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San Francisco Delta Risk Assessment Year 1 Report Appendices

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APPENDICES

Appendix A. Detailed Study Area Descriptions

Upper San Francisco Estuary Study Site

The San Francisco Estuary (SFE) in California is the largest estuary on the west coast of the United States (SFEP 2020). Its watershed extends from the Sierra Nevada mountains west through the Coastal Range mountains and to the Golden Gate. It encompasses an area almost 162,000 km^2 in size, which is approximately 40% of the state's land area (SFEP 2020, CWSC 2020a). The estuary is comprised of four smaller bays:

1. Suisun Bay is the furthest upstream and northeast of the other three bays. It is shallow, marshy, and the least saline due to its proximity to the confluence of the Sacramento and San Joaquin rivers (SFEP 2020). Rural land use predominates its watershed (SFEP 2020).
2. San Pablo Bay (North Bay) is west of Suisun Bay and forms the northern basin of San Francisco Bay (SFB). It is also strongly influenced by freshwater inputs from Suisun Bay and is surrounded by rural areas (SFEP 2020).
3. Central Bay is south of San Pablo Bay and forms the central basin of the SFB that outflows via the Golden Gate strait to the Pacific Ocean. It is the deepest and most saline of the four bays due to its proximity to the coastal marine environment, diurnal tides, and tidal currents (SFEP 2020). Industrial and urban land uses heavily dominate its shores (SFEP 2020).
4. South Bay is south of the Central Bay and forms the southern basin of SFB. It is a shallow coastal lagoon and extends from the Golden Gate approximately 50 km south to form extensive marshes, backwater channels, and salt ponds (SFEP 2020).

The three northern (upper) bays of the San Francisco Estuary (USFE) are geographically and hydrologically distinct from the South Bay (Conomos et al. 1985). The South Bay is a shallow, tidally influenced, lagoon-type estuary (Conomos et al. 1985), whereas the Upper San Francisco Estuary is strongly influenced by freshwater inflows from the Sacramento and San Joaquin rivers. The two rivers and their tributaries drain 95% of the SFE watershed and account for 90% of the freshwater discharge into the estuary (Conomos et al. 1985). Precipitation and snowmelt account for most of the freshwater inputs into the Sacramento River, whereas in the drier region of central California where precipitation and snowmelt are less, groundwater aquifers account for freshwater inputs into the San Joaquin River.

Water flow within the estuary is complex with freshwater from the east flowing west through Suisun Bay, San Pablo Bay, and then south into Central Bay and South Bay. Twice a day, however, tides push marine water from the Pacific Ocean through the Golden Gate strait into Central San Francisco Bay. The saline water flows north into San Pablo Bay, continues east into Suisun Bay, then into the inlets of the Sacramento and San Joaquin rivers, and into the Sacramento-San Joaquin River Delta. Basin morphometry, tides, tidal currents, wind, and freshwater stream flows are major factors that affect water transport, circulation, and mixing within each bay. The end result is the creation of a vast estuarine ecosystem with unique habitats and water quality conditions that support hundreds of diverse aquatic, estuarine, and marine species.

Human activities, however, including hydraulic mining, dam and levee construction, wetland infill, urban development, and agricultural practices in the USFE have resulted in land

subsidence, decreased water quality, contaminant loading, and saltwater intrusion. Sediment loading, as well as freshwater flows within the estuary have also been altered. Suspended sediment contributions from the Sacramento and San Joaquin rivers prior to the California Gold Rush in 1848 were estimated to be 15.3 x 10^5 m^3 (Porterfield 1980). The impact of hydraulic mining in the headwaters of the two rivers during and after the gold rush up until the early 1900s resulted in the sediment loading increasing to 137.6 x 10^5 m^3 (Porterfield 1980). In addition to partially filling in Suisun, San Pablo, and San Francisco bays, the sediments also changed water flows, sediment deposition, contaminant distribution, habitat quality and quantity, and water quality throughout the estuary (CWSC 2020b). The impacts on primary producers and consumers, benthic organisms, and fish caused cascading effects on the SFE food webs (CWSC 2020b). Dredging, which also has a deleterious effect on benthic species, was implemented in the early 1900s and continues today to keep deep channels within each of the four bays open for shipping. Dredge spoils have also been used to create new habitat. Water has also been diverted from the Sacramento River to provide freshwater in central and south California for agricultural, urban, and environmental needs. Less water has resulted in lower flows that have hindered passage for migratory fish, including salmon from reaching their natal streams to breed.

Today the status and trends for the SFE indicate continued challenges for resource managers (SFEP 2020). Freshwater flows through the estuary and its floodplains are no longer adequate to sustain wetland habitats, support food webs, and regulate water quality. Tidal marsh restoration activities in recent years, however, have made progress in the estuary and efforts are still ongoing to restore critical wetland habitat in the Sacramento-San Joaquin River Delta region. Fish communities continue to decline, as do birds and other valued species, primarily due to habitat loss and contaminants. Land subsidence in the Delta and San Joaquin River Valley also continues, making those regions more susceptible to flooding, habitat alteration, and saltwater intrusion. Lastly, climate change has added an additional level of pressure to an already stressed ecological region. Sea level rise, ocean acidification, warmer temperatures, and prolonged and at times extreme weather patterns resulting in years of drought, as well as catastrophic floods are already having an impact on the landscape, habitats, and species in the SFE.

The focus of this ecological risk assessment study was the eastern portion of the USFE and included the watersheds of the Sacramento River, the San Joaquin River, the Sacramento-San Joaquin River Delta, and Suisun Bay (**Figure A1**). This region has been the most severely impacted due to human activities and is also the region that is still showing declines in most indicators used to evaluate its ecological services (SFEP 2019).

The Sacramento River
The Sacramento River is the largest river in California and is estimated to supply about 22 million acre-feet of water annually to the Central Valley of California, which equates to 35% of the state's water supply (McClurg 1997). The river originates in the northern part of the state in the Klamath Mountains near Mount Shasta. It flows south approximately 640 km and drains about 72,000 km^2 of primarily agricultural lands in the Sacramento Valley (Carter and Resh 2005). It eventually merges with the San Joaquin River to form an extensive inland river delta, the Sacramento-San Joaquin River Delta (Delta) with Suisun Bay at its entrance just to the west.

Regional weather patterns and the diverse topography of the watershed, ranging from mountain ranges to sea level marshes and agricultural lands, results in the watershed receiving 66-75% of northern California's annual precipitation. The benefit was the creation of the Delta, a vast

freshwater riverine ecosystem that provides extensive riparian and marsh habitats, supporting hundreds of endemic and migratory species of birds, fish, waterfowl, and wildlife. The region supports almost 40 native freshwater fish, including 5 species of anadromous fish (Abell et al. 2000), as well as provides rearing habitat for 70% of all salmon caught off the California Coast (McClurg 1997). Accelerated erosional processes in the nearby mountain ranges have also resulted in the creation of organically fertile soils in the lowlands that now support over 2 million acres of agriculture (McClurg 1997).

Figure A1.   Upper San Francisco Estuary study area and risk regions delineated in it.

Conversely, that amount of precipitation also made the lowland areas highly vulnerable to flooding (Stene 2015). Actions over the last 150 years have resulted in the construction of numerous dams, levees, canals, and floodways along the river and its tributaries, not only for flood control, but also for navigational improvements and providing hydroelectric power to the region. Pumps and pipes were also installed to distribute water for irrigation and to meet growing urban population needs within the region, as well for distribution to the more drought prone central and southern areas of California (Stene 2015). The result is a highly engineered watershed.

The river and its watershed are now irreversibly altered with significant losses in riparian and wetland habitats, to the detriment of the diverse species that utilized them. With a current population of 2.8 million people living in the Sacramento River watershed, demand for water and arable land continue to grow. Concurrently, contaminants from historical mining activities, dredging, agricultural land use practices, and urban development have impacted many species of resident and migratory fish, birds, and wildlife populations in the watershed (Domagalski and Brown 1994, Domagalski et al. 2000, USGS 2020a). Mercury, arsenic, copper, zinc, and lead from mining and acid mine drainage, pesticides/insecticides (organochlorine, organophosphate), herbicides, and nutrients (nitrates and phosphates) from agricultural land use practices, as well as contaminants in stormwater runoff from urban areas are of particular concern. Toxic effects in aquatic species are detectable in the Sacramento River, as well as in the Sacramento-San Joaquin River Delta into which it discharges.

The San Joaquin River
The San Joaquin River is the longest river in central California at 589 km in length. It originates in the south-central Sierra Nevada mountains. It flows west-southwest into the rich agricultural lands of the San Joaquin Valley and then northwest before merging with the Sacramento River to form the Sacramento-San Joaquin River Delta. Its watershed totals about 40,400 km^2 in area (USGS 2020b). It provides critical habitat for millions of birds, fish, and wildlife. It is also home to approximately 4.5 million people as of 2000 (Delta Vision 2020).

Similar to the Sacramento River watershed, human activities over the last 150 years have resulted loss or alteration of over 95% of the wetlands in the San Joaquin River watershed (USFW 2006). The drainage of marshes and swamps for agriculture, as well as the construction of levees, canals, and dams along its length for flood control, irrigation, hydroelectric power, and drinking water have made the San Joaquin River one of the most impacted rivers in the west (Jahagirdar 2006). Compounding those impacts is land subsidence due to extensive groundwater extraction for irrigation and drinking water. (WEF 2020a).

The river is also considered the most polluted in the west (Jahagirdar 2006, Lee and Jones-Lee 2006). Decades of pesticide (organochlorine, organophosphate), insecticide, and fertilizer (nitrates, phosphates) applications on the surrounding agricultural lands have resulted in their ubiquitous presence throughout the watershed (Lee and Jones-Lee 2006). Agricultural land use practices have also resulted in increased particle and nutrient loading to the river and its tributaries, causing increased turbidity, increased salinity, and low dissolved oxygen issues in the water. In addition, acid mine drainage from abandoned mines in the mountainous headwater reaches of the river and its tributaries, coupled with urban runoff have resulted in elevated concentrations of metals, including mercury, copper, zinc, and cadmium.

Natural geologic sources of metal contaminants are also an issue. In the 1980s, selenium contamination was discovered in the San Joaquin Valley and traced back to natural reservoirs

of selenium in the Coastal Range west of the valley (Presser and Ohlendorf 1987). Unknown at the time, hydrogeological erosional processes were causing its release into the valley where it accumulated in evaporation ponds used for irrigation drainage water at the Kesterson Reservoir (WEF 2020b). The ponds also provided important habitat for migratory waterfowl as part of the San Luis National Wildlife Refuge. In 1983, the discovery of dead and deformed waterfowl, as well as fish was eventually traced to the selenium in the evaporation ponds (Presser and Ohlendorf 1987, WEF 2020b). The reservoir was closed in 1986, the water evaporated, and a soil cap was placed over the remaining depressions (WEF 2020b). The incident served to identify the prevalence of naturally occurring selenium throughout the region and resulted in ongoing monitoring since then to detect potential hotspots.

The Sacramento-San Joaquin River Delta
The Sacramento-San Joaquin River Delta (Delta) is an inverted river delta of channels and islands created by the convergence of the Sacramento and San Joaquin rivers. It is over 2,900 km^2 in area and flows into Suisun Bay just to the west (McClurg 1997). The Sacramento River accounts for 80% of its freshwater inflow and in its entirety, the Delta provides water to 27 million people, and is the main source of freshwater for the rest of the state (McClurg 1997, Ingebritsen et al. 2016, CDWR 2020a). Historically the Delta was a vast tidal freshwater marsh with innumerable islands created by the force of the two rivers forming channels and waterways through the nutrient-rich peat and alluvial soils. In the late 1800s, however, demand for farmland resulted in the construction of more than 1800 km of levees along the channels to protect the surrounding land from flooding (Ingebritsen et al. 2016). The land was then drained, cleared, and used for large-scale agricultural operations. Today 73% of the Delta lands have been reclaimed for agricultural use, however many of its original swamps and backwaters have been retained. The remainder of the Delta watershed is comprised of urban development (8.7%), undeveloped lands (10%), and waterways and sloughs (8.3%).

One of the major consequences of land reclamation and agricultural practices in the Delta over the years has been land subsidence (Ingebritsen et al. 2016, SFEP 2019). Wind erosion of exposed soils, decomposition of organic carbon in the peat soils, and soil compaction have caused many of the 57 islands in the central and western Delta on which crops are grown have subsided 3 to 7.6 m below sea level (Ingebritsen et al. 2016, SFEP 2019). Levee maintenance and repair to protect the land from tidal and freshwater flooding have been implemented and are ongoing. Drainage ditches have been installed on the islands as well to collect excess water and maintain groundwater levels by pumping the water into the adjacent stream channels. These management actions have resulted in loss of intertidal habitat within the Delta, as well as put a major source of the state's freshwater at risk from saltwater intrusion (SFEP 2019). Currently, upstream dams are used to control flooding and regulate salinity within the Delta, however increased demands for water, continued land subsidence, rising sea levels, and earthquakes are placing greater stresses on an already vulnerable ecosystem.

The interface of saline water from the coast with freshwater from the Sacramento and San Joaquin rivers and their tributaries within the Delta provides a unique estuarine environment supporting diverse fish, birds, wildlife, and plant species. It supports 25% of all warm water and sport fish, including endangered Delta smelt and is a key migration route for anadromous fish including the endangered winter-run Chinook salmon (McClurg 1997). Currently it is estimated that there are more than 55 fish species and more than 750 plant and wildlife species in the Delta (CDWR 2020a). Its wetlands also support at least half of the Pacific Flyway migratory waterfowl. Natural and anthropogenic impacts to, as well as contaminants in the Delta, however, have resulted in approximately 100 species of wildlife, 140 plant species, and 13 fish species to be listed as threatened or endangered (CDWR 2020a).

Suisun Bay

Suisun Bay is located at the mouth of the Delta where the Sacramento and San Joaquin rivers converge. It is approximately 24 km long and (USGS 1964) and is relatively shallow due to the historical, as well as ongoing transport of suspended sediments into it from the two rivers. The bay includes two sub-basins, Grizzly Bay to the northeast and Honker Bay to the east, and is encompassed along its entire northern region by 202 km^2 of marshland, the Suisun Marsh, which is the largest contiguous brackish marsh on the west coast (WEF 2020c). Together Suisun Bay's tidal and diked marshes, sloughs, and upland grasslands comprise more than 10% of California's wetlands (WEF 2020c). They provide essential habitat and food for 40 fish species, 221 bird species, 45 species of mammals, 16 reptile and amphibian species, and numerous plant species (CDFW 2020a). They also serve a key role, providing resting and feeding grounds, for thousands of migratory birds as part of the Pacific Flyway (WEF 2020c).

The water quality in Suisun Bay is heavily influenced by freshwater inputs from the Sacramento and San Joaquin rivers, and Delta to the east, as well as from diurnal tidal marine water entering the bay from San Pablo Bay to the west. The convergence of the two water masses created the highly diverse and unique estuarine/wetland environment of Suisun Bay. It also made the region highly susceptible to flooding. In response, and similar to management actions taken in the Delta region, more than 370 km of levees were constructed over the last 130 years in Suisun Marsh (WEF 2020c). The other challenge of unregulated inflows of tidal and riverine water into the bay was daily and seasonal changes in flows and volumes of water, resulting in either too high saline or freshwater concentrations for endemic species. The fluxes in saline versus freshwater concentrations were extreme enough that deleterious effects were impacting species and food webs within the bay. In response, the California Department of Water Resources built salinity control gates in the 1980s to restrict the inflow of higher salinity water into the bay during incoming tides, as well as retain lower salinity water from the Sacramento River during ebb tides (CDFW 2020a).

The Suisun Bay watershed is surrounded by rural development and agriculture. Like the Delta region, it too has been impacted by sedimentation, historical infill of wetlands, habitat loss, and contaminants. The bay receives contaminants not only from land use practices in its watershed, but also from the Sacramento River, San Joaquin River, the Delta, and their watersheds upriver. Contaminants include agricultural use pesticides, insecticides, herbicides, and fungicides, as well as metals and nutrients.

Suisun Bay is also home to the Suisun Bay Reserve Fleet, as part of the National Defense Reserve Fleet (NDRF) managed by the U.S. Maritime Administration (MARAD). The fleet is located along the northwest shore of Grizzly Bay and has been stationed there since 1946. At its peak in 1952, Suisun Bay hosted 340 ships comprised of its ready reserve fleet vessels, as well as obsolete commercial and decommissioned U.S. Navy ships awaiting disposal (MARAD 2018). By the early 2000s, environmental concerns regarding spilled fuels, PCBs, metals including zinc, mercury, and lead, and anti-fouling chemicals from the obsolete, derelict ships anchored there resulted in a lawsuit by the state of California against MARAD. Congress responded and authorized the National Oceanic and Atmospheric Administration (NOAA) to conduct a Damage Assessment, Response, and Restoration Project Assessment (DARRPA). The assessment was started in 2008 and resulted in an agreement in 2009 to clean and remove all derelict ships from the bay. Seven years later, all 57 derelict vessels had been removed. Today, the Suisun Bay Reserve Fleet is much smaller, however, the bay still hosts the largest number of vessels of the three remaining NDRF reserve fleet locations (MARAD 2018). Moreover, contamination from the vessels is still present in the water column and sediments, though in much lower concentrations than historically.

According to the 2019 State of the Estuary Report, Suisun Bay is the most impaired of the four basins (SFEP 2019). Fish data from the 1980s to the present show dramatic declines in fish abundance and diversity, as well as in native species composition and distributions of fish communities in both the bay and in Suisun Marsh (SFED 2019). Seasonal high flows in the Sacramento and San Joaquin rivers also occur less frequently, resulting in less productive, low salinity habitats being created to support ecological processes that support crucial food webs in the bay and marsh (SFEP 2019). Drought has also been a factor, impacting water quantities and distributions both in the Delta-Suisun Bay region and San Francisco Bay proper from 2011-2019. State mandated restrictions on potable water use, however, did result in a 27% reduction in water use by 2017 even though there was a 31% increase in population. In the Delta-Suisun region water consumption decreased 31% per capita (SFEP 2019).

Restoration projects in Suisun Bay, specifically in Suisun Marsh were initiated after the completion of the Suisun Marsh Management Plan in 2014 (CDFW 2020b). The 30-year plan includes restoring 20-28 km^2 of tidal marsh, enhancing more than 40,000 managed wetlands, improving water quality, and fish and wildlife habitat (CDFW 2020b). Recent fish data indicate that recently restored wetlands are already being utilized by fish, including the endangered longfin smelt (SFEP 2019). Moreover, the proportion of native fish in the marsh has improved during the last five years. Work also continues to reestablish historical floodplain habitat and riparian woodlands in some locations, as well as release water from dams at strategic times to simulate natural river flows and restore fluvial dynamics processes (SFEP 2019).

Appendix B.   Detailed Salinity Information

Salinity

Salinity in natural waters is an important factor in determining water chemistry, its physical and thermodynamic properties, and the biological processes taking place within it. In the coastal waters of San Francisco, it plays a key role in the water quality, flow dynamics, and biodiversity within the SFE. The SFE is characterized by mixed semi-diurnal tides with roughly two unequal high tides per day that push coastal saline water from the Golden Gate north through San Pablo and Suisun bays to the Delta region in the northeast (CDWR and CDWF 2015). The extent of its reach, however, is influenced by freshwater flows into the Delta from the Sacramento, San Joaquin, and Mokelumne river systems. Lower river flows result in further inland incursions of tidally influenced saline water, whereas higher flows push the saline water further downstream. Land subsidence in the Delta, as well lower river flows due to increased demands for agriculture and urban development have increased the potential for saltwater intrusions into the Delta. To prevent them from occurring, channel operations, as well as water releases from dams and tidal gates are used to supplement freshwater flows as part of the water management program of the Delta region (CDWR and CDWF 2015).

The tidally influenced movements of saline and fresh water twice a day in the SFE aids in circulating and mixing the two water columns along a gradient from mostly saline waters in the west to primarily freshwater furthest upstream in the Delta. The result is a dynamic estuarine ecosystem with zones of varying salinities across the estuary. Low salinity zones (LSZ) have long been recognized as significant fish nursery habitat for numerous species, including federal and state listed Delta smelt and Chinook salmon within the SFE (Turner and Chadwick 1972, Herbold et al. 1992, Grimaldo et al. 2009, Sommer et al. 2011, USBR 2019). When freshwater flows into the estuary are high the LSZ expands and moves downstream. Conversely, it contracts when tides are high or when freshwater flows are low.

The common metric for measuring ocean salinity is the PSU (practical salinity unit) based on seawater conductivity. It is used in identifying the LSZ within the SFE. X_2 is an estuarine habitat suitability indicator, correlated with river flow, that is used to denote how high or low the habitat suitability is within the LSZ (Jassby et al. 1995). The location of X_2 is the distance from the Golden Gate Bridge in km to the location of the 2 PSU isohaline. Lower X_2 values indicate locations closer to the Golden Gate, whereas higher numbers indicate locations closer to the Delta. Most commonly, however, X_2 (high habitat suitability) is located between Suisun Bay and the confluence of the Sacramento and San Joaquin Rivers (Jassby et al. 1995, Kimmerer 2002, Feyrer et al. 2007, Sommer et al. 2011). This low salinity isohaline has been strongly associated with several critical life stages of the Delta smelt (Moyle 2002, Bennett 2005, Feyrer et al. 2007, Sommer et al. 2011). Pre-migration adult Delta smelt generally occur relative to the location of X_2 and undergo an upstream migration during winter associated with "first flush" events to their presumed freshwater spawning grounds (Grimaldo et al. 2009, Sommer et al. 2011). Juvenile Delta smelt then move downstream towards the low salinity zone where optimal rearing conditions exist.

The location of X_2 changes from year to year, season to season, and within tidal cycles due to changes in river flows and tides. Water diversions and other water management actions have also had an impact by altering flow regimes within the Delta and causing the location of X_2 to change dramatically from what would naturally occur. When the large water export facilities are in operation, net negative flow within the Old and Middle Rivers can occur, drawing in seawater, and thus the low salinity zone, towards the interior of the Delta.

Appendix C. Search Terms and Toxicity Data Analyses

Literature Search Terms
The following search terms were used in Google Scholar to search the toxicity literature for exposure-response information:

Selenium AND "delta smelt"
Pyrethroid* AND "delta smelt"
Pyrethroid* smelt
("delta smelt" OR "sacramento splittail" OR "threadfin shad" OR "longfin smelt") AND ("methylmercury" OR "mehg" OR "methyl mercury" OR "methyl-mercury")
pyrethroid* AND (smelt OR "delta smelt" OR pelagic)
pyrethroid* AND (fish OR smelt OR "delta smelt" OR pelagic)
(daphnia OR magna OR hyalella OR azteca) AND (diazinon OR malathion OR chlorpyrifos)
("delta smelt" or fish) AND (bifenthrin OR cyfluthrin OR cyhalothrin OR deltamethrin) AND toxicity
("delta smelt" OR fish) AND (imidacloprid OR fipronil) AND toxicity
("delta smelt" OR fish) AND (atrazine OR imidacloprid OR fipronil) AND toxicity
("delta smelt" OR fish) AND (bifenthrin OR cyfluthrin) AND toxicity
("delta smelt" OR fish) AND (atrazine OR imidacloprid OR fipronil OR endosulfan) AND toxicity
("delta smelt" or fish) AND (bifenthrin OR cyfluthrin OR cyhalothrin OR deltamethrin) AND toxicity
(daphnia OR magna OR hyalella OR azteca) AND ("inorganic mercury" OR "inorganic hg" OR "HgCl2")
(daphnia OR magna OR hyalella OR azteca OR "delta smelt" OR fish) AND (esfenvalerate OR selenium OR deltamethrin OR "lambda-cyhalothrin" OR cyhalothrin OR imidacloprid OR atrazine)
inorganic mercury toxicity invertebrates
(daphnia OR magna OR hyalella OR azteca) AND (esfenvalerate OR deltamethrin OR fipronil) AND toxic*
(daphnia OR magna OR hyalella OR azteca) AND esfenvalerate AND toxic*
Organophosphate AND toxicity (fish OR invertebrates)
Deltamethrin AND toxicity (fish OR invertebrates)
Malathion AND toxicity (fish OR invertebrates)
Diazinon AND toxicity (fish OR invertebrates)
Endosulfan AND toxicity (fish OR delta smelt OR invertebrates)
Endosulfan sulfate AND toxicity (fish OR delta smelt OR invertebrates)
Imidacloprid AND toxicity (fish OR delta smelt OR invertebrates)
Fipronil AND toxicity (fish OR delta smelt OR invertebrates)

Toxicity Analysis
The "drc" package (Ritz and Streibig 2020) version 3.0-1 in R version 3.6.3 (R Core Team 2020) was used to generate and compare nonlinear regression models for select compounds in each chemical group. Nonlinear Weibull and log-logistic regression models were generated and compared using Akaike's Information Criterion (AIC) values to identify the most parsimonious regression model. The model with the lowest AIC value was selected for further evaluation.

To evaluate the mathematical uncertainty associated with each dose-response equation the 95% prediction intervals for each model were calculated. Prediction intervals estimate where future observations (data) will occur with a specified degree of confidence. Prediction intervals differ from confidence intervals, which estimate where a parameter will be between two set values for a certain proportion of times with a specified degree of confidence. In the case of dose-response models confidence intervals estimate where the regression curve is expected to occur with a confidence of 1-α; whereas prediction intervals estimate where *n* future observations are

expected to occur with a confidence of 1- α. In this analysis, prediction intervals were calculated for one future outcome ($n = 1$). Since risk assessment aims to predict environmental outcomes, prediction intervals are a more appropriate metric to gauge suitability of dose-response datasets for BN parameterization.

To determine the suitability of these dose-response models for the risk assessment, three main criteria were used:
1. What range or ranges of point estimates (EC_x) displayed clear upper and lower predictive bounds?
2. To what extent could EC_x values be discerned from one another, i.e. what was the degree of overlap for prediction intervals between point estimates?
3. Were data or means used in analyses? For some studies replicate data for each experimental treatment were not available, so treatment means were used to calculate dose-response equations. Using means in lieu of raw data is not ideal and changes the statistical interpretation of prediction intervals. Instead of predicting future data, prediction intervals calculated with means were assumed to correspond with expected mean responses to a certain dose or concentration of chemical.

Three dose-response curves of varying usefulness to the risk assessment are presented (**Figure 8**). Curve A is based on data from Rider and LeBlanc (2005) and shows 48-hour malathion toxicity to *Daphnia magna* in terms of percent immobilization. They used two replicates per treatment, with 10 daphnia per replicate. This experimental design with replicates is preferred when performing regression analysis. Organism responses to the chemical stressor can be diagramed across the entire dose-response curve. Curve A is plotted with 95% confidence intervals, 95% prediction intervals, and the data. A 2-parameter log-logistic regression was used to fit this curve. Curve A is the preferred type of exposure-response model to be used in risk assessment.

Curve B is based on data from Connon et al. (2011) and shows 96-hour ammonium chloride toxicity to 57-day-old Delta smelt in terms of percent survival. Points correspond to mean survival values based on data from 4 replicates per treatment. Only nominal concentrations were reported in the paper. The 2-parameter Weibull regression model is generated using these means. The prediction intervals allow for distinction between different parts of the curve. The two main limitations of this model are 1) prediction intervals are estimating mean responses, resulting in the true variability of the toxicity data being underestimated and 2) nominal concentrations are used as the predictor variable, resulting in additional uncertainty stemming from potential inaccuracies in true exposure concentrations. This model is sufficient for a risk assessment.

Curve C is based on data from Connon et al. (2009) and shows 24-hour esfenvalerate toxicity to 52-day-old Delta smelt in terms of percent survival. Points correspond to mean survival rates and again only nominal concentrations were reported. The 2-parameter Weibull regression model is generated using these means. Unlike Curve B, however, Curve C has very wide prediction intervals and does not span the complete exposure-response relationship (LC_0-LC_{100}) for Delta smelt survival. The range of toxicity that is depicted by the model therefore has very high statistical uncertainty. Large mathematical uncertainty can be accounted for in the models, however, problems arise when uncertainty is so high that an LC_{10} is not different from an LC_{90} (e.g.). These large uncertainties often arise due to experiments that were not designed to elucidate the dose-response relationship. This uncertainty underestimates the true variability in toxicity because nominal concentrations and means were used in the modeling. This model is insufficient for risk assessment.

Appendix D. Distributions and Concentrations of Pyrethroids and Metals in the Study Area
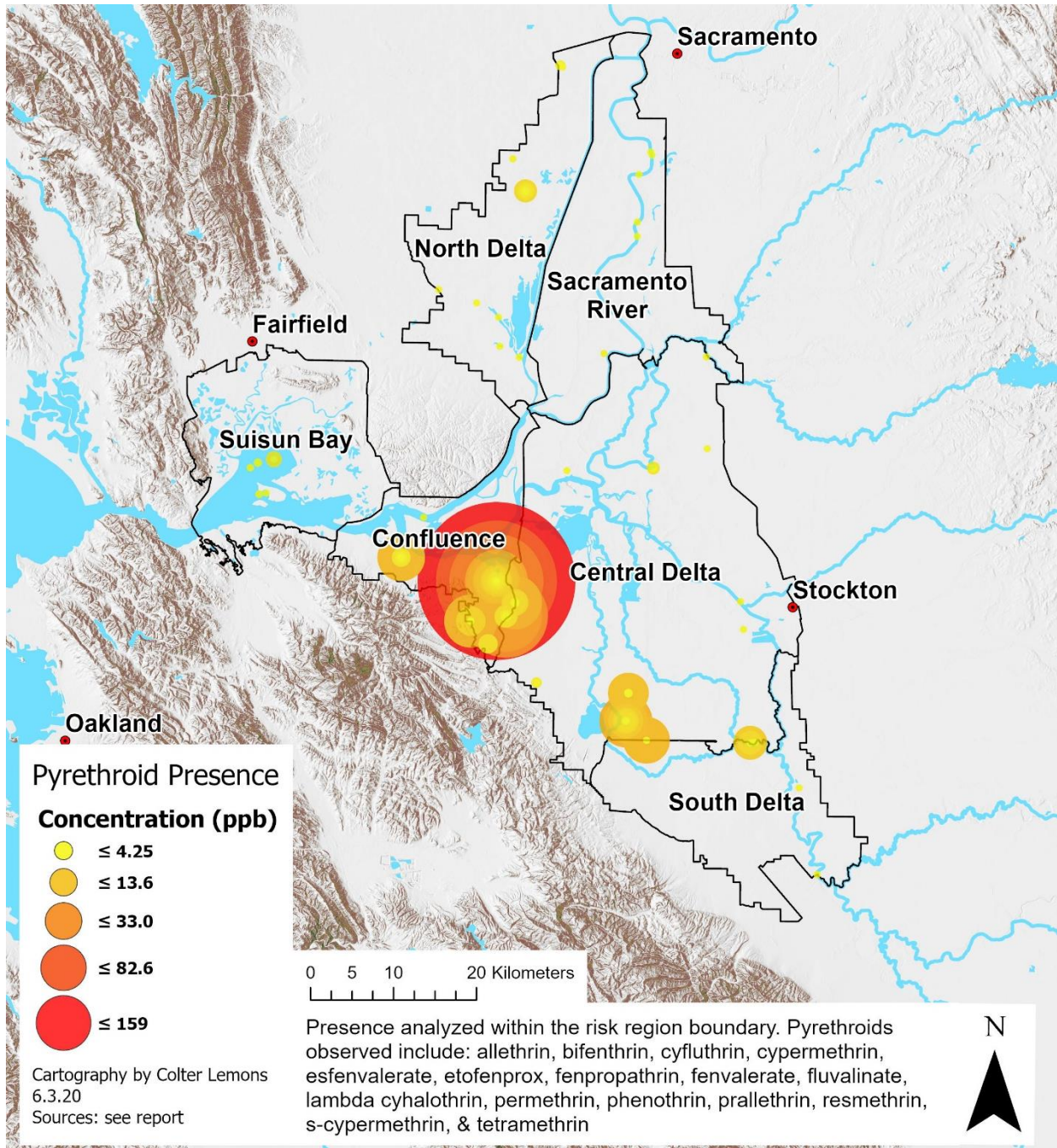
Figure D1   Pyrethroid pesticide distributions and concentrations within the study area.
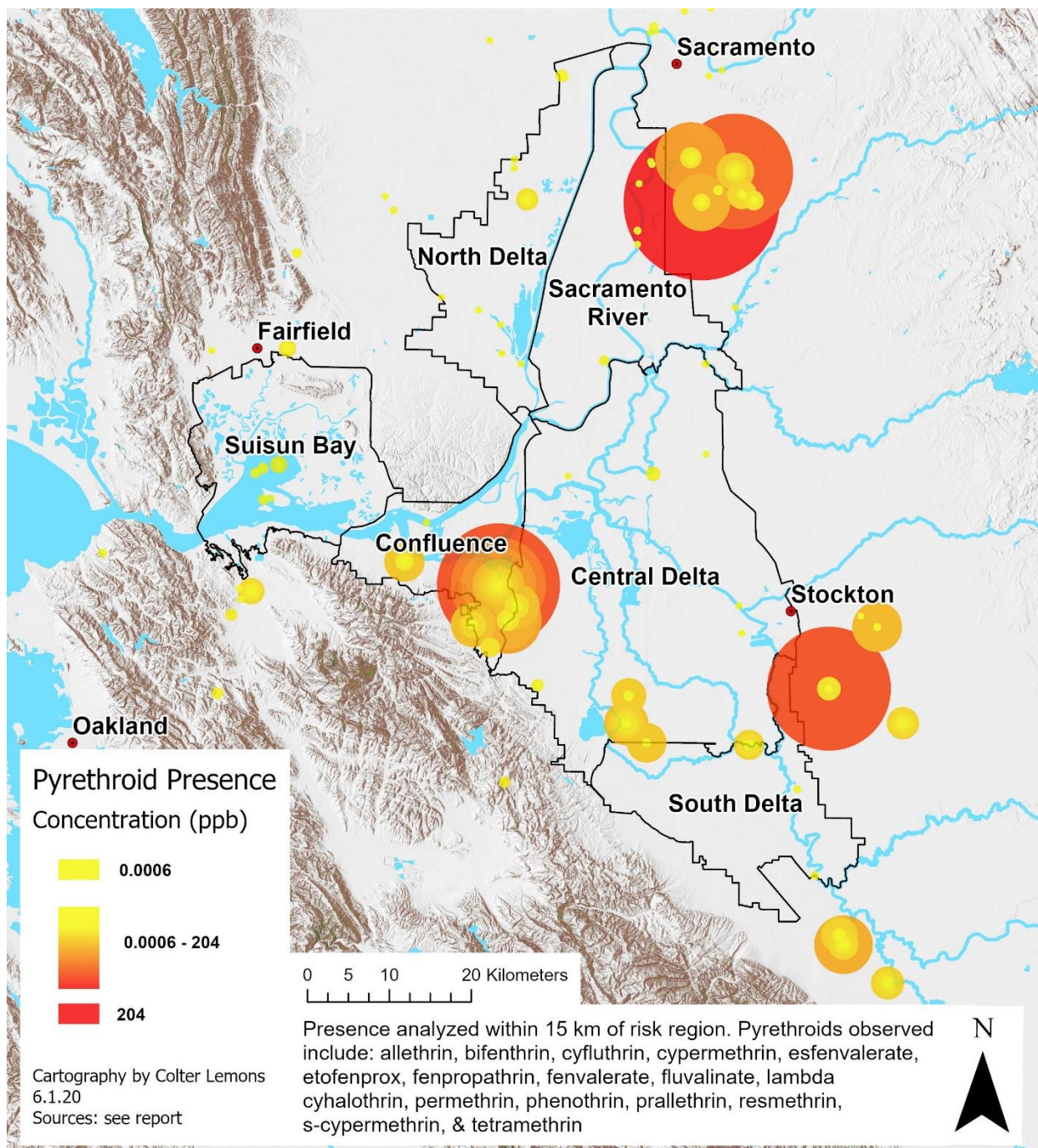
Figure D2 Pyrethroid pesticide distributions and concentrations within the study area and 15 km buffer outside the study area.
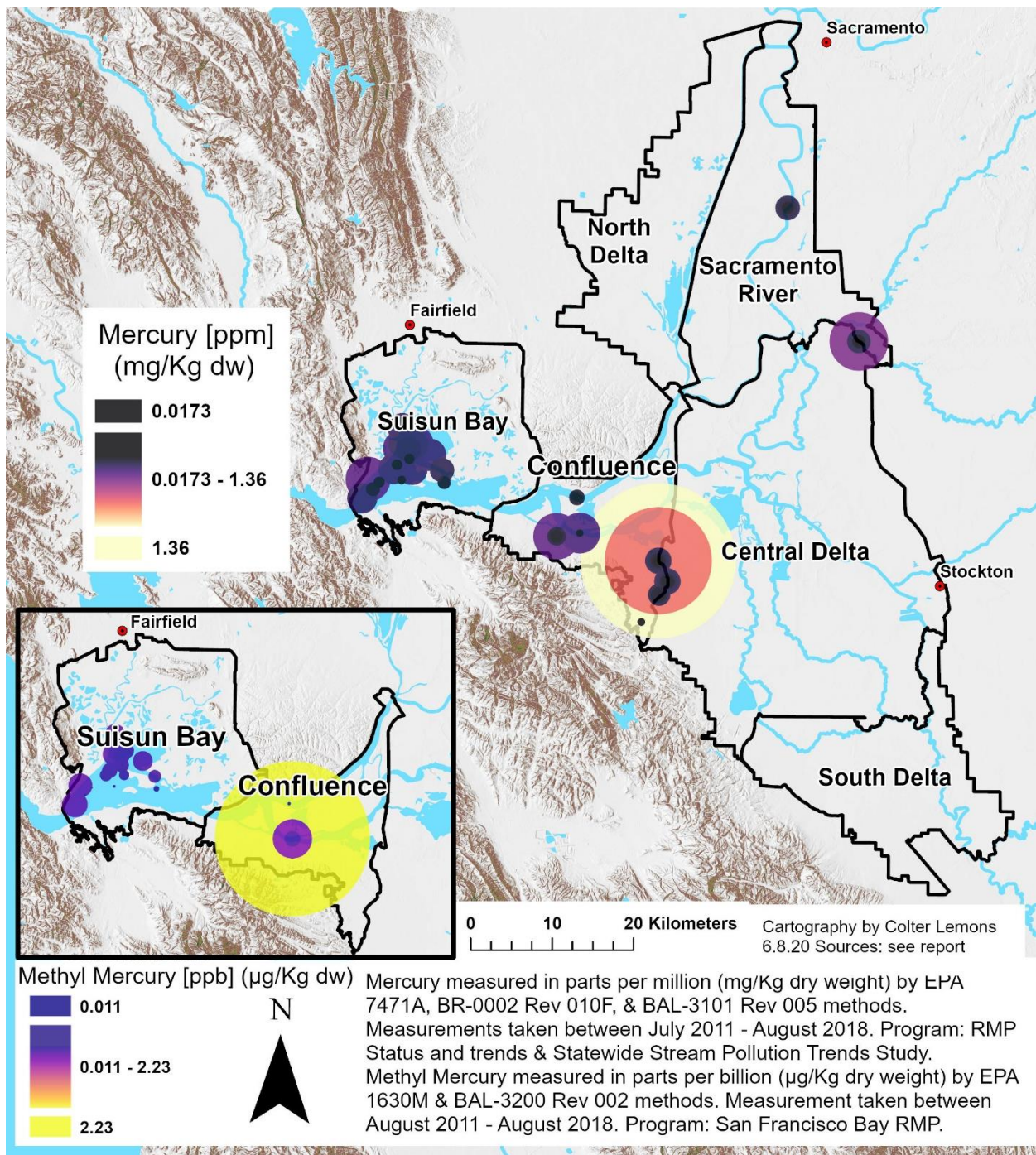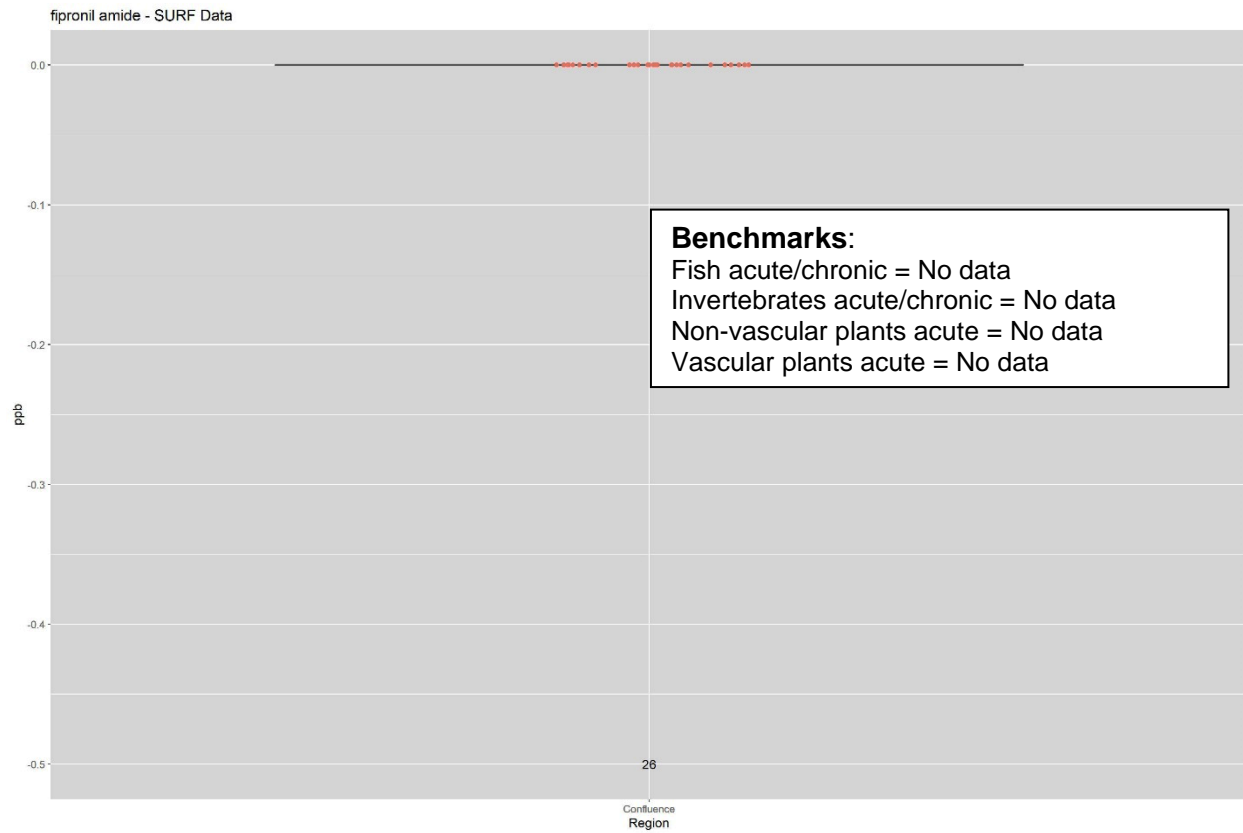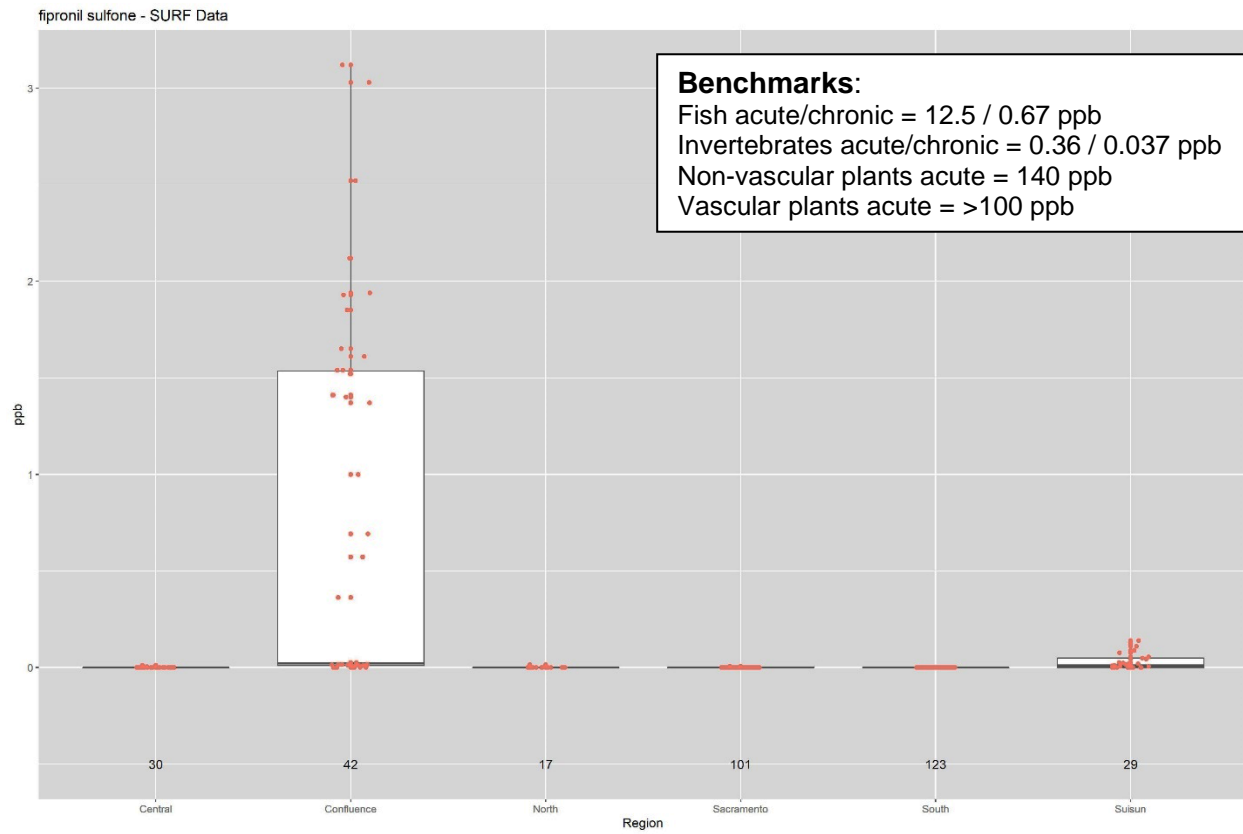
Figure D3 Mercury and methylmercury (dry weight) distributions and concentrations within the study area.
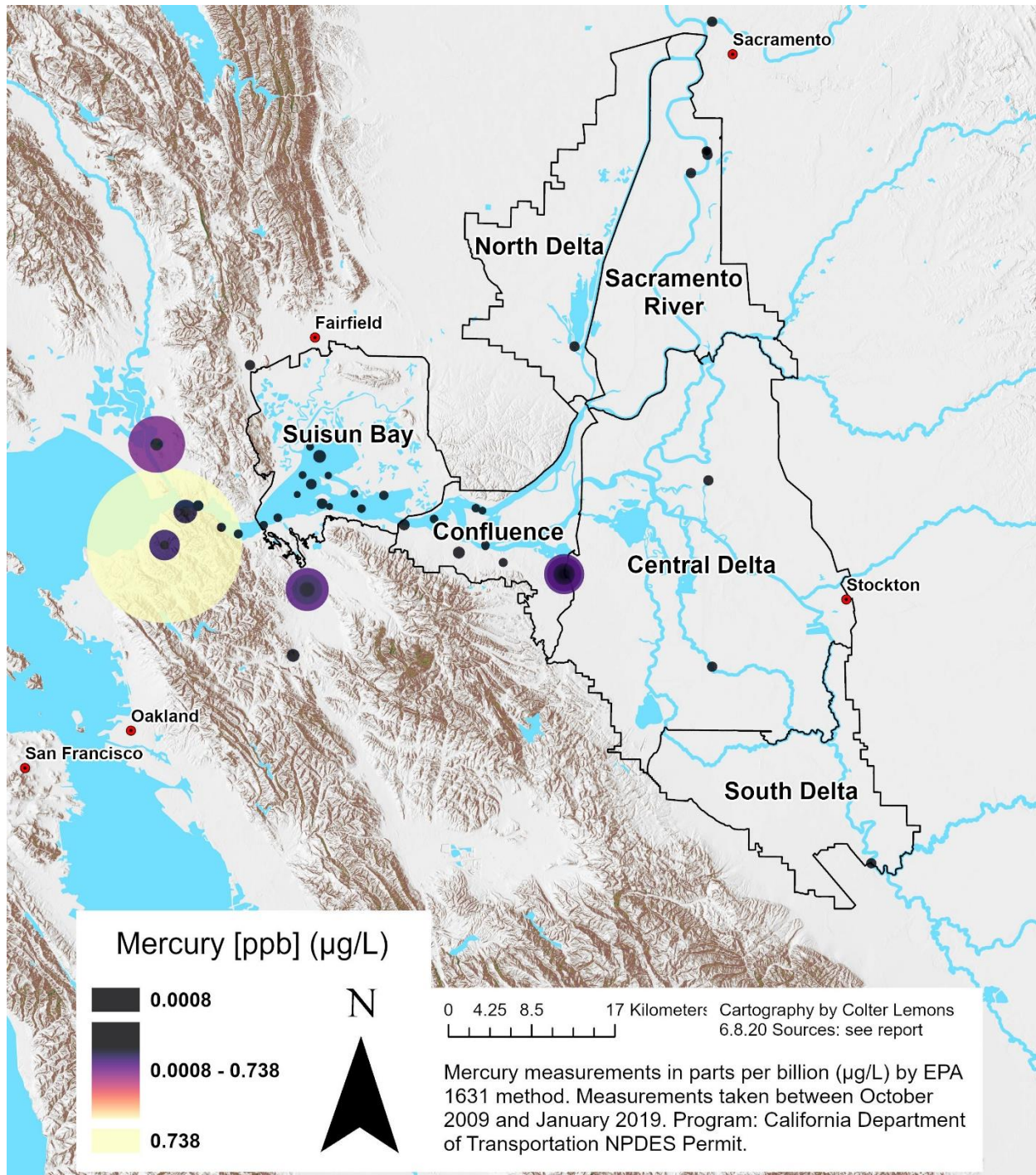
Figure D4   Mercury (Total) distributions and concentrations within the study area and 15 km buffer outside the study area.
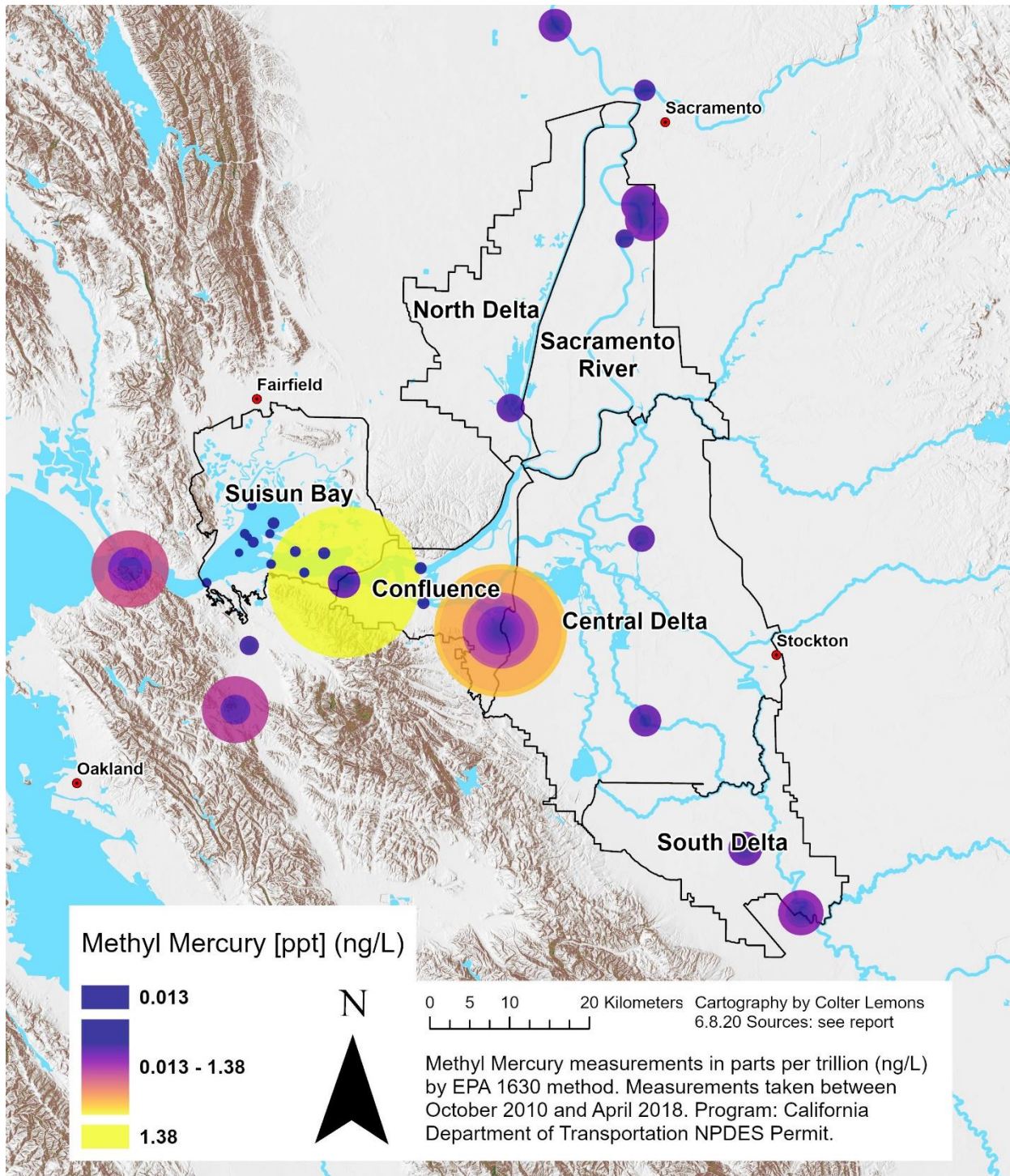
Figure D5   Methylmercury (Total) distributions and concentrations within the study area and 15 km buffer outside the study area.
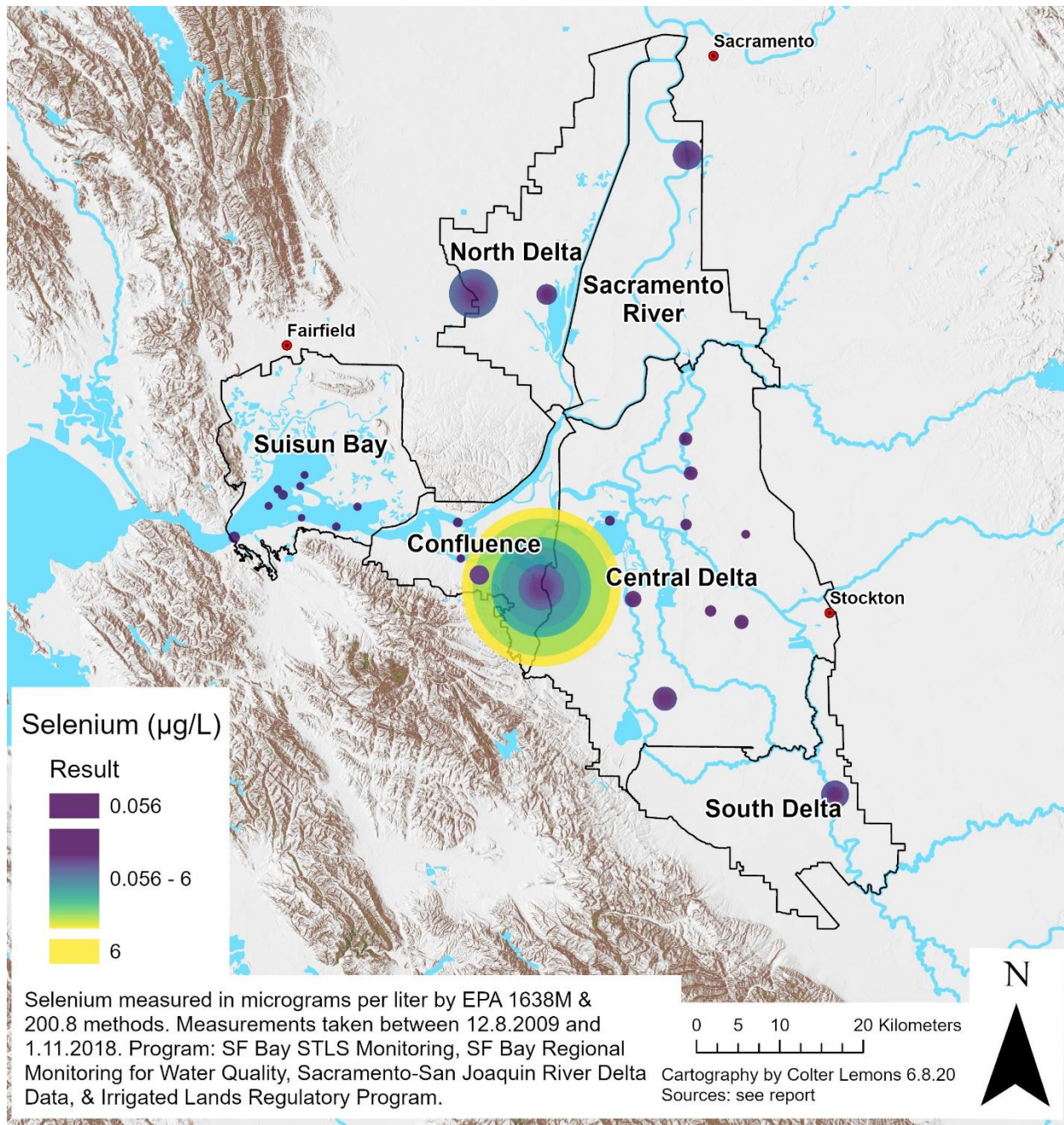
Figure D6   Selenium distributions and concentrations within the study area.
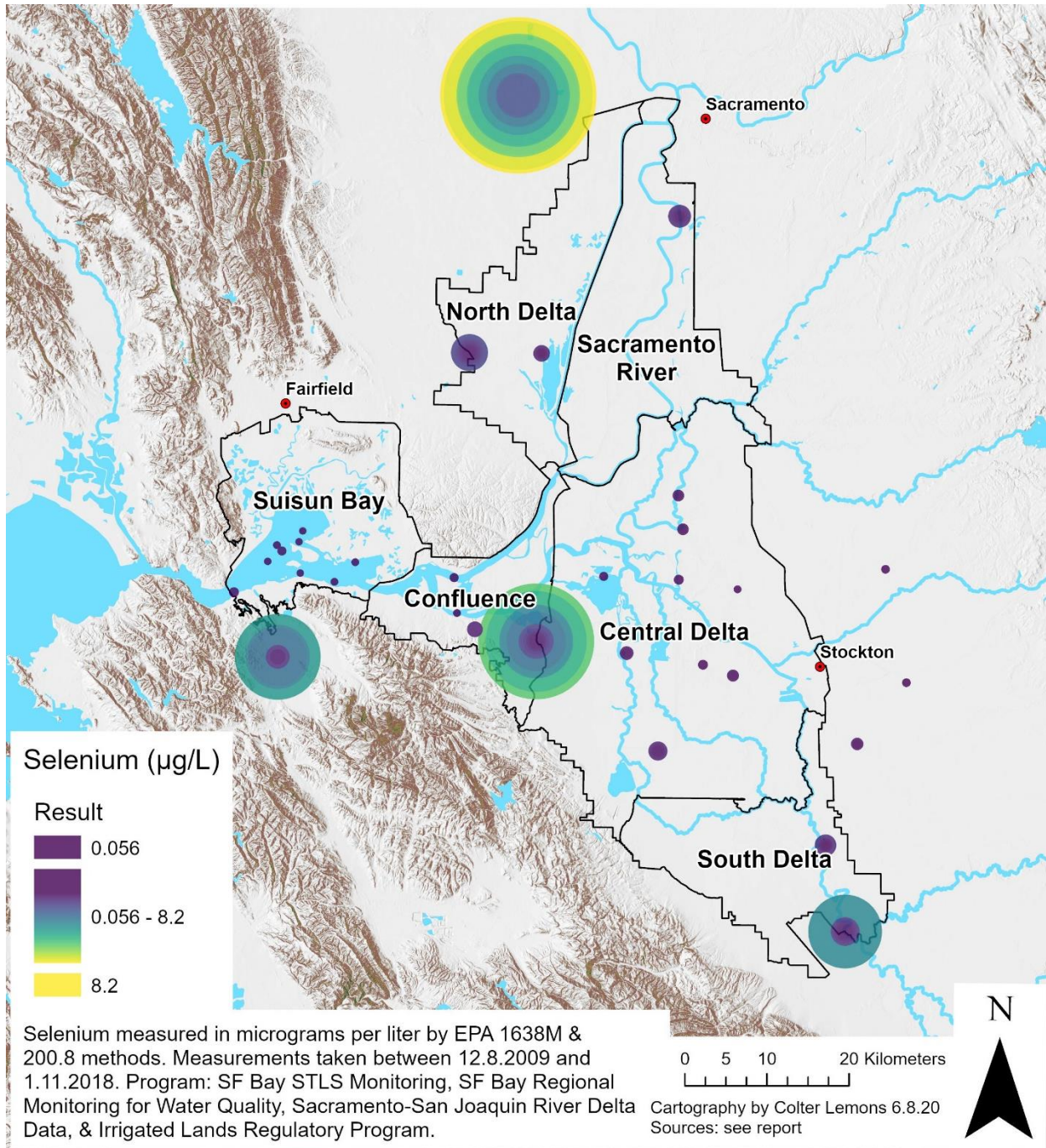
Figure D7   Selenium distributions and concentrations within the study area and 15 km buffer outside the study area

Appendix E. Boxplots of Risk Region Aqueous Pesticide Data from 2009 - 2019. (Data were obtained from the SURF database and plotted using R software). Plots are for chlorpyrifos, dicofol, endosulfan, fipronil amide, fipronil sulfide, fipronil sulfone, lambda cyhalothrin, lindane, malathion, permethrin, and s-cypermethrin pesticides.

chlorpyrifos - SURF Data

Benchmarks:
Fish acute/chronic = 0.9 / 0.57 ppb
Invertebrates acute/chronic = 0.05 / 0.04 ppb
Non-vascular plants acute = 140 ppb
Vascular plants acute = No data

dicofol - SURF Data

Benchmarks:
Fish acute/chronic = 26.5 / 4.4 ppb
Invertebrates acute/chronic = 70 / 19 ppb
Non-vascular plants acute = >5,000 ppb
Vascular plants acute = No data

E-1

endosulfan - SURF Data

Benchmarks:
Fish acute/chronic = 0.05 / 0.023 ppb
Invertebrates acute/chronic = 0.3 / 0.01 ppb
Non-vascular plants acute = 428 ppb
Vascular plants acute = No data

fipronil amide - SURF Data

Benchmarks:
Fish acute/chronic = No data
Invertebrates acute/chronic = No data
Non-vascular plants acute = No data
Vascular plants acute = No data

fipronil sulfide - SURF Data

Benchmarks:
Fish acute/chronic = No data
Invertebrates acute/chronic = No data / 0.11 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data

fipronil sulfone - SURF Data

Benchmarks:
Fish acute/chronic = 12.5 / 0.67 ppb
Invertebrates acute/chronic = 0.36 / 0.037 ppb
Non-vascular plants acute = 140 ppb
Vascular plants acute = >100 ppb

E-3

lambda cyhalothrin - SURF Data

Benchmarks:
Fish acute/chronic = 0.039 / 0.031 ppb
Invertebrates acute/chronic = 0.0035 / 0.002 ppb
Non-vascular plants acute = >310 ppb
Vascular plants acute = No data

lindane (gamma-bhc) - SURF Data

Benchmarks:
Fish acute/chronic = 2.9 / 0.85 ppb
Invertebrates acute/chronic = 54 / 0.5 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data

malathion - SURF Data

Benchmarks:
Fish acute/chronic = 8.6 / 2.05 ppb
Invertebrates acute/chronic = 0.06 / 0.049 ppb
Non-vascular plants acute = 2040 ppb
Vascular plants acute = 24,000 ppb

ppb

| 361 | 78 | 331 | 387 | 321 | 48 |
| Central | Confluence | North | Sacramento | South | Suisun |

Region

permethrin - SURF Data

Benchmarks:
Fish acute/chronic = 0.395 / 0.0515 ppb
Invertebrates acute/chronic = 0.0195 / 0.0014 ppb
Non-vascular plants acute = 68 ppb
Vascular plants acute = No data

ppb

| 210 | 125 | 402 | 429 | 326 | 54 |
| Central | Confluence | North | Sacramento | South | Suisun |

Region

s-cypermethrin - SURF Data

Benchmarks:
Fish acute/chronic = 0.195 / 0.14 ppb
Invertebrates acute/chronic = 0.21 / 0.069 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data

Appendix F. Boxplots of Risk Region Water Quality and Metals Data from 2009 - 2019.
(Data were obtained from CEDEN and SURF databases and plotted using R software).

A   Nitrate + Nitrite as N, Dissolved - Water Samples

A   Nitrate + Nitrite as N, Total - Water Samples

A   Nitrate as N, Dissolved - Water Samples

A   Nitrate as N, Total - Water Samples

A Phosphorous as P, Total - Water Samples
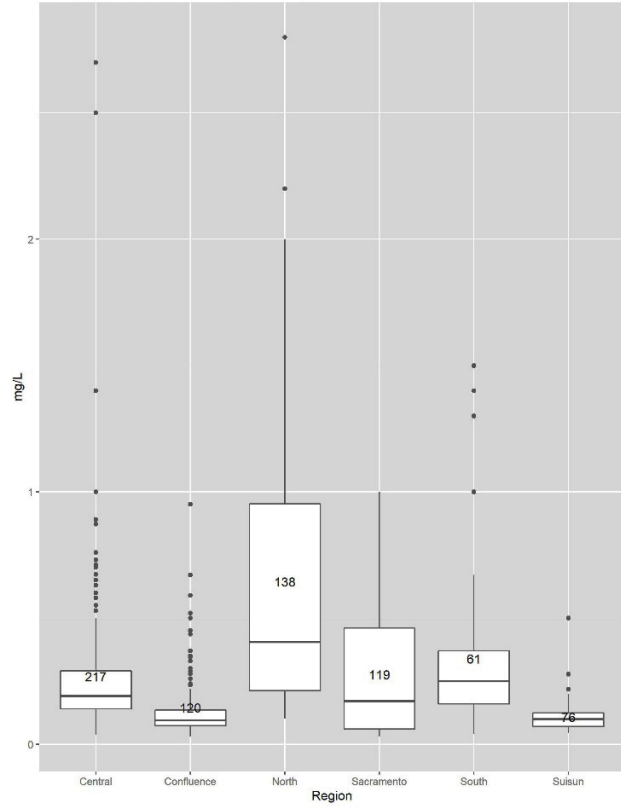
B Phosphorous as P, Total - Sediment Samples
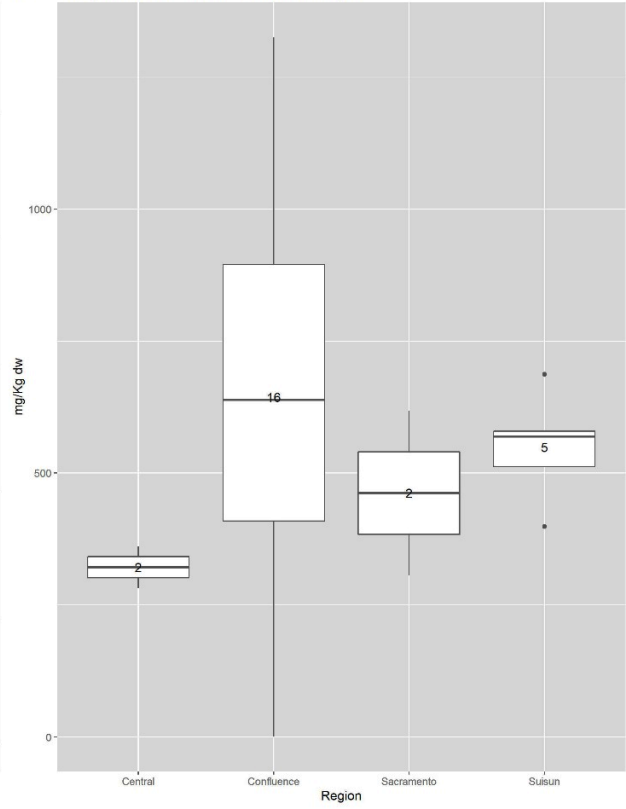
A Phosphorus as P, Dissolved - Water Samples

F-2
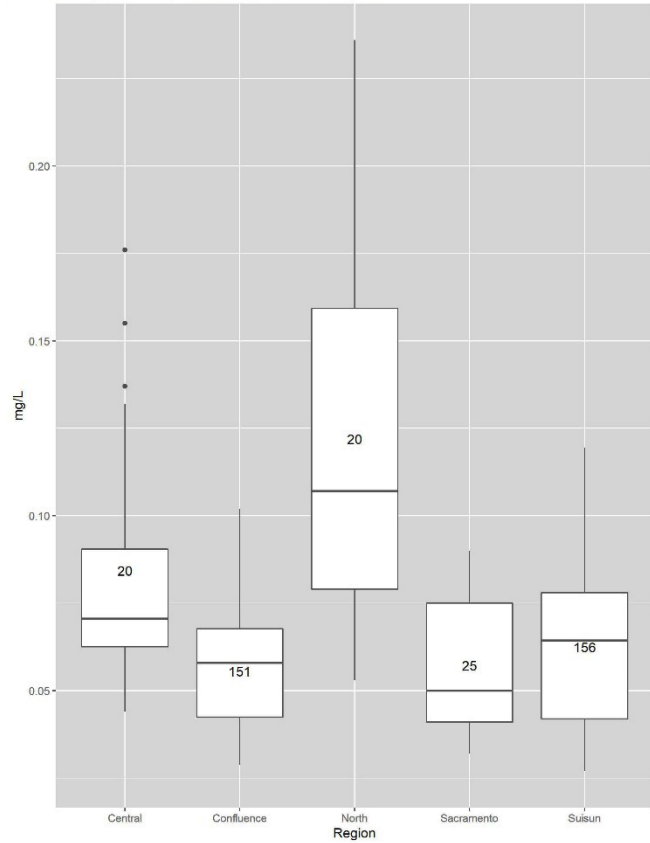
Salinity, Total - All Samples
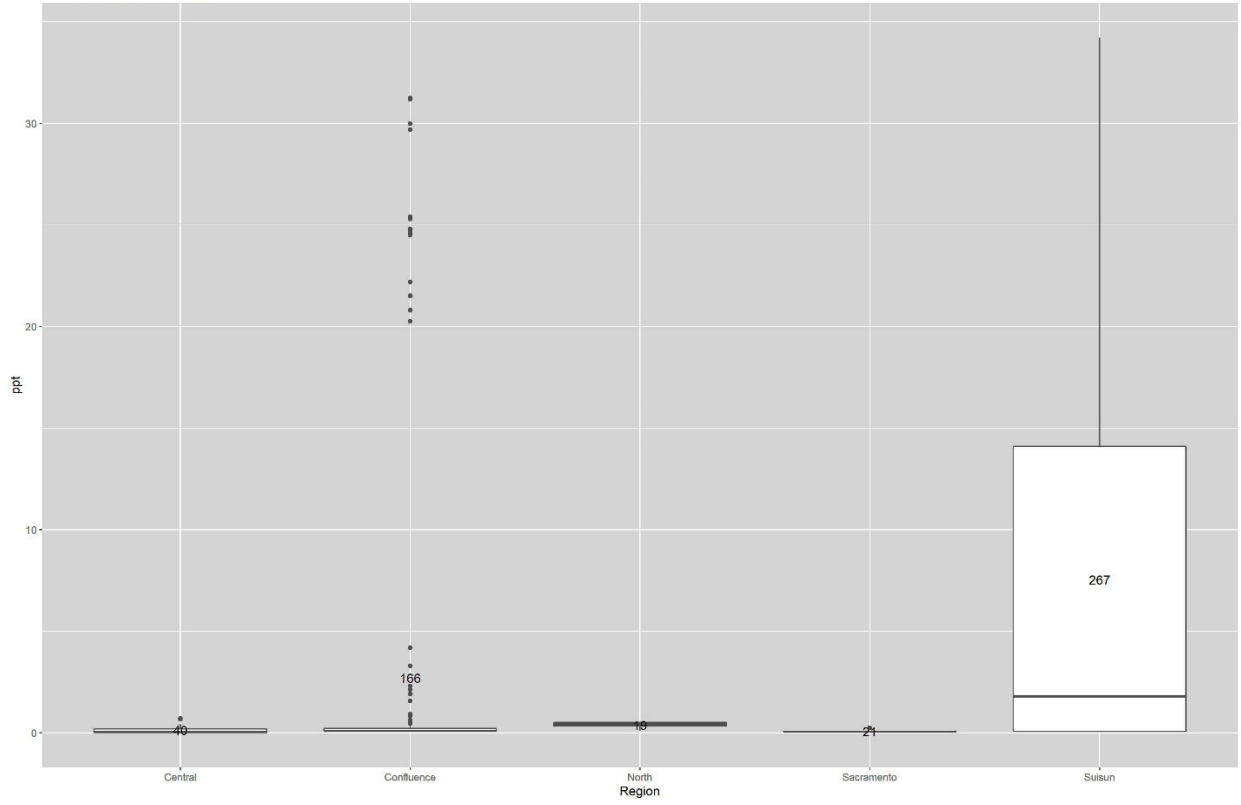
A Salinity, Total - Water Samples
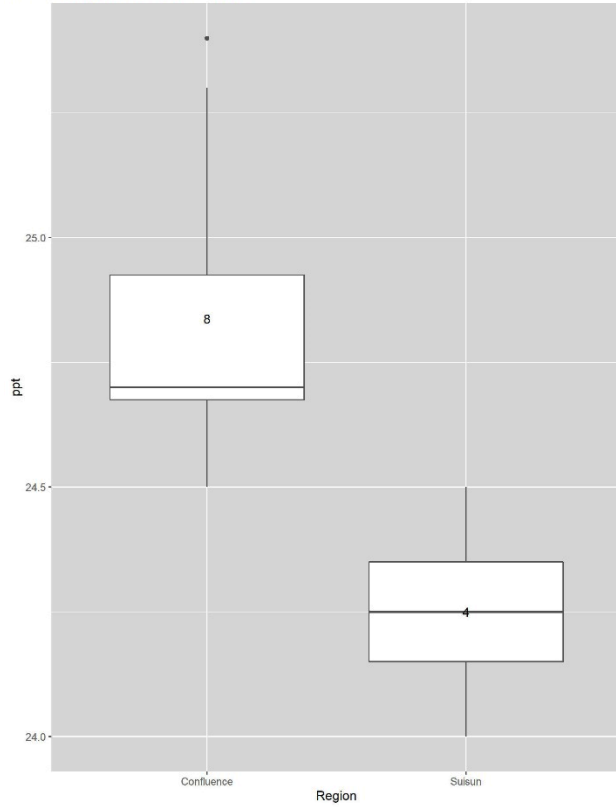
B Salinity, Total - Sediment Samples

F-3
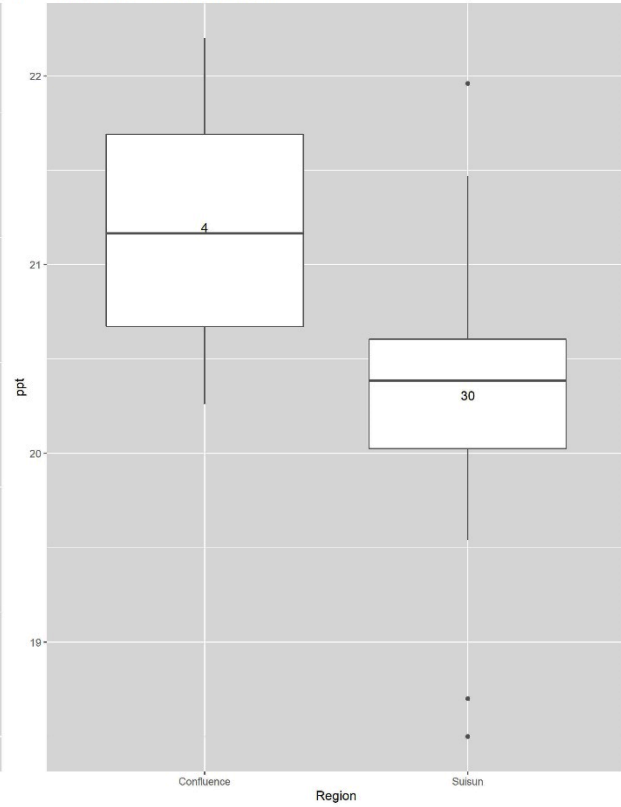
A Temperature - Water Samples
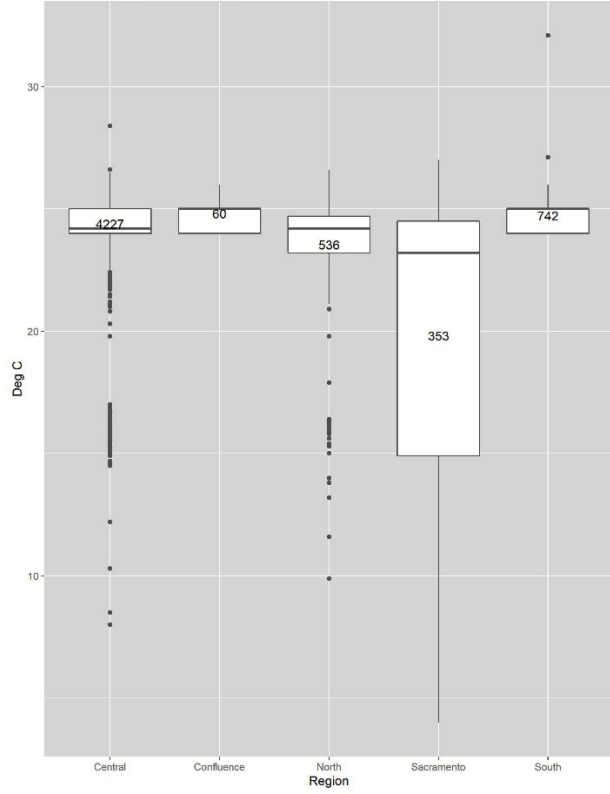
B Temperature - Sediment Samples
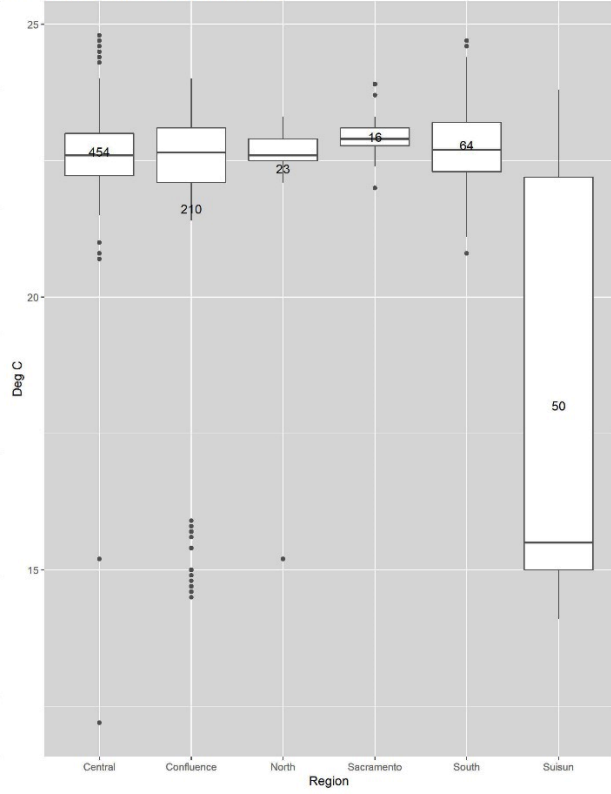
A Selenium, Total - Water Samples
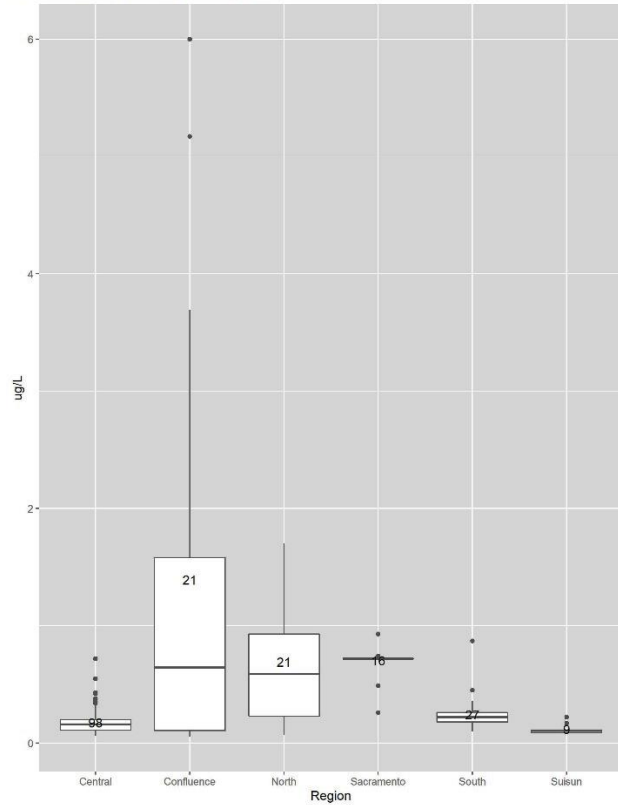
B Selenium, Total - Sediment Samples

F-4
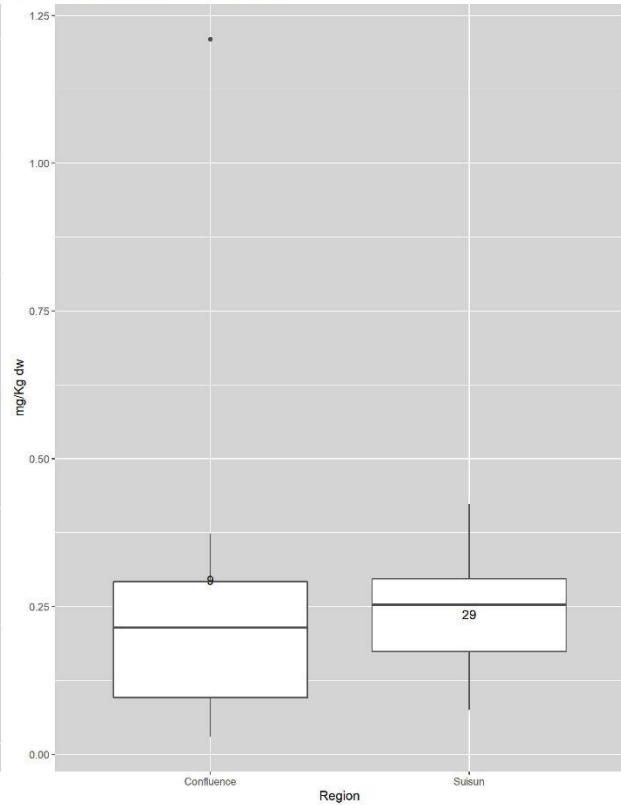
A   Mercury, Dissolved - Water Samples
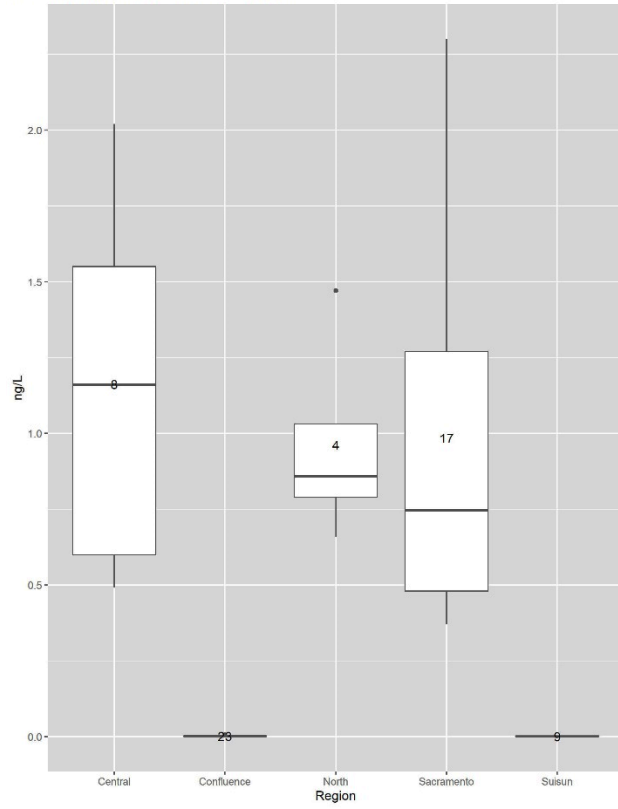
A   Mercury, Total - Water Samples

B   Mercury, Total - Sediment Samples

F-5

A Mercury, Methyl, Dissolved - Water Samples   **B**

A Mercury, Methyl, Total - Water Samples   **B** Mercury, Methyl, Total - Sediment Samples

F-6
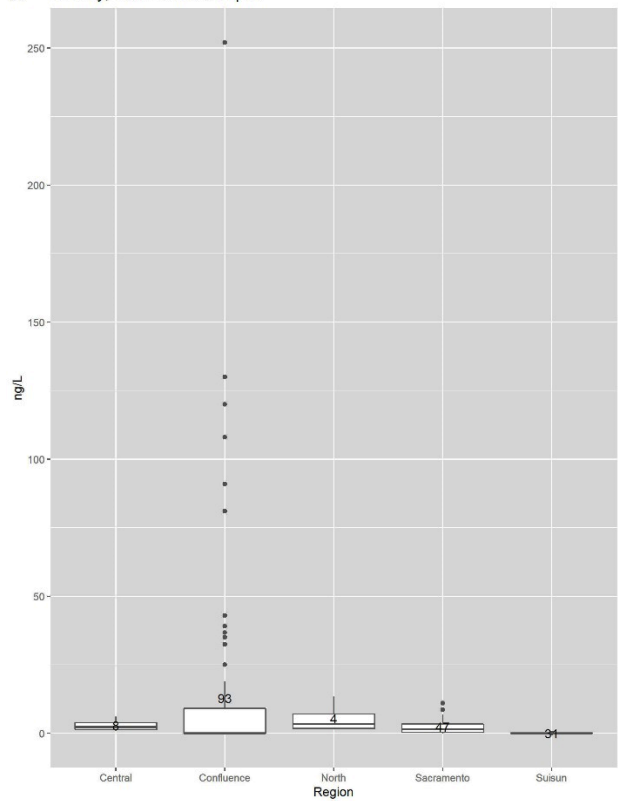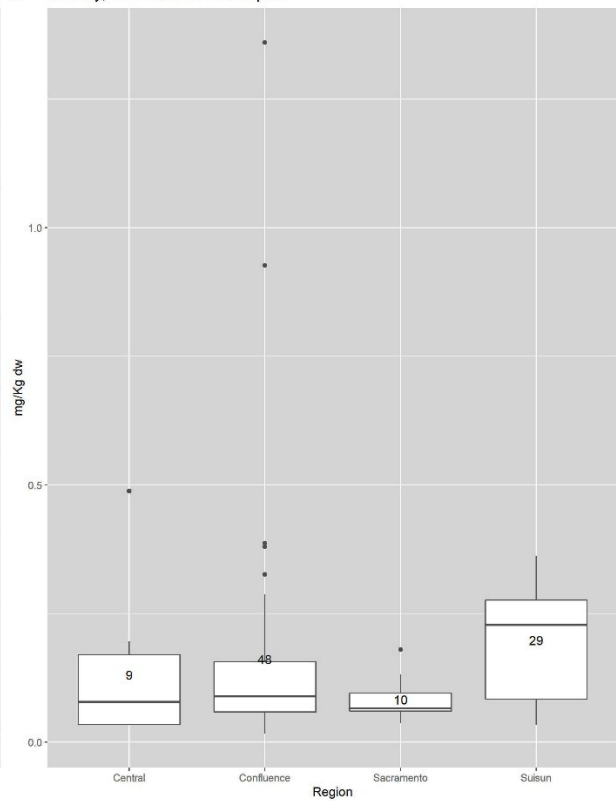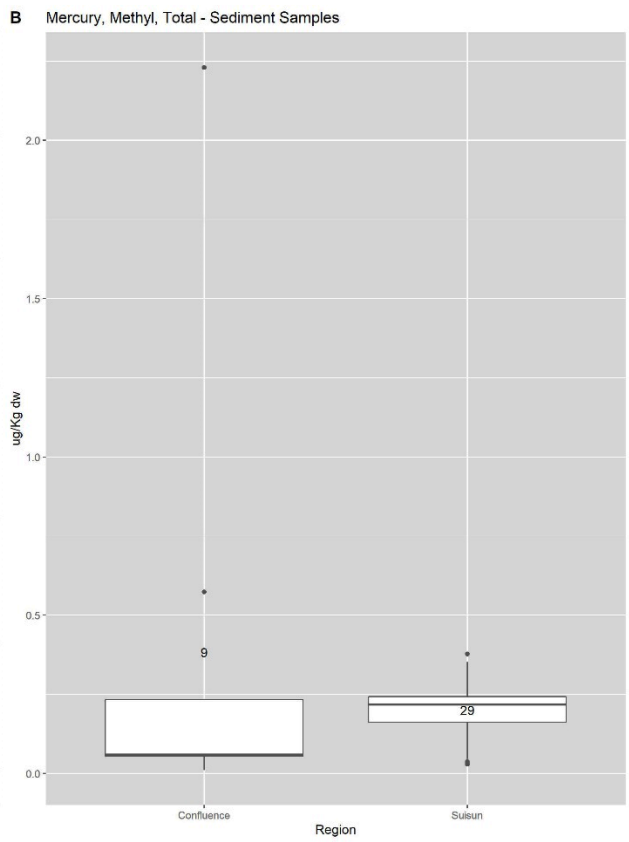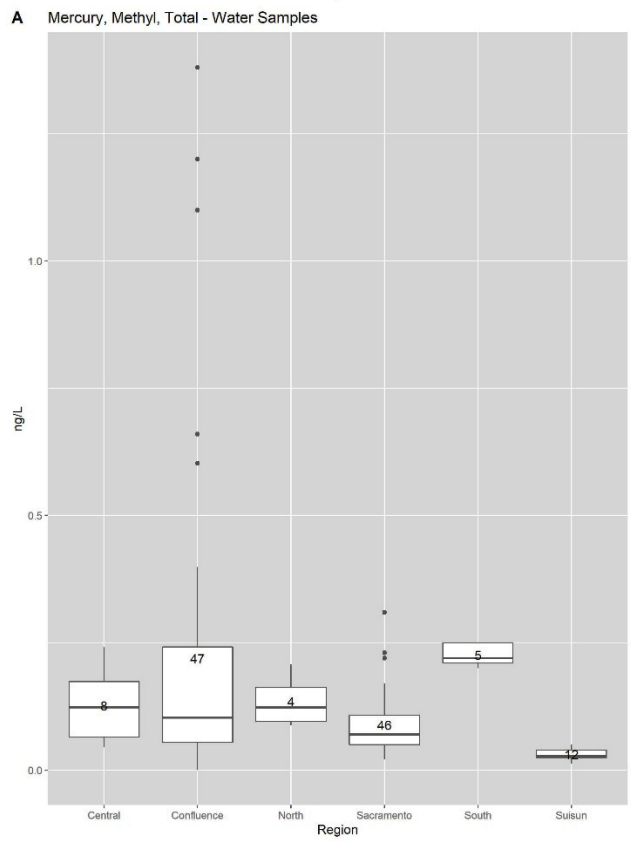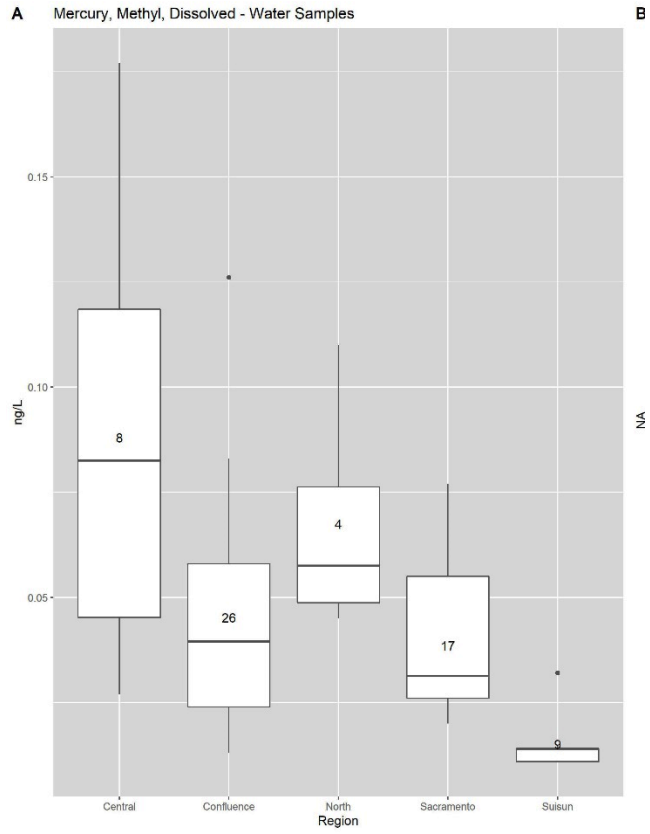
Appendix G. Chinook catch counts for each risk region from 2010 – 2019. Data were from the Kodiak Trawl, Midwater Trawl, & beach seine surveys in each risk region per water year for each of the four runs of Chinook for the last ten complete water years.

2010	Chinook Catch / Water Year				2011	Chinook Catch / Water Year			
Region	Fall	Late Fall	Spring	Winter	Region	Fall	Late Fall	Spring	Winter
Central	298	4	17	2	Central	605	4	92	3
Confluence	2714	12	762	71	Confluence	6773	26	1473	140
North	153	NA	2	NA	North	200	NA	9	3
Sacramento	2225	13	322	36	Sacramento	5919	27	1044	96
South	143		158	11	South	2091	2	1441	24
Suisun	NA	NA	NA	NA	Suisun	NA	NA	NA	NA
NA	1419	26	92		NA	6175	48	578	183

2012	Chinook Catch / Water Year				2013	Chinook Catch / Water Year			
Region	Fall	Late Fall	Spring	Winter	Region	Fall	Late Fall	Spring	Winter
Central	978	4	135	3	Central	1106	4	167	16
Confluence	8181	27	2259	185	Confluence	9918	40	2893	253
North	240	NA	11	3	North	275	NA	34	3
Sacramento	10194	31	1404	139	Sacramento	13585	46	1927	269
South	4100	2	2594	95	South	8930	2	3240	97
Suisun	NA	NA	NA	NA	Suisun	NA	NA	NA	NA
NA	9389	69	668	205	NA	14191	81	1008	469

2014	Chinook Catch / Water Year				2015	Chinook Catch / Water Year			
Region	Fall	Late Fall	Spring	Winter	Region	Fall	Late Fall	Spring	Winter
Central	1360	4	170	17	Central	1395	4	179	18
Confluence	11010	45	4228	325	Confluence	11396	67	5342	360
North	573	NA	41	3	North	576	NA	41	3
Sacramento	51098	47	2733	379	Sacramento	52314	54	2940	414
South	9994	2	3536	99	South	10000	2	3606	99
Suisun	NA	NA	NA	NA	Suisun	NA	NA	NA	NA
NA	31756	82	1073	506	NA	33098	88	1527	566

2016	Chinook Catch / Water Year				2017	Chinook Catch / Water Year			
Region	Fall	Late Fall	Spring	Winter	Region	Fall	Late Fall	Spring	Winter
Central	1713	4	190	18	Central	1855	4	206	19
Confluence	12454	82	6027	413	Confluence	18770	100	9952	717

2016	Chinook Catch / Water Year				2017	Chinook Catch / Water Year			
North	585	NA	41	3	North	673	NA	49	3
Sacramento	55854	59	3202	433	Sacramento	67646	68	5996	561
South	10087	2	3730	99	South	11682	2	4958	117
Suisun	NA	NA	NA	NA	Suisun	NA	NA	NA	NA
NA	39531	99	1629	603	NA	40275	117	1717	647

2018	Chinook Catch / Water Year				2019	Chinook Catch / Water Year			
Region	Fall	Late Fall	Spring	Winter	Region	Fall	Late Fall	Spring	Winter
Central	1910	4	213	19	Central	3360	6	237	22
Confluence	20061	102	11176	806	Confluence	23877	125	12988	904
North	684	NA	50	3	North	705	NA	52	3
Sacramento	69657	77	6237	587	Sacramento	73742	87	6806	733
South	12762	2	5488	125	South	13359	2	5714	128
Suisun	NA	NA	NA	NA	Suisun	NA	NA	NA	NA
NA	41077	121	1788	719	NA	42435	131	1869	1043

Appendix H.   Delta Water Outflow Data Plots from 2014 - 2019

Net Delta outflow measured at Chipps Island for the last six years from 2014 through 2019. Solid blue line is 7 day rolling average of flow, dashed blue line is daily data. Solid red line is 7 day rolling average of delta water exports, dashed red line is daily export data, and the dashed black vertical line is showing the first peak flow event of the water year at or approaching 10,000cfs.
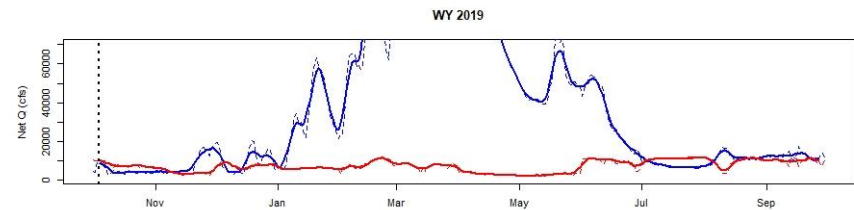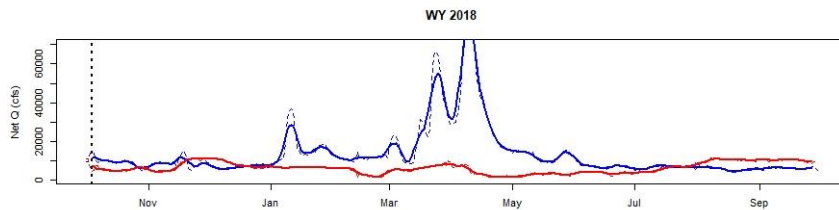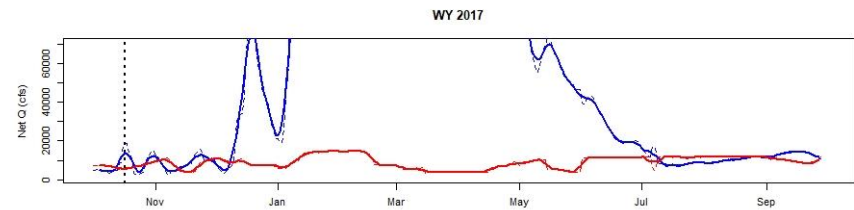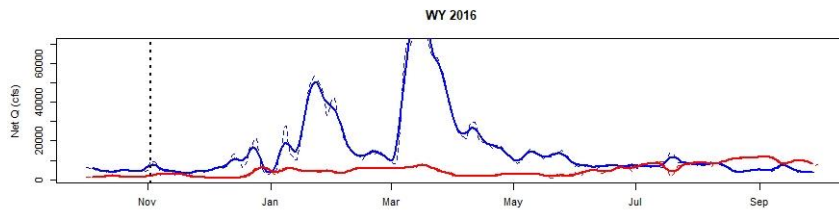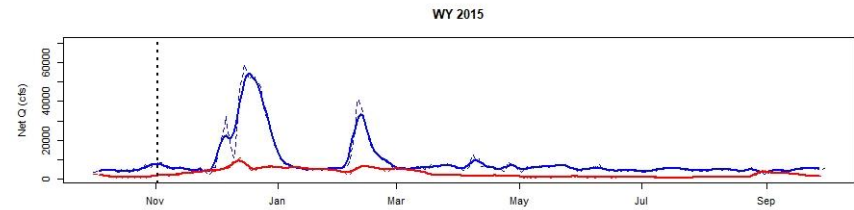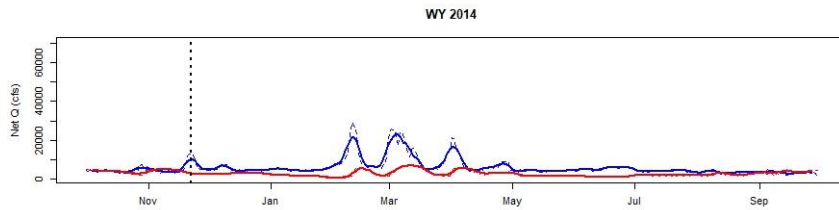
Appendix I.   Pesticide, Water Quality, and Metals Data Plotted by Risk Region. R
software was used to generate the plots.

North Delta Risk Region

North Region Maximum Monthly bifenthrin

North Region Maximum Monthly Chlorpyrifos

North Region Maximum Monthly cyfluthrin

North Region Maximum monthly lambda cyhalothrin

North Region Maximum Monthly malathion

North Region Maximum Monthly permethrin
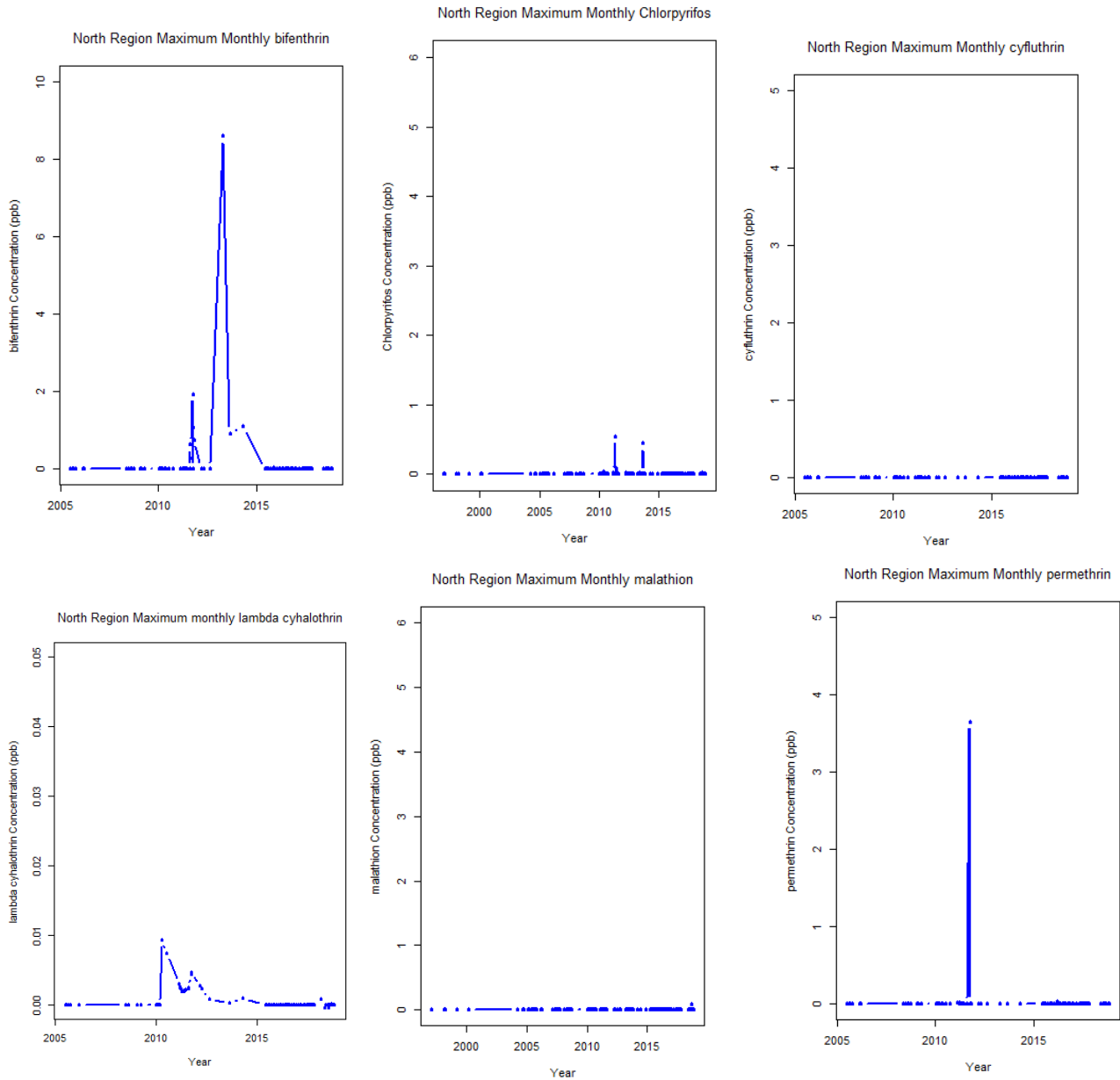
North Region Mean Monthly Mercury, Total - Water Samples (8/16-2/17)
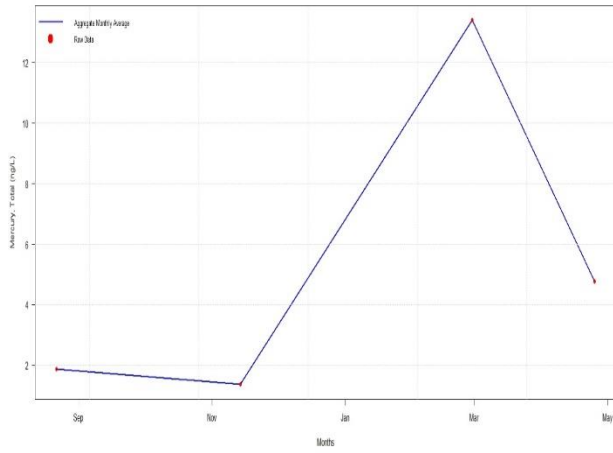
North Region Mean Monthly Mercury, Methyl, Total - Water Samples (8/16-4/17)
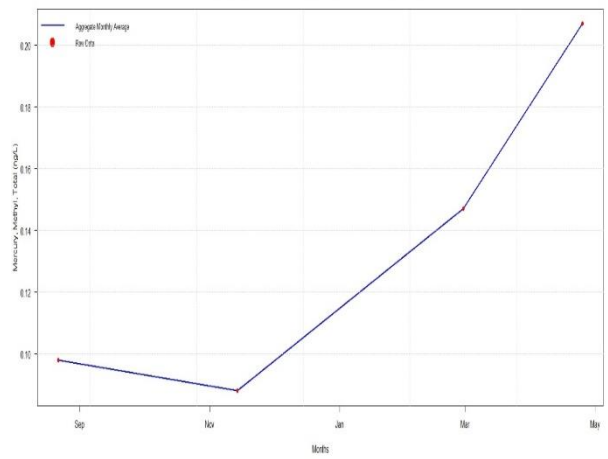
North Region Maximum Monthly Selenium, Total - All Samples
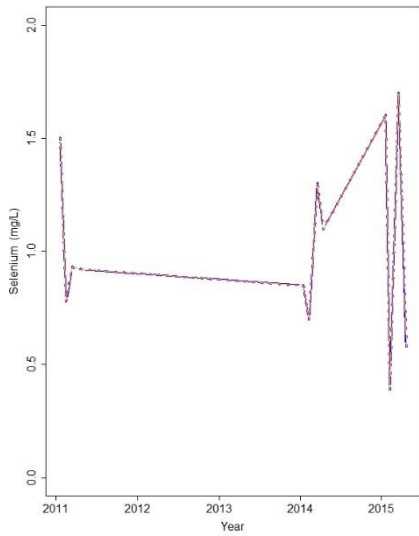
North Region Mean Monthly Phosphorus as P, Total - Water Samples
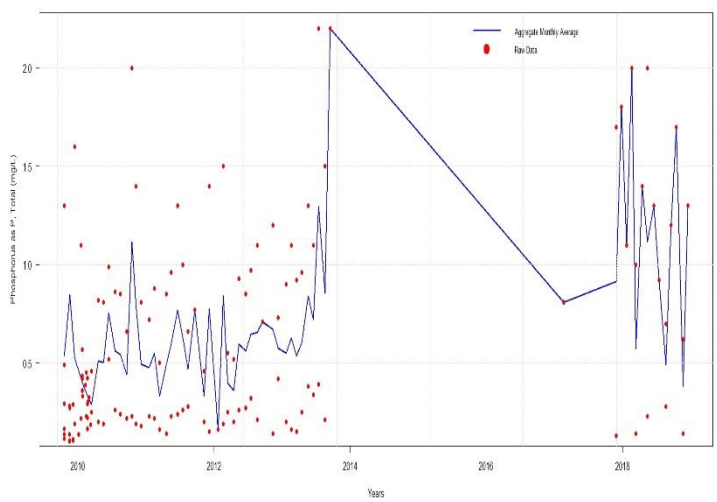
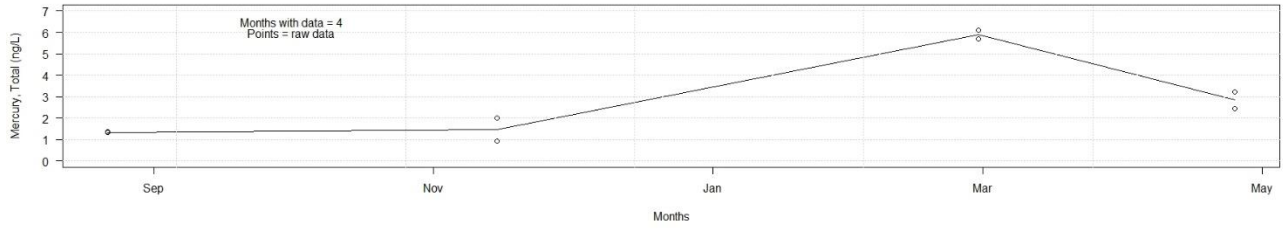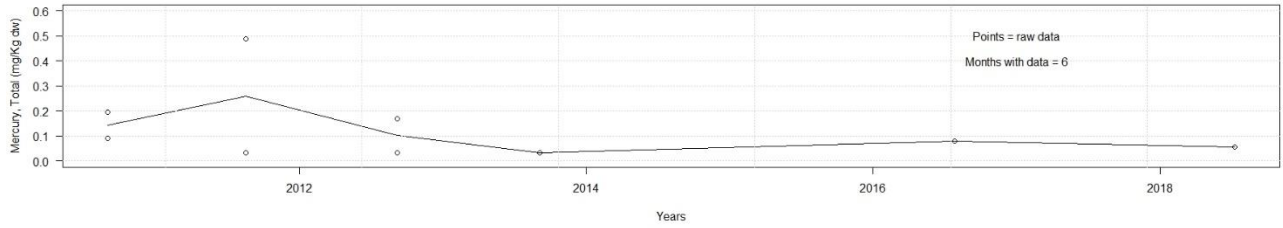North Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
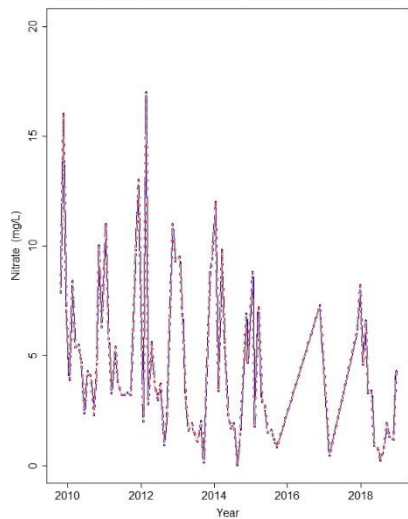
North Delta Region Maximum Monthly Water Temperature(°C) - All Samples
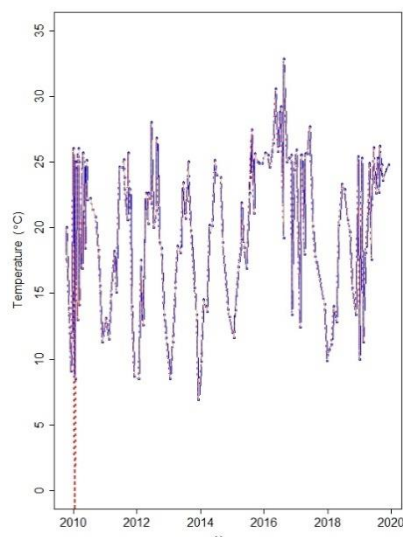
North Delta Region Average Monthly Temperature(°C) - All Samples
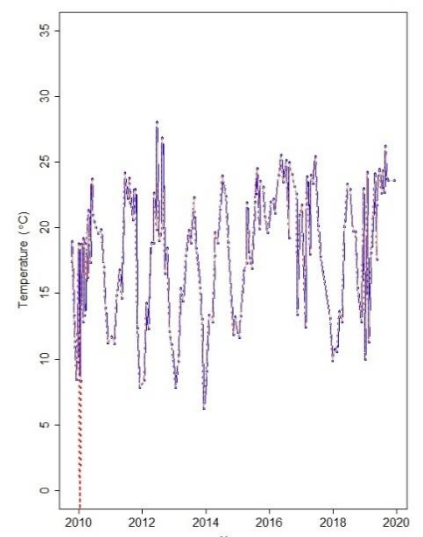
Sacramento River Risk Region
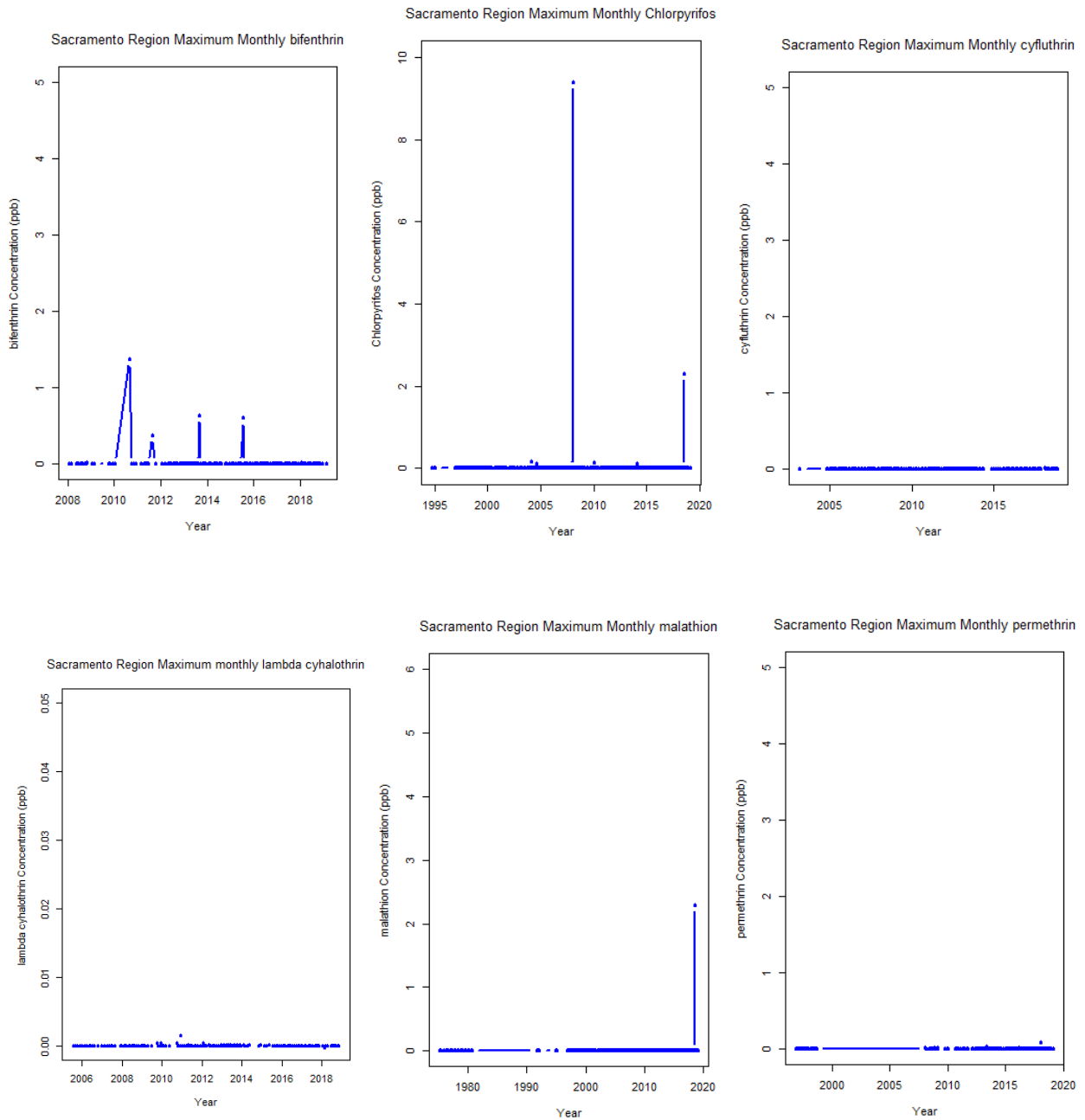
Sacramento Region Maximum Monthly bifenthrin

Sacramento Region Maximum Monthly Chlorpyrifos

Sacramento Region Maximum Monthly cyfluthrin

Sacramento Region Maximum monthly lambda cyhalothrin

Sacramento Region Maximum Monthly malathion

Sacramento Region Maximum Monthly permethrin
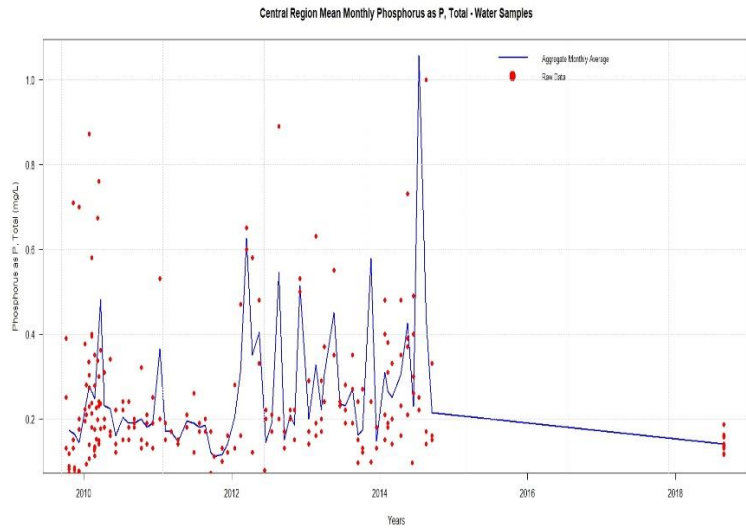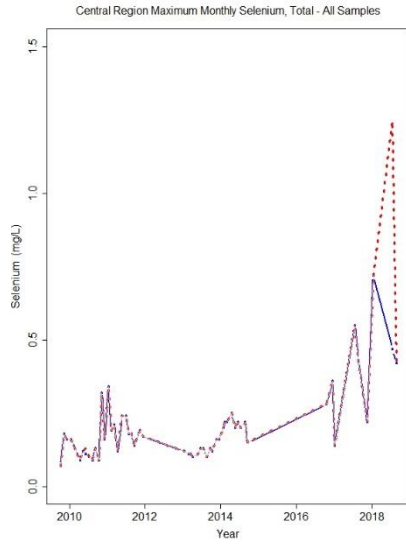
Sacramento Region Mean Monthly Mercury, Total - Water Samples
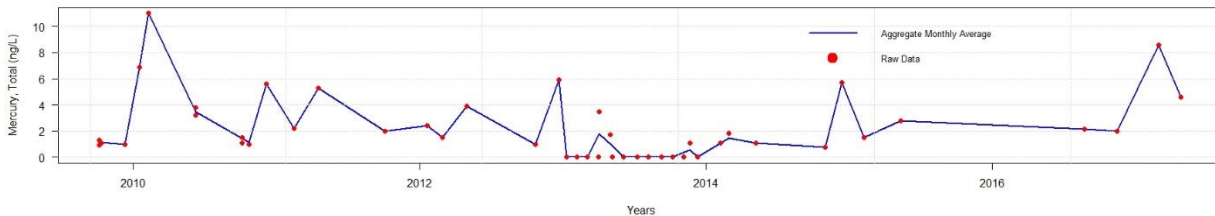
Sacramento Region Mean Monthly Mercury, Total - Sediment Samples

Sacramento Region Mean Monthly Mercury, Methyl, Total - Water Samples

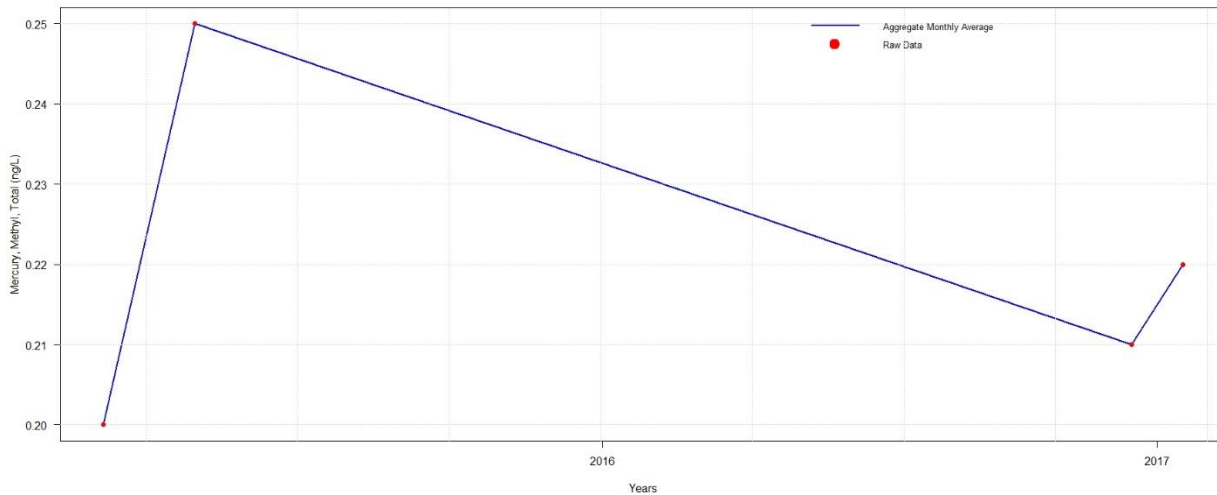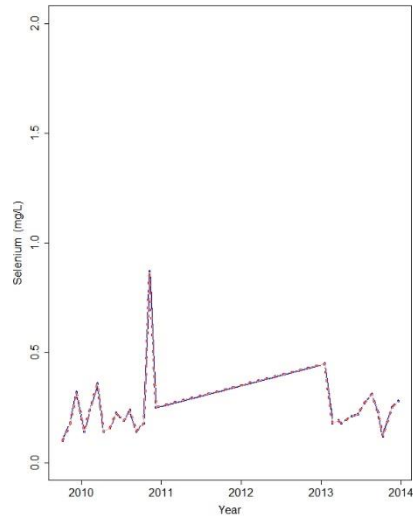Sacramento Region Maximum Monthly Selenium, Total - All Samples

Sacramento Region Mean Monthly Phosphorus as P, Total - Water Samples

Sacramento Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples

Sacramento Region Maximum Monthly Water Temperature(°C) - All Samples

Sacramento Region Average Monthly Temperature(°C) - All Samples
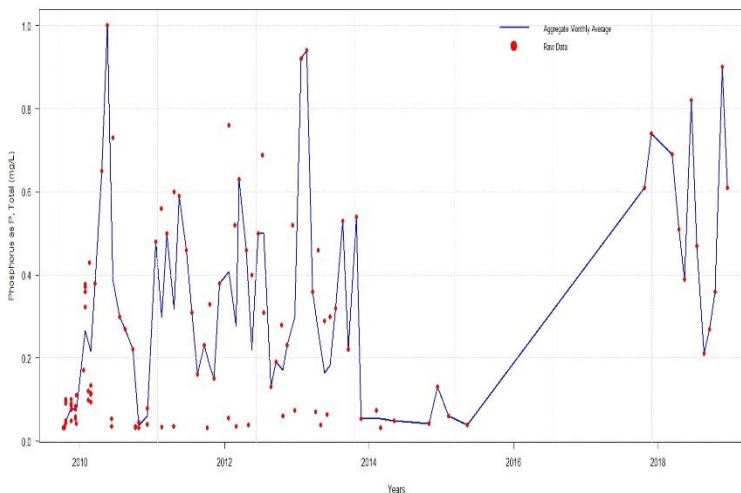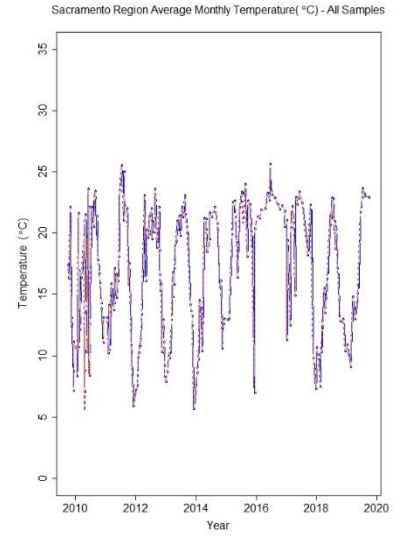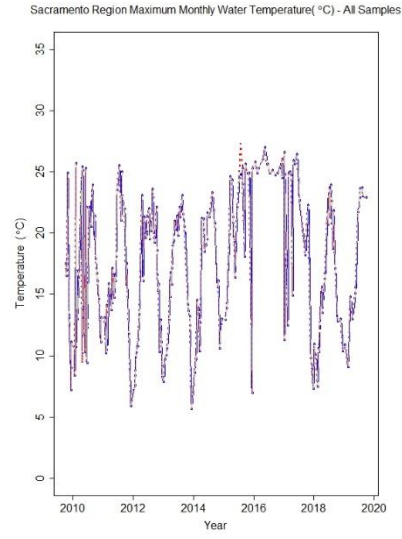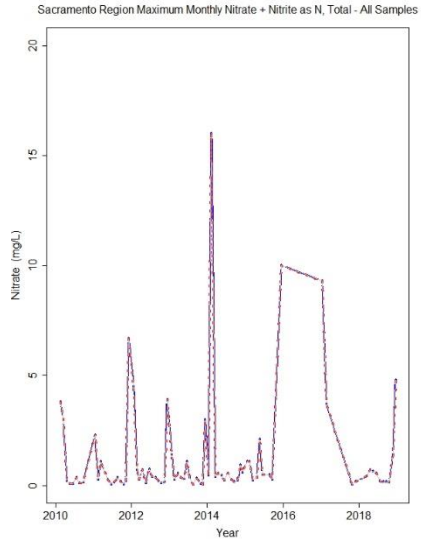
Central Delta Risk Region

Central Region Maximum Monthly bifenthrin

Central Region Maximum Monthly Chlorpyrifos

Central Region Maximum Monthly cyfluthrin

Central Region Maximum Monthly malathion

Central Region Maximum Monthly permethrin

I-6
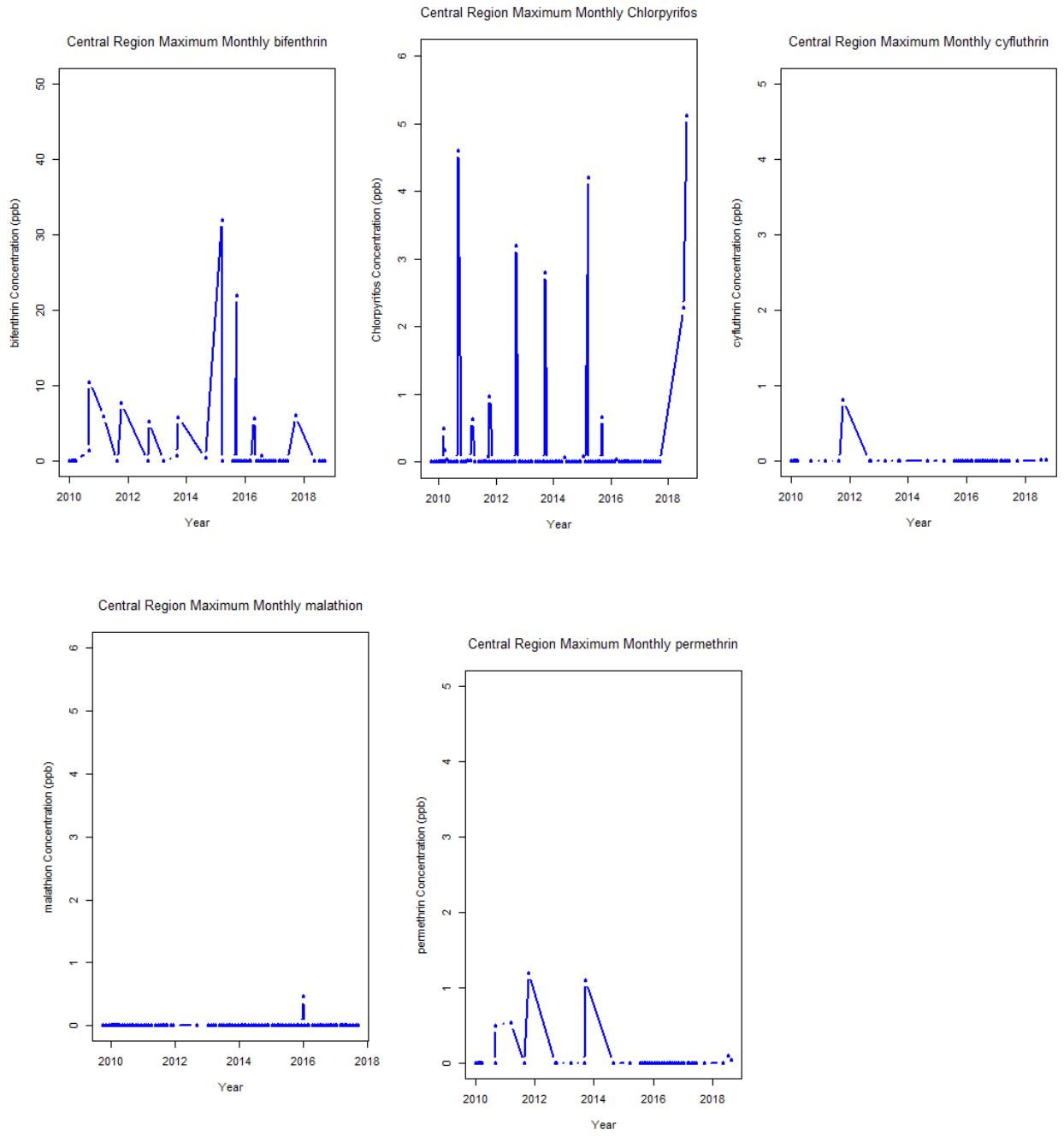
2016 - 2017 Central Region Mercury, Total - Water Samples

Months with data = 4
Points = raw data

Mercury, Total (ng/L)

Months

Central Region Mean Monthly Mercury, Total - Sediment Samples (All Years)

Points = raw data

Months with data = 6

Mercury, Total (mg/Kg dw)

Years

Central Region Mean Monthly Mercury, Methyl, Total - Water Samples (8/16-4/17)

Aggregate Monthly Average
Raw Data

Mercury, Methyl, Total (ng/L)

Months

Central Region Maximum Monthly Selenium, Total - All Samples

Central Region Mean Monthly Phosphorus as P, Total - Water Samples

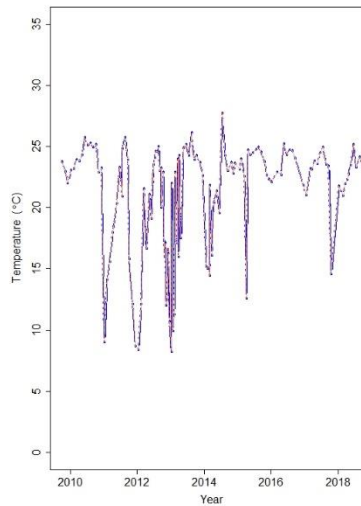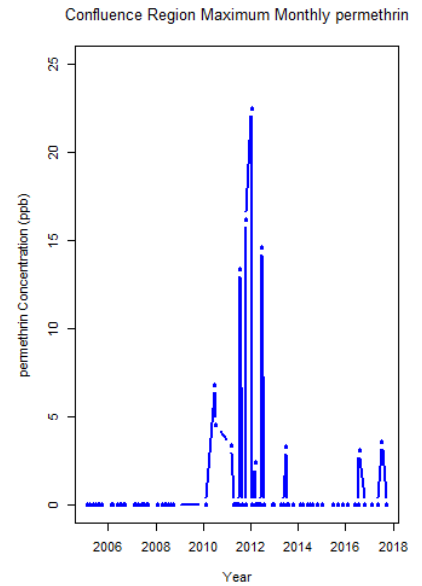Central Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples

Central Delta Region Maximum Monthly Water Temperature(°C) - All Samples

Central Delta Region Average Monthly Temperature(°C) - All Samples

South Delta Risk Region
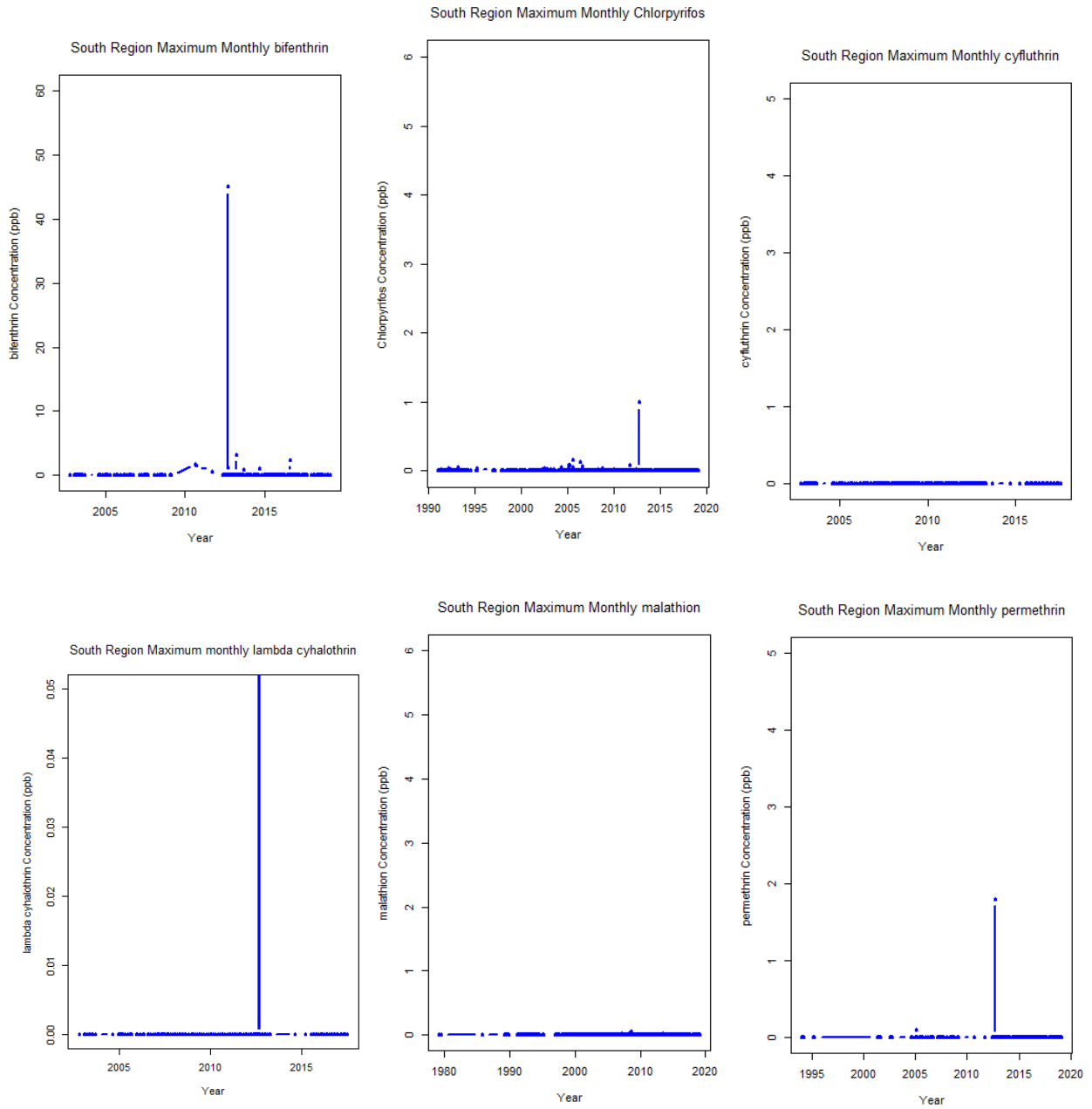
South Region Maximum Monthly bifenthrin

South Region Maximum Monthly Chlorpyrifos

South Region Maximum Monthly cyfluthrin

South Region Maximum monthly lambda cyhalothrin

South Region Maximum Monthly malathion

South Region Maximum Monthly permethrin

South Region Mean Monthly Mercury, Methyl, Total - Water Samples

South Region Maximum Monthly Selenium, Total - All Samples

South Region Mean Monthly Phosphorus as P, Total - Water Samples
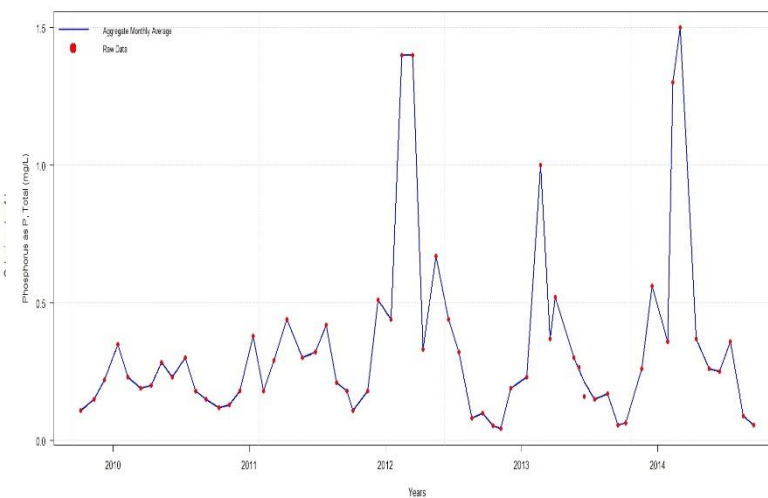
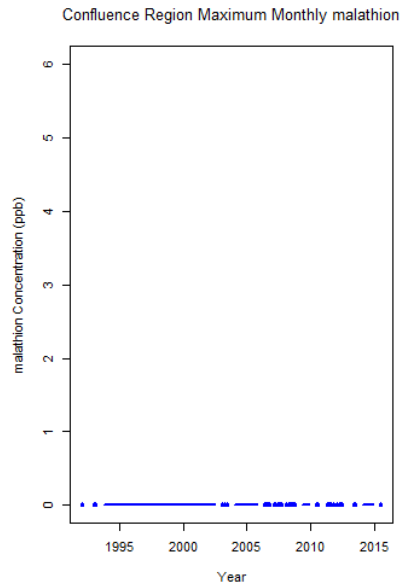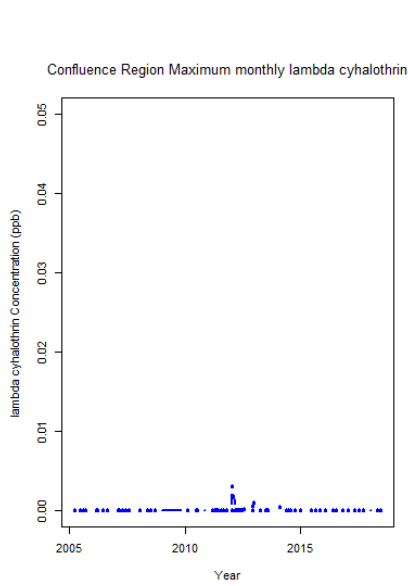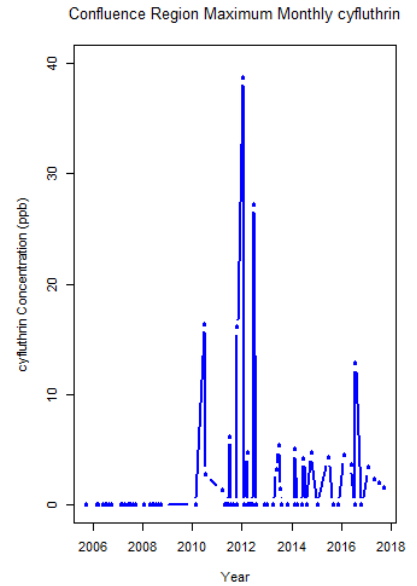## South Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
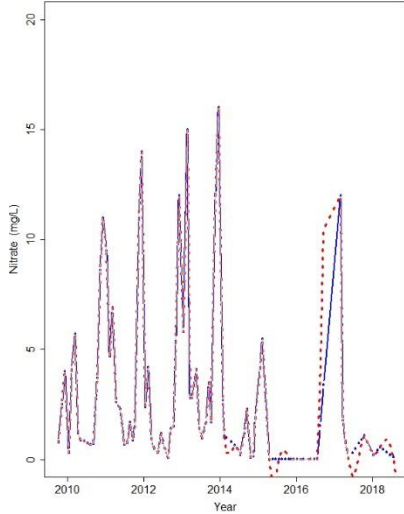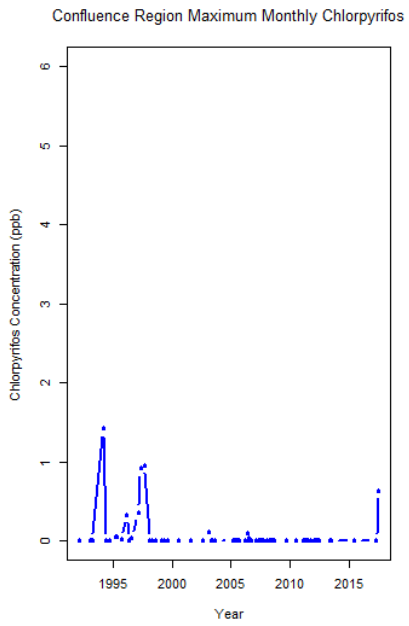

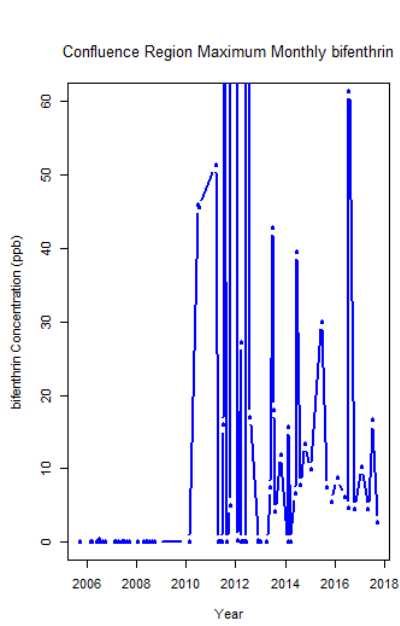## South Delta Region Maximum Monthly Water Temperature(°C) - All Samples
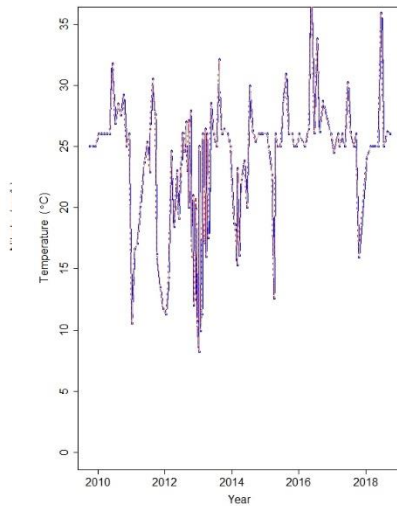
## South Delta Region Average Monthly Temperature(°C) - All Samples

I-10

Confluence Risk Region

Confluence Region Maximum Monthly bifenthrin

Confluence Region Maximum Monthly Chlorpyrifos

Confluence Region Maximum Monthly cyfluthrin

Confluence Region Maximum monthly lambda cyhalothrin

Confluence Region Maximum Monthly malathion

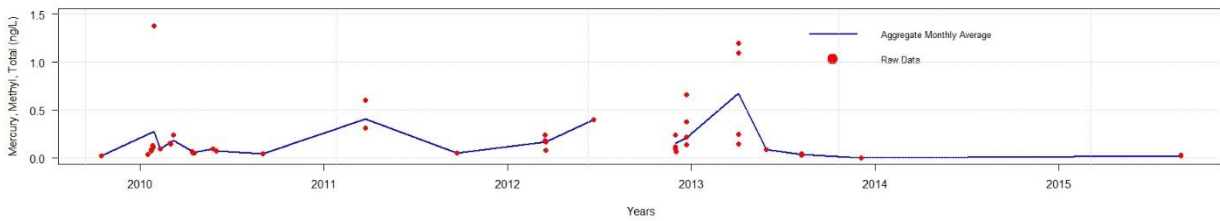Confluence Region Maximum Monthly permethrin

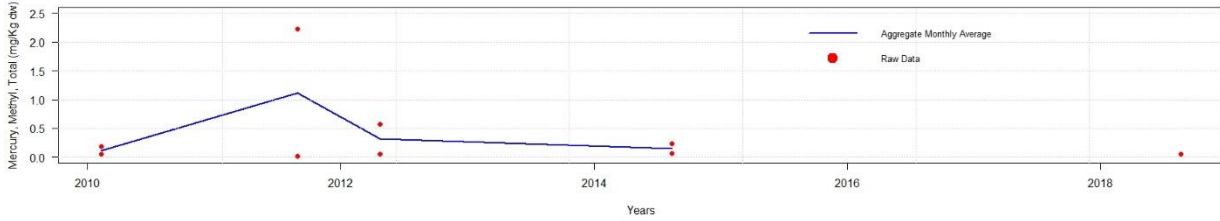Confluence Region Mean Monthly Mercury, Total - Water Samples (8/16-2/17)
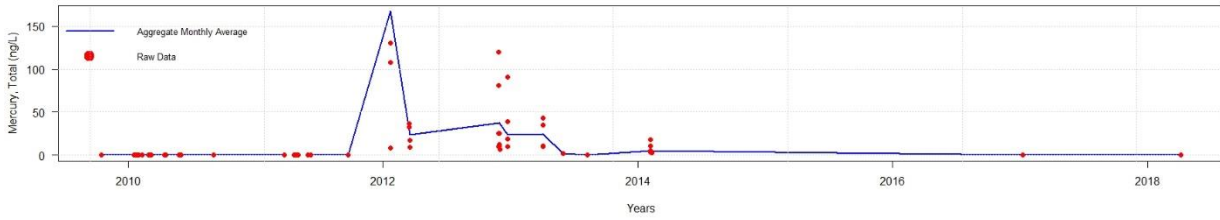
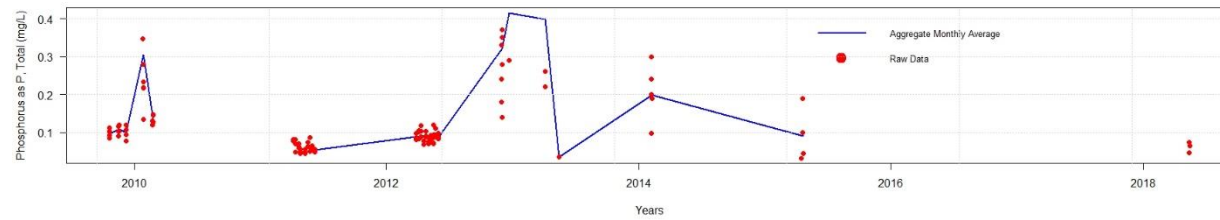Confluence Region Mean Monthly Mercury, Total - Sediment Samples
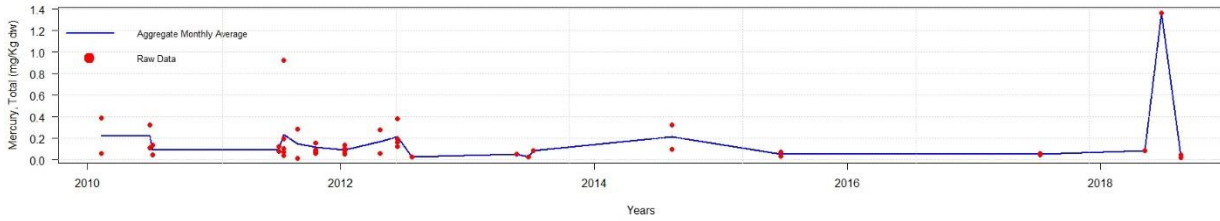
Confluence Region Mercury, Methyl, Total - Water Samples
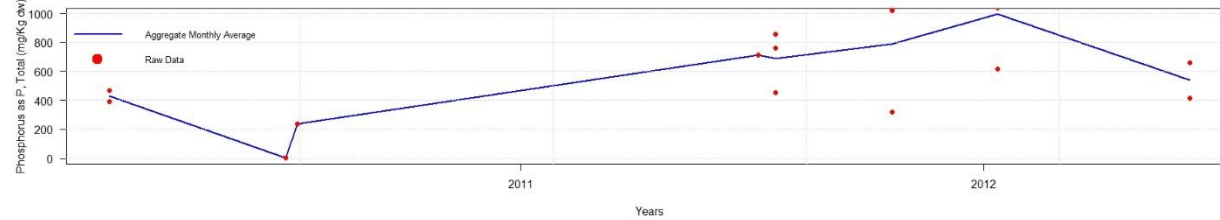
Confluence Region Mean Monthly Mercury, Methyl, Total - Sediment Samples

Confluence Region Mean Monthly Phosphorus as P, Total - Water Samples

Confluence Region Mean Monthly Phosphorus as P, Total - Sediment Samples

I-12

Confluence Region Maximum Monthly Selenium, Total - All Samples

Confluence Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples

Confluence Region Maximum Monthly Water Temperature(°C) - All Samples

Confluence Region Average Monthly Temperature(°C) - All Samples

Confluence Region Minimum Monthly Temperature(°C) - All Samples

I-13

Suisun Bay Risk Region

Suisun Region Maximum Monthly bifenthrin

Suisun Region Maximum Monthly Chlorpyrifos

Suisun Region Maximum Monthly cyfluthrin

Suisun Region Maximum monthly lambda cyhalothrin

Suisun Region Maximum Monthly malathion

Suisun Region Maximum Monthly permethrin

Suisun Region Mercury, Total - Water Samples

Suisun Region Mean Monthly Mercury, Total - Sediment Samples

Suisun Region Mean Monthly Mercury, Methyl, Total - Water Samples

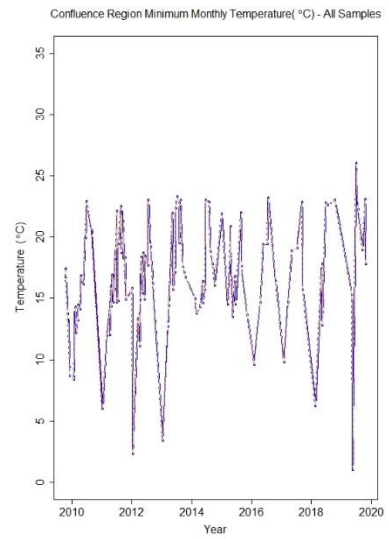Suisun Region Mean Monthly Mercury, Methyl, Total - Sediment Samples

Suisun Region Maximum Monthly Selenium, Total - All Samples

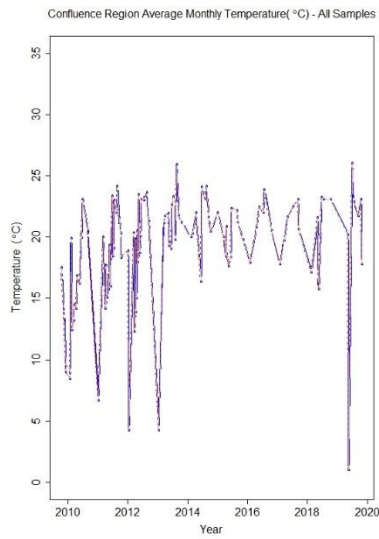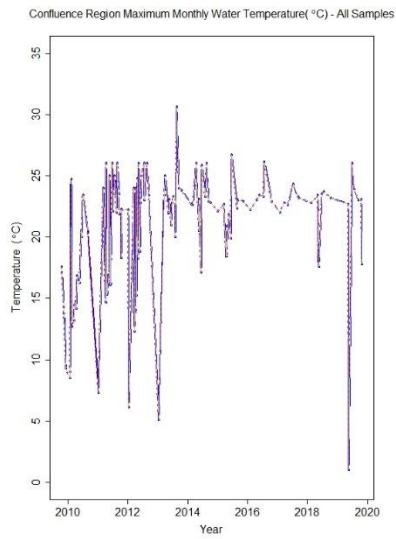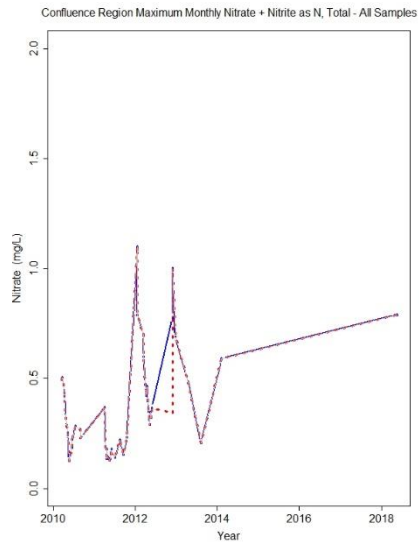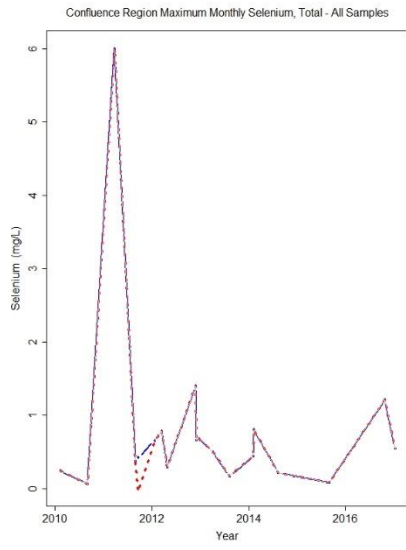Suisun Region Mean Monthly Phosphorus as P, Total - Water Samples

I-15

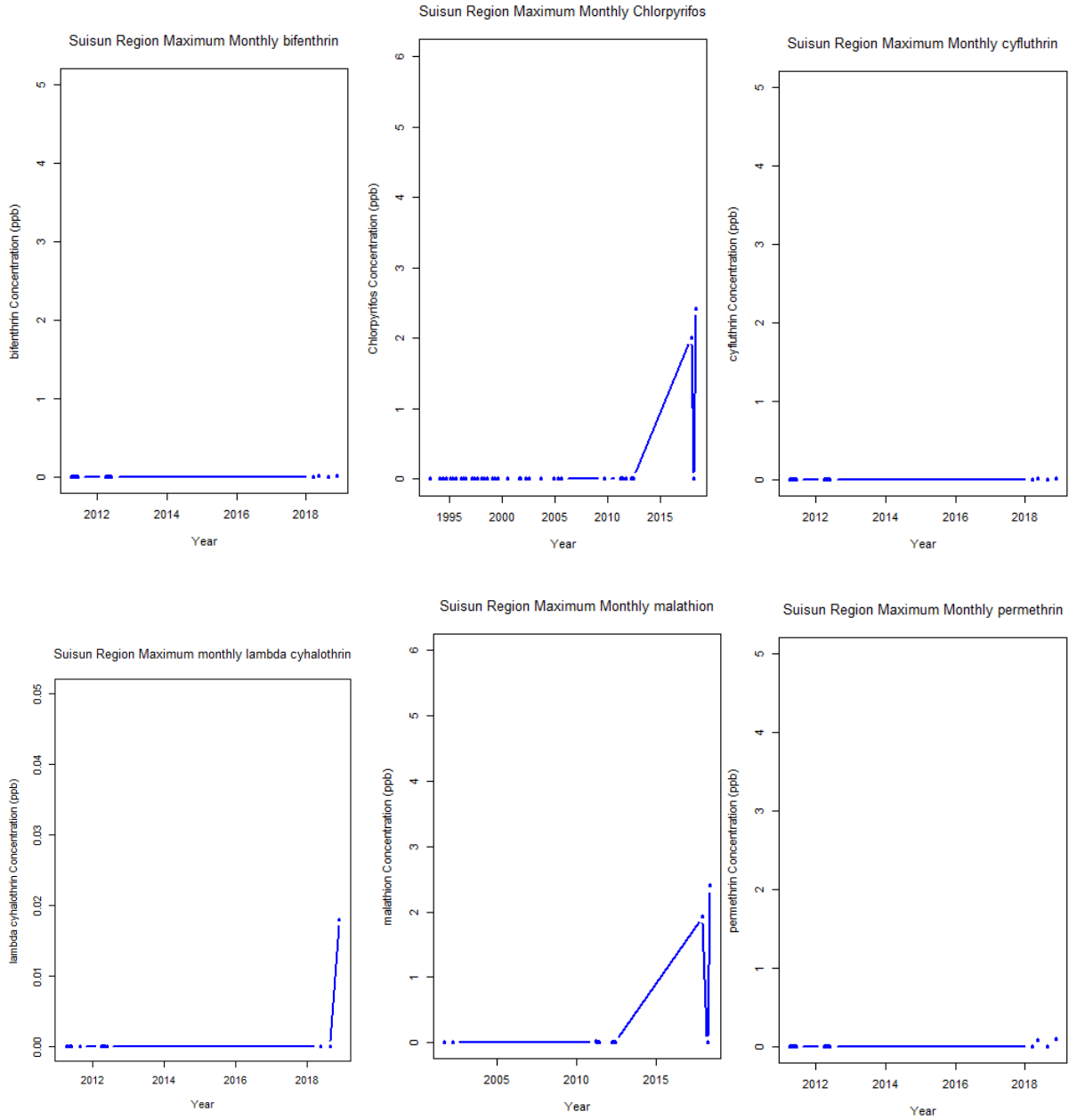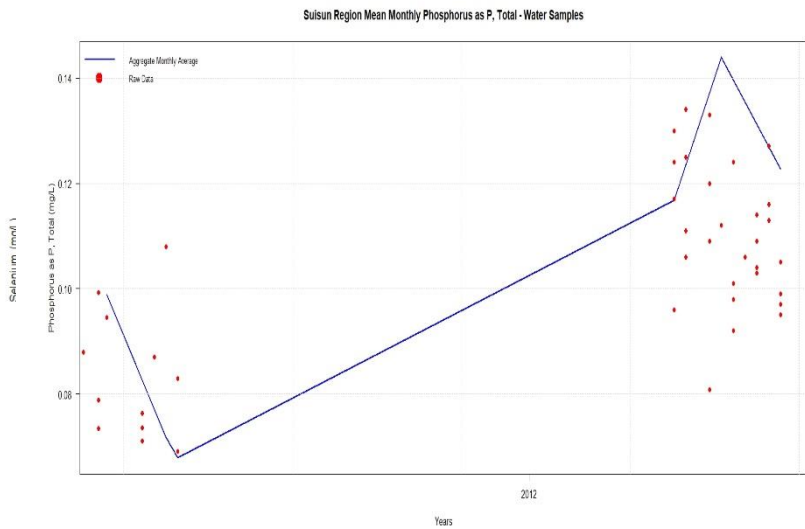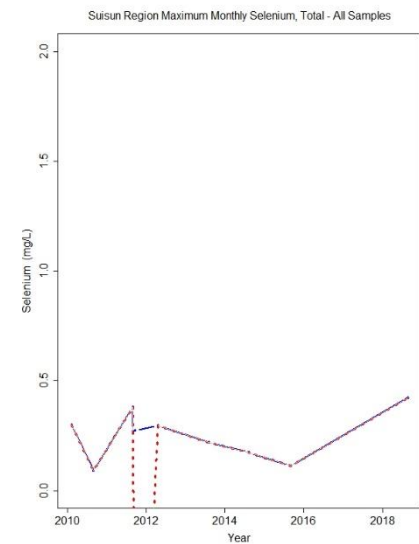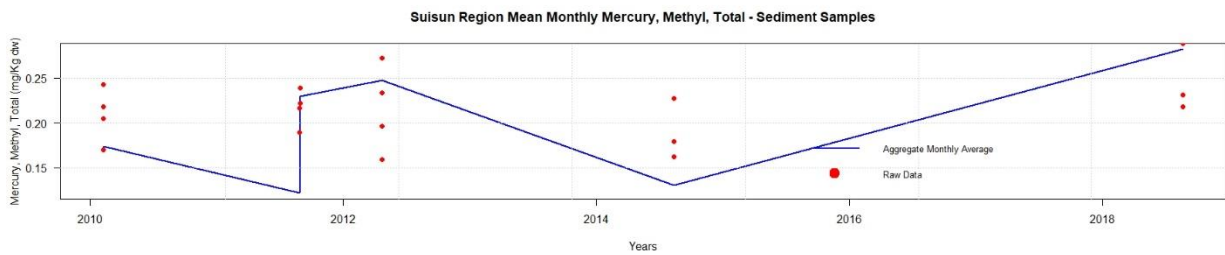Suisun Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples

Suisun Region Average Maximum Monthly Temperature(°C) - All Samples

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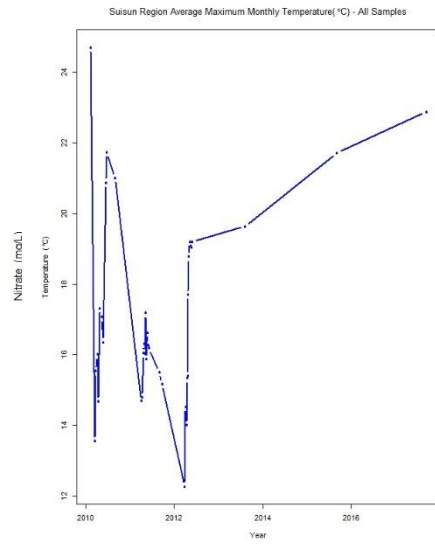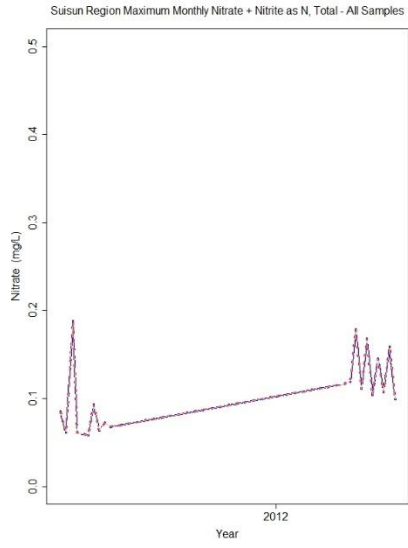CDWR and CDFW [California Department of Water Resources and California Department of Fish and Wildlife]. 2015. Fish Restoration Program Cache Slough Complex Conservation Assessment. Draft Volume 1: Characterization Report. Prepared by the California Department of Water Resources and the California Department of Fish and Wildlife, with assistance from Stillwater Sciences, Davis, California. Contract No. 4200009291. November

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