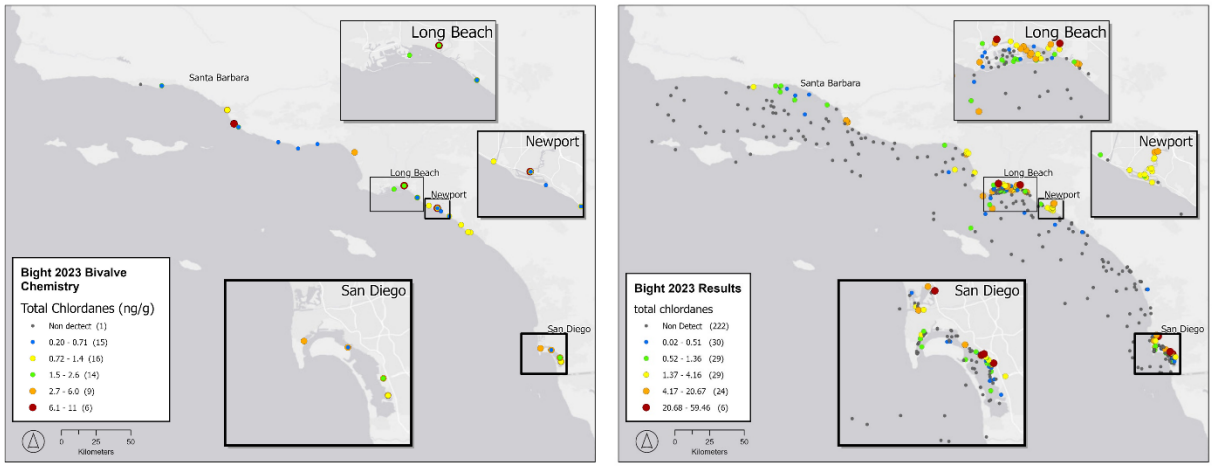


Figure 15. Maps of total chlordane concentrations in bivalves (left, ng/g wet weight) and surficial sediments (right, ng/g dry weight) in Bight '23. Concentration data is binned into non-detect values, minimum to 25th percentile, 25th percentile to median, median to 75th

percentile, 75th percentile to 90th percentile, and 90th percentile to maximum. Numbers in parentheses after concentration ranges are the number of samples in each bin.

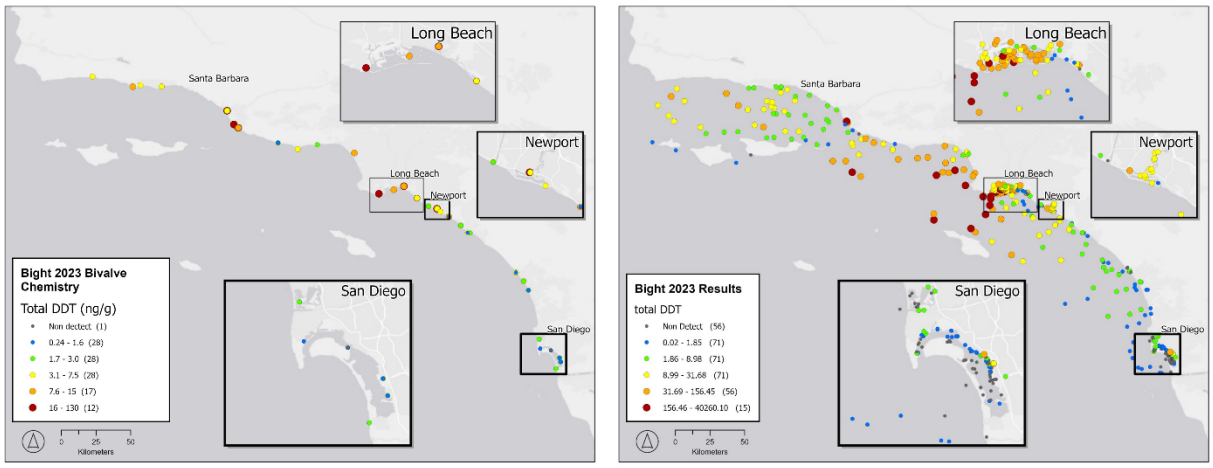


Figure 16. Maps of total DDT concentrations in bivalves (left, ng/g wet weight) and surficial sediments (right, ng/g dry weight) in Bight '23. Concentration data is binned into non-detect values, minimum to 25th percentile, 25th percentile to median, median to 75th percentile, 75th percentile to 90th percentile, and 90th percentile to maximum. Numbers in parentheses after concentration ranges are the number of samples in each bin.

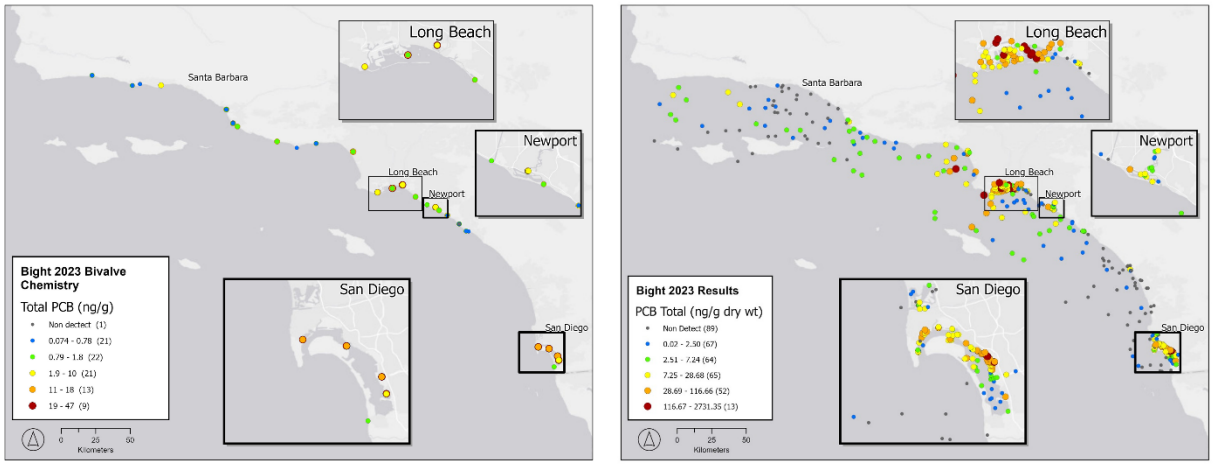


Figure 17. Maps of total PCB concentrations in bivalves (left, ng/g wet weight) and surficial sediments (right, ng/g dry weight) in Bight '23. Concentration data is binned into non-detect values, minimum to 25th percentile, 25th percentile to median, median to 75th

percentile, 75th percentile to 90th percentile, and 90th percentile to maximum. Numbers in parentheses after concentration ranges are the number of samples in each bin.

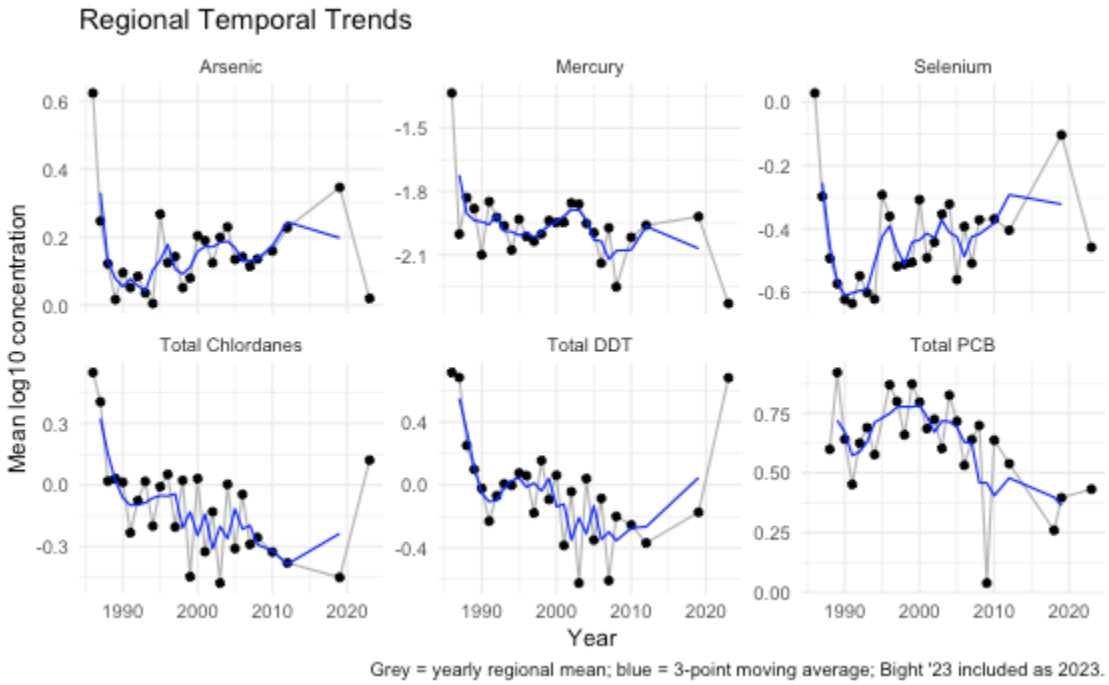


Figure 18. Three-point moving average for contaminant trends (inorganics in µg/g wet weight, organics in ng/g wet weight) in Southern California Bight bivalves, from NOAA Mussel Watch and Bight '23.

Table 17. Spearman correlations (ρ) and p-values (*=significant at α=0.05) of bivalve contaminants by wet weight in Southern California Bight bivalves from monitoring programs since 1985: NOAA Mussel Watch (until 2019) and Bight '23 (2024).

analyte	ρ	p
As	+0.18	0.36
Hg	-0.36	0.07
Se	+0.26	0.19
Chlordanes	-0.55	0.003*
DDTs	-0.54	0.004*
PCBs	-0.42	0.03*

Table 18. Spearman correlations (ρ) for bivalve wet-weight analytes in selected areas of the Southern California Bight from 1985-2024 (left-hand value for each analyte) and from 1995-2024 (right-hand value for each analyte), based on data from NOAA Mussel Watch and Bight '23. Asterisks indicate statistical significance: *p < 0.05, **p < 0.01, and ***p<0.001.

locale	As	Hg	Se	Chlordanes	DDTs	PCBs
Channel Islands Harbor	-0.15/-0.15	-0.52/-0.52	-0.15/-0.15	+0.43/+0.08	0/-0.07	-0.64/-0.64
Los Angeles/Long Beach Harbor	+0.12/-0.007	-0.09/+0.01	+0.41**/+0.13	-0.25/-0.19	-0.71***/-0.14	-0.23*/-0.45
Newport Bay	-0.11/-0.08	-0.54**/-0.30	+0.38*/+0.40	-0.19/-0.15	+0.008/-0.03	-0.57**/-0.68**
San Diego County	+0.003/-0.04	-0.36***/-0.25*	+0.28***/+0.18	-0.41***/-0.18*	-0.32***/-0.18***	-0.11/-0.21