The Relative Contributions of Contaminants to Environmental Risk in the Upper San Francisco Estuary

Progress Report Year 1

Prepared for

The Metropolitan Water District of Southern California

Prepared by

Wayne G. Landis, Steven R. Eikenbary, Ethan A. Brown, Colter P. Lemons, Emma E. Sharpe, and April J. Markiewicz

Institute of Environmental Toxicology
Huxley College of the Environment
Western Washington University
Bellingham, WA 98225

June 30, 2020

Table of Contents

List of Figures

APPENDICES

List of Tables

List of Appendices

REFERENCES

Acknowledgements

Funding for this research was provided by the Metropolitan Water District of Southern California to the Institute of Environmental Toxicology at Huxley College of the Environment at Western Washington University through contract agreement number 189788. The following organizations provided data and information for this report: the California Department of Fish and Wildlife, the California Department of Pesticide Regulation, and the Metropolitan Water District of Southern California.

Special thanks to the Technical Advisory Team who have provided valuable feedback in the construction of the conceptual model, information about data resources, and technical feedback.

Specifically, we would like to thank Anna Conlen (U.S. Geological Survey, West Sacramento Projects Office) for numerous conversations and guidance on many technical aspects of the hydrodynamics of the region, Cyril Michel (UC Santa Cruz and NOAA Fisheries Southwest Fisheries Science Center) provided key literature and insights on the topic of salmonid survival throughout the region, and Andy Rehn (California Department of Fish and Wildlife) for providing data and commentary into the California Stream Condition Index.

Many thanks as well to Richard Connon (UC Davis) for providing toxicity test data and answering our questions regarding previous studies he has conducted, and to Inge Werner (Ecotox Centre), Juergen Geist and Sebastian Beggel (Technische Universität München), and Michelle Hladik (USGS) for their help and guidance with consolidating available toxicity data for the USFE region.

List of Acronyms and Abbreviations

AM	Adaptive Management
BN	Bayesian Networks or Bayes Nets
BMI	Benthic Macroinvertebrate
BN-RRM	Bayesian Network Relative Risk Model
CDPR	California Department of Pesticide Regulation
CPT	Conditional Probability Table
CI	Confidence Interval
CS	Chinook salmon
CSCI	California Stream Condition Index
CVP	Central Valley Project
DS	Delta smelt
DO	Dissolved Oxygen
EPA	Environmental Protection Agency (US EPA)
ERA	Ecological Risk Assessment
GIS	Geographic Information Systems
Hg	Mercury
MeHg	Methylmercury
MWD	Metropolitan Water District of Southern California
NOAA	National Oceanic and Atmospheric Administration
OCs	Organochlorine pesticide/insecticide
OPs	Organophosphate pesticide/insecticide
PAHs	Polycyclic Aromatic Hydrocarbons
PBDEs	Polybrominated Biphenyl Ethers (flame retardants)
PCBs	Polychlorinated Biphenyls
PCDDs/TCDDs	Polychlorinated dibenzo-p-dioxin (dioxins)
RRM	Relative Risk Model
SFE	San Francisco Estuary
SFEI	San Francisco Estuary Institute
SFEP	San Francisco Estuary Partnership
SWP	State Water Project
THg	Total Mercury
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USDR	United States Department of Reclamation
USFE	Upper San Francisco Estuary
USGS	United States Geological Survey
WF	Water Flow
WG	Water Gage
WQ	Water Quality

Risk Terminology and Glossary

Adaptive Management: An iterative process of "learning by doing," where managers learn about current management practices through monitoring data and use the new knowledge to improve the next set of management decisions (Holling 1978, Nyberg et al. 2006).

Assessment Endpoint: An aspect of the natural system that is of value to society or the local community, as well as important to the ecology of the system.

Bayesian Networks: Bayesian networks (Bayes Nets or BNs) are directed acyclic graphs that links sources of stressors, habitats and endpoints through a web of nodes using conditional probability to estimate the likely outcome (McCann et al. 2006).

Bayesian Network Relative Risk Model (BN-RRM): A relative risk model where the linkages between the conceptual models are described by using a Bayesian network (also called a Bayes Net) (Ayre and Landis 2012).

Conceptual Model: Diagrammatic description of the interactions that stressors have with ecological components and their associated endpoints.

Conditional Probability Table: (CPT) Describes, using conditional probabilities, the relationship between two or more input nodes in the BNs. The relationship can be direct P(B|A), indirect P(B|A), P(C|B), a shared cause P(B|A), (P(C|A) or shared effect (P(C|A,B).

Effect: A change in the state or dynamics of an organism or other components of the ecological system resulting from exposure to a stressor. An indirect effect occurs when the initial effect results in additional stressors or effects to any component of the system.

Entrapment Area: An area where suspended particles and small, immature life stage aquatic species (eggs, larvae, juveniles) are concentrated by estuarine circulation or other factors.

Exposure: In the formulation of the relative risk model it is the colocation of a stressor with a receptor in a geographic area or habitat.

Habitat: The type of environment in which the receptors are found. Receptors may live exclusively within a single habitat or may move between and use several habitats.

Measurement Endpoint: An effect that is measured (e.g., toxicity test or field survey) and can be used to link the effects of a stressor to the assessment endpoints.

Stressor: Anything that is physical, chemical, or biological in nature which causes an effect to an organism or system. Initial stressors may result in secondary stressors, as in the case of excess nutrient input (initial stressor) causing mortality due to microbial activity and a decrease in oxygen (secondary stressor).

Receptor: The organism or group of organisms that have the potential to be affected by a stressor.

Relative Risk Model: A cause and effect modeling approach used to calculate risk to endpoints due to multiple stressors entering a number of habitats and having an effect on the endpoint(s) (Landis and Wiegers 1997, 2005).

Response: The effect on the receptor as a result of exposure to a stressor.

Risk: The probability, actual or relative, of an unwanted effect on a receptor judged by society to be important (Hines and Landis 2014).

Source: An anthropogenic input or activity that releases or creates a stressor in the environment. The characteristics of a stressor may be influenced by the type of source.

Uncertainty: There are two types of uncertainty we can address in ecological studies: epistemic and linguistic uncertainty (Regan et al. 2002). Uncertainty addressed in this risk assessment is mainly epistemic uncertainty.

Epistemic Uncertainty – This includes uncertainty of the knowledge of the state of a system. This could be limitations from measurement devices or uncertainty due to scarce data, extrapolation, and variability in spatial and temporal scales.

Linguistic Uncertainty – This is the uncertainty due to the language and vocabulary used in scientific writing. This vocabulary can be very technical and context dependent. At times it can also be ambiguous and vague.

Executive Summary

This three-year regional-scale ecological risk assessment is being conducted to identify the chemicals or groups of contaminants contributing the greatest ecological risk to species in the Suisun/Delta region. The goal is to determine the relative contributions of contaminants specifically responsible for reducing native pelagic fish species, adversely impacting macroinvertebrate community structure, and causing concomitant reductions in ecosystem services within the upper San Francisco Estuary. This Progress Report describes the research and activities conducted in Year 1 that included the evaluation of the various datasets for each of the assessment endpoints, as well as recommendations made as to their utility to support the risk assessment process, as well as data gaps to be addressed.

The Sacramento-San Joaquin River Delta Watershed (Delta) drains the entirety of the Central Valley of California with many different contaminants ending up in Suisun Bay and the Delta. Agricultural and urban land use practices are the primary sources for contaminants. Other stressors exist, such as habitat alteration, water quality, changes in water flows and amount, and alterations in the landscape. Key species such as Delta smelt and Chinook salmon have been in decline. Delta smelt species is a key forage fish endemic to California and only present in the San Francisco Estuary. Chinook salmon pass through this region as they migrate out to sea and then back to their spawning areas upstream. Macroinvertebrates are key components of aquatic systems and the community structure. The potential effects have made it imperative that a methodology be constructed to assess the risks to the USFE and to have that process be part of an adaptive management program for future decision making.

The methodology applied in this study is the multiple stressor regional-scale ecological risk assessment using the Bayesian network relative risk model (BN-RRM). The assessment will identify the chemicals or groups of contaminants and other stressors contributing to the ecological risk to the study area. The long-term goal is to determine the relative contributions of contaminants and other stressors responsible for reducing native pelagic fish species, adversely impacting macroinvertebrate community structure, and causing concomitant reductions in ecosystem services within the USFE. The goal of year 1 was to assess the current data available for the USFE regarding multiple stressors and their suitability for the conduct of an ecological risk assessment Bayesian network relative model.

Specific groups of contaminants include metals (mercury, methylmercury, selenium, copper, lead, zinc, cadmium), pesticides, including insecticides such as organophosphates: diazinon, chlorpyrifos, malathion, organochlorides: DDT and its degradates, pyrethroids, imidacloprid and other high use neonicotinoids, fipronil and its degradates, some other herbicides, and fungicides. Other stressors include: Seasonal and water quality parameters included water temperature, pH, ammonia/ammonium, salinity, dissolved oxygen, as well as geographical and vegetative parameters including shoreline morphology (nursery habitat), riparian vegetation/canopy cover, tidal influences, and control dam water discharges. The specific endpoints considered in this analysis are macroinvertebrate community structure, Delta smelt abundance and Chinook salmon outmigrant abundance.

The analysis demonstrates that the data are sufficient to populate the segments of the conceptual model to parameterize the derived BN-RRM. Data are available for each of the six risk regions: North Delta, Sacramento River, Central Delta, South Delta, Confluence and Suisan

Bay. We have mapped the monitoring stations and downloaded observations from the CEDEN and SURF datasets. Information from the literature on the ecology and hydrology of the region were collected. GIS maps of land cover and terrain have been compiled. From the last 10 years there are 161,333 collection points from SURF and 259,885 observations from CEDEN for the study area and a 15 km buffer. Information regarding flows, occurrence of fish populations and California Stream Condition Index results have also been collected and analyzed. Data are available for each portion of the risk assessment and the project is ready to build and parameterize the Bayesian network to estimate risk.

INTRODUCTION

Project Overview

The Sacramento-San Joaquin River Delta Watershed (Delta) drains the entirety of the Central Valley of California with many different contaminants ending up in Suisun Bay and the Delta. Agricultural and urban land use practices are the primary sources for these contaminants. Contaminants have long been considered a threat to fish, as well as other aquatic organisms in the Suisun/Delta region of the upper San Francisco Estuary (USFE). The USFE contains key species and ecosystem services. The Delta smelt, a key forage fish endemic to California and only present in the San Francisco Estuary. Chinook salmon are an iconic species and many runs pass through the USFE to spawning grounds upstream. The macroinvertebrate community is a food resource to multiple fish and other species. The habitats in the region support these and numerous other birds, mammal, amphibian, and insect species, as well as provide recreational opportunities and water for irrigation, drinking, transportation.

This report summarizes the first year of a three-year program conducting a multiple stressor regional-scale ecological risk assessment to identify the chemicals or groups of contaminants contributing the greatest ecological risk to species in the Suisun/Delta region. The long-term goal is to determine the relative contributions of contaminants specifically responsible for reducing native pelagic fish species, adversely impacting macroinvertebrate community structure, and causing concomitant reductions in ecosystem services within the upper San Francisco Estuary. In year one of the study, the specific goal was to build a conceptual model with a causal source to impact structure and to evaluate the existing datasets as to their suitability for use in the risk assessment. At the end of the first year the stage is set to conduct a regional scale ecological risk assessment.

Ecological Risk Assessment

The ecological risk assessment process we are applying is the Bayesian Network Relative Risk Model (BN-RRM). It is the current incarnation of the Relative Risk Model (Landis and Wiegers 1997, 2005, 2007) using Bayesian networks to describe the relationships between sources of stressors, stressors, habitats, effects, and endpoints (Ayre and Landis 2012). Bayesian networks easily incorporate a variety of types of data, including that from expert elicitation, as well as integrate probabilistic interactions and provide detailed descriptions of uncertainty and the importance of the variables in the estimation of risk. This approach has been used across the world to assess risks in estuaries of Southeast Queensland, Australia (Graham et al. 2019), as well as in the South River, VA (Landis et al. 2017a, 2017b, Johns et al. 2017), and in Africa (O'Brien et al. 2018). Specific types of stressors have included stormwater runoff (Hines and Landis 2014), invasive species, and emergent diseases (Herring et al. 2015, Ayre et al. 2014).

The BN-RRM is also applicable to adaptive management (Landis et al. 2017b). The Bayesian networks can be updated as additional information and data are obtained to guide future management options. It has also been used to explore the effects of proposed management actions on risks to specific endpoints by making adjustments to input nodes within the Bayesian network and re-running the model (Johns et al. 2017, Graham et al. 2019).

Conceptual Model

The conceptual model (CM) (**Figure 1**) is based on the sources-stressors-habitat-effects-impacts structure of the BN-relative risk model for risk assessment. The fundamental structure has proven appropriate in a number of previous studies on marine and freshwater systems across the world. These include Padilla Bay (Herring et al 2015), South River (Landis et al 2017a, Johns et al 2017), estuaries near Brisbane, Australia (Graham et al 2019), and four rivers/estuaries in Puget Sound (Landis et al 2020). Use of the structure facilitates the assessment of the available data sources to build quantitative cause-effect models in order to estimate risk. The next sections take each segment and describes the data sources available.

Building of the CM starts at each end. The Sources describes the entities in the study area that generate the stressors that of interest in the risk assessment. The Impacts section is a listing of the endpoints that, by definition, have an importance to the stakeholders and managers of the site. In this study the sources are Central Valley Agriculture, Effluents, Land Use practices, Stormwater Runoff, Transportation, and Marine Shipping/transportation.

Central Valley agriculture is a source of pesticides, nutrients, and other contaminants entering via the tributaries and due to activities of this key California industry. Effluents constitute the various regulated point sources in the study area. Some of the effluents are municipal wastewater from residential areas, some are industrial, and others may be a combination. Land use information is important in characterizing the types of other inputs to the system, some by non-point source contributions, stormwater inputs, and habitat alteration for the endpoint species. Transportation includes trains, cars, the roads and the materials that these activities release to the aquatic system. There is also a large amount of marine shipping in the study area including numerous shipping channels and other waterways.

At the other end of the model are the endpoints chosen for this initial study. Chinook salmon are an iconic species in the region, highly managed and regulated. Using the entity-attribute system of defining an endpoint, Chinook is the entity and the attribute is survivorship of the in- and out-migrating fish. Delta smelt are endangered and an iconic species for the USFE. The entity is the Delta smelt and the attributes are habitat quality and population abundance. The third endpoint is macroinvertebrates. Macroinvertebrates are a key component of the USFE system. In this instance the entity is macroinvertebrates and the attribute is community structure. The California Stream Condition Index (CSCI) is a statewide measure for stream and river quality that is based on the Index of Biotic Integrity. In this study, we will use the data on which the information is calculated to apply current multivariate tools to search for patterns in community structure in the study area.

The Sources and Impacts bracket the cause-effect framework in the conceptual model. In between the two, the stressor and habitats/location nodes estimate the exposures from multiple stressors across the USFE. The stressors include such classics as pesticides, metals, legacy contaminants, the water quality characteristics of the USFE, and alterations to the landscapes and waterways from dredging, breaching of levees and other activities. The Habitat/Location section sets the spatial areas where the stressors and endpoints intersect. These areas are mapped within each risk region. Delta smelt and Chinook salmon habitats are key since they directly affect the endpoints. Macroinvertebrate habitat is also related directly to each endpoint.

Other habitats include the transition zones from estuary to sub-basins to rivers to riverine habitats, and finally to marshlands.

Effects is the final section and lists the variety of effects that are initiated by exposure to ecological stressors. First is habitat effects, as in change in location, addition due to restoration activities, blockage to migration and other physical effects. There are also direct effects such as toxicity, both acute and chronic, and indirect as populations and communities are altered.

The next step is to evaluate the sources of information available to populate the framework and to perform the risk calculations. The next sections describe the sources of information and how they apply.

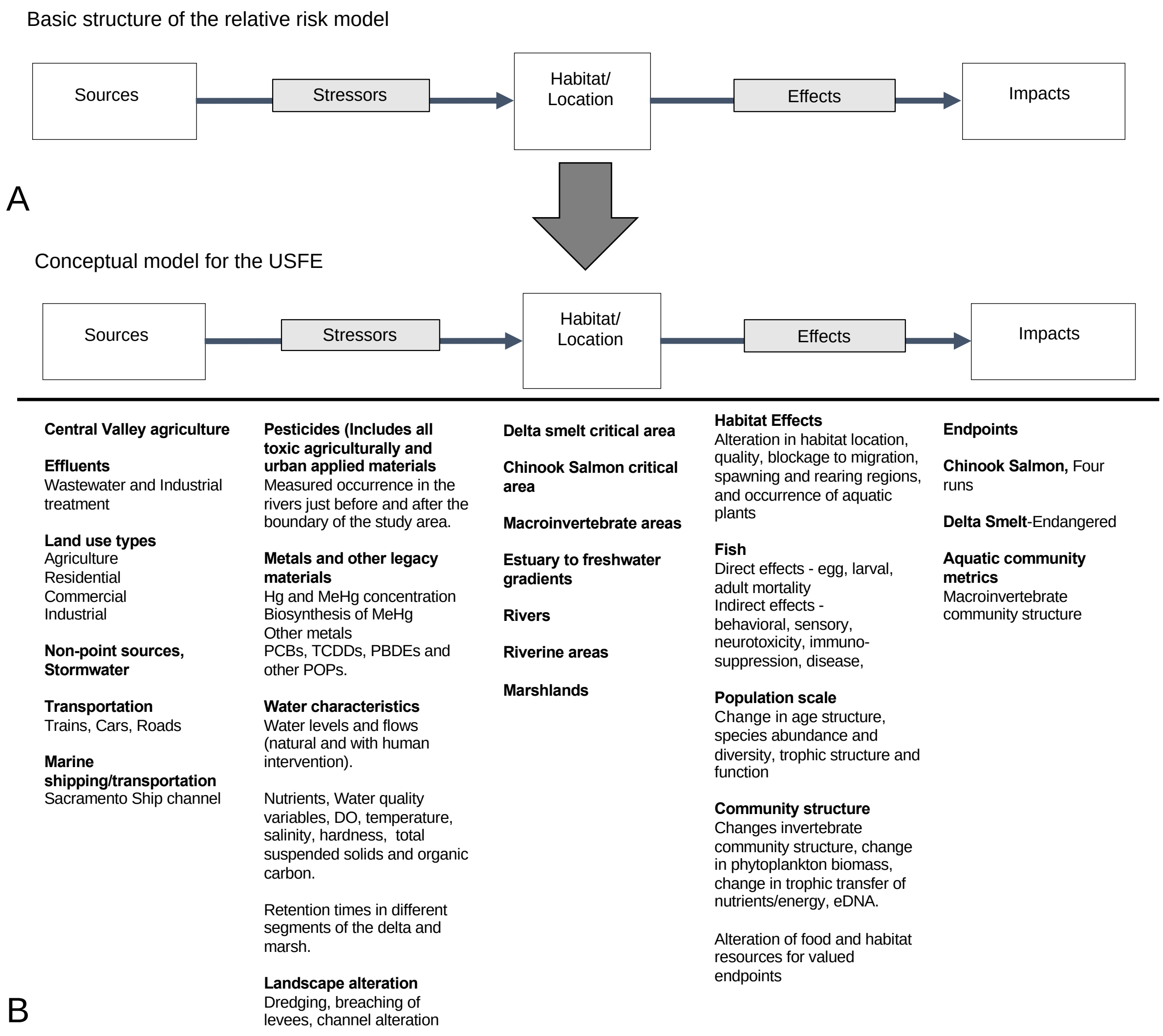


Figure 1. The relative risk model for ecological risk assessment. The basic format of the relative risk model is presented in **Figure 1a**. The basic format is then populated by the site-specific factors for the USFE study area (**Figure 1b**). The conceptual model is the basis for the derivation of the Bayesian network.

Organization of the Report

The next sections provide the background on the use of the Bayesian-network Relative Risk Model, the determination of the risk regions, sources, stressors, and endpoints to be evaluated, and the data requirements. Risk regions are delineated for comparative purposes within the USFE. An overview of the data sources and the analysis tools are then presented. The data include extensive monitoring results from over the last ten years, the wealth of GIS information, as well as the available toxicity data for the contaminants at the site. Finally, we compare the available information to the needs of the risk assessment process and evaluate the quality of the information and any uncertainties. Of all the sites that we have investigated the USFE has the most extensive. The questions will center on the specific pathways under investigation and if there are better endpoints or questions to answer given the information.

METHODS

Building the Conceptual Model for the Risk Assessment

The first step is to construct the conceptual model for the ecological risk assessment. This is done using the Sources-Stressors-Habitats/Locations-Effects and Impacts of the BN-RRM (**Figure 1**). This process included consultation with stakeholders and managers, an initial analysis of the issues of the site, and the construction of an initial conceptual model. Each step is described next.

Stakeholder and Outreach Meetings

The first step is the determination of the specific management questions and goals to be addressed. The process begins with a stakeholder meeting with key resource managers, staff scientists, technical personnel, representatives from affiliated non-government organizations and the broader public involved in the region.

In the fall of 2019, a set of presentations were made and discussions were held with representatives of a number of agencies including the Metropolitan Water District of Southern California, the California Department of Pesticide Regulation, and the Department of Fish and Wildlife. A seminar was presented that was open to the broader scientific and regulatory community and was broadcast online. During the remainder of the fall the Technical Advisory Team was constituted to provide a larger representative team for program overview.

A tour of the site was also conducted via boat to provide a broader context of the site, including the variety of habitats, land uses, restoration activities, recreational opportunities, the industries, agricultural lands and urban areas.

We also did an initial assessment of the data sources, management issues, key species, and sources to build a strawman conceptual model for presentation and update. These steps are summarized below.

Sources

Field research data, monitoring data, technical and published reports, GIS files and other data are used to locate sources of stressors, as well as quantify water, sediment, and tissue concentrations of contaminants. The primary sources of the stressors were from agricultural activities, urban development (loss of arable lands, stormwater runoff), transportation (shipping, vehicles), and point sources (municipal wastewater facilities, industries). Our previous research has also shown that water quality parameters, such as seasonal temperatures and dissolved oxygen, as well as habitat quality, quantity, and location are important to consider in the ecological risk assessment.

Stressors

In this study, the contaminants identified to be considered included select metals (mercury, methylmercury, selenium, copper, lead, zinc, cadmium), pesticides (organophosphates: diazinon, chlorpyrifos, malathion, organochlorides: DDT and its degradates, pyrethroids, imidacloprid and other high use neonicotinoids, fipronil and its degradates, some herbicides, and fungicides. Seasonal and water quality parameters included water temperature, pH, ammonia/ammonium, dissolved oxygen (DO) and salinity, as well as geographical and vegetative parameters including shoreline morphology (nursery habitat), riparian and aquatic vegetation/canopy cover (shading, temperature refugia), tidal influences, and control dam water discharges.

Habitats

Habitats/locations selected for inclusion in the risk assessment were specific to the assessment endpoints (Delta smelt, Chinook salmon, and macroinvertebrate communities) for food, water, shelter and space depending on their life stage. The habitats included open water/channels/rivers, shallow embayments, marshes, aquatic/riparian vegetation (rooted and floating), and sediments. The ability to include habitats in the risk calculation enables ecological risks to be determined for specific endpoints at site-specific locations within the landscape.

Effects

The effects from land disturbances and alterations, chemical contaminants, changes in water flows (quantity, distribution) and water quality, and climate change on the assessment endpoints in the study area are not equal. If a source generates stressors that affect habitats important to the assessment endpoints the effect and ecological risk is high. If there is minimal interaction the effect and risk is low. If one component does not interact with one of the other two components, there is no effect and no risk. Effects are usually categorized as affecting survival, growth, and reproduction. Their overall impacts, however, may result in species population declines or extinction, changes in species compositions, and disruptions to aquatic and marine food webs.

Endpoints

The assessment endpoints were macroinvertebrate community structure, Delta smelt abundance (larval, juvenile, adult life stages), and Chinook salmon abundance (all runs: Fall, Late Fall, Winter, and Spring).

Risk Regions

It is also important to identify and map the management issues in the study area including the geographic distribution of the endpoints and stressors. The importance of a specific stressor to elicit a response in a specific endpoint can dramatically change depending on the region within the study area and its management goals. The study area is therefore divided into geographically explicit risk regions usually based on watershed delineations. Six risk regions were delineated in the study area. Five were located in the Sacramento-San Joaquin Delta:

North Delta, Sacramento River, Central Delta, and South Delta risk regions that are aligned north to south, and the Confluence risk region located west of the Central Delta. The sixth risk region was the Suisun Bay watershed located just west of the Confluence risk region and the Delta. The boundaries of each risk region may need to be adjusted based on the availability and quality of the data once the risk assessment is conducted in Year 2 of this study.

Risk Calculations

Risk is then calculated for each region. These risk estimates can be summarized at the spatial scale of the entire study using a variety of techniques. Bayesian networks are the computational environment used to estimate risk, describe uncertainty, and identify the variables that are key to the estimation of risk. The methodology for the construction of the Bayesian network has been published (Ayre and Landis 2012, Hines and Landis 2014, Herring et al. 2015, Landis et al. 2017a, Johns et al. 2017, Graham et al. 2019). We used those same techniques in this project. A brief description follows.

Finalizing the Conceptual Model

The Bayesian network (BN) is derived from a conceptual model that is based on the current understanding of causal relationships within the study area. The conceptual model is developed in consultation with the stakeholders and has a cause-effect structure consisting of five categories: sources of stressors, stressors, habitat/location, effects, and impacts. The resulting model identifies the relevant direct and indirect factors that contribute to risk, as well as defines the causal interactions, relationships, cumulative effects, and deleterious impacts.

Once completed, the conceptual model provides the framework to construct the BN-RRM for each risk region in the study area (**Figure 1b**). The acquisition of the data was based on this expanded framework.

Acquisition of Datasets and Analyses

A critical part of the process is the acquisition and analysis of the datasets that are used to build the conditional probability tables (CPTs) and to confirm the cause-effect relationships (Ayre and Landis 2012, Hines and Landis, 2014, Landis et al. 2017a). The first phase of this project entailed collecting and compiling the extensive data from monitoring studies, field research, and laboratory experiments conducted in the upper SFE. Data were also compiled from studies conducted in similar estuarine environments to supplement the site-specific data. For example, information on the toxicological responses of the selected species endpoints to contaminant stressors in the upper SFE, as well as in similar estuarine sites were used in constructing the BN-RRM.

Interactions of pesticides and other contaminants with a species can also be informed by using an adverse outcome pathway (AOP) model that identifies the sequential biochemical events that elicit the toxicological response in the organism exposed to the contaminant. High throughput cell- and biochemical-based toxicity tests are part of the AOP approach to conduct a number of tests and then evaluate the combined data to predict potential toxicological effects. Together, these sources of data can provide key information on changes in the reproduction and survival of valued organisms, their population dynamics, and community structure. Studies describing

the effects of nutrients on water quality and community structure have also been conducted at a variety of estuarine sites and may contain useful information (Graham et al. 2019).
An extensive and thorough evaluation of all the data, reports, and results from studies at similar types of sites is conducted. The first step is an examination of data quality, especially the availability of metadata and GPS locations within the study area. Next an exploratory analysis occurs, in recognition that large datasets may contain apparent associations by chance because of the large number of variables and samples. In some instances, *p* values lower than 0.05 are used to reduce the chance of spurious associations. Data associations are also evaluated to ensure they make sense compared to the extensive knowledge base on the known interactions within the study area.

For chemical concentrations in water, tissues, or sediment actual measurements using standardized analytical methods are preferred rather than from models. For toxicological data, exposure-response relationships derived from curve fitting are used instead of estimated point values (LC_{50}, EC_{50}). Many agencies, and especially NOAA, have exposure- response data on their website that can be used to construct exposure-response equations that include confidence intervals. Alternatively, Netica software has a case-learning algorithm that also is excellent in determining relationships between variables and incorporates a description of the uncertainty in the derived CPT. In situations where sufficient data do not exist for a specific endpoint and uncertainty is too high to base a management decision, the interaction between the risk assessment team and the stakeholders is vital.

Study Area and Description of Risk Regions

Study Area

The study area is located in the Central Valley of California and encompasses an area of approximately 3,441 square kilometers. It is delineated by the Legal Delta Boundary established under the Delta Protection Act (Section 12220 of the Water Code) (CDWR 2020a) and the Suisun Boundary, Conservation Zone 11, as defined by the Bay Delta Conservation Plan (**Figure 2**). To encompass the entire Suisun Bay channel, the Suisun Bay boundary was extended to border the Suisun Bay Estuaries California Small Watershed, HUC12 identification 180500010401. In total, the area includes the southern half of the Sacramento River watershed, the northern half of the San Joaquin River watershed, the Delta, and Suisun Bay, Suisun Marsh and its watershed. The study area extends over portions of six counties. They are, from northwest to southwest: Yolo, Solano, Sacramento, San Joaquin, the northeast corner of Alameda, and Contra Costa counties (WEF 2020a). A more detailed description of the study area is provided in **Appendix A**.

Risk Regions

As part of the BN-RRM methodology, the study area was then divided into six smaller sub (risk) regions based on hydrological delineations and land use similarities. Boundary lines follow those delineations. The resulting risk regions, from north to south, are: North Delta, Sacramento River, Central Delta, and South Delta, and from east to west: Confluence and Suisun Bay. The inner risk region delineations approximated the sub regions proposed in the Delta Regional Monitoring Program, but were clipped to the nearest HUC12 watershed.

The North Delta risk region is delineated by the Legal Delta Boundary on its north and west border. Its east border includes the Sacramento Deep Water Ship Canal and is adjacent to the western border of the Sacramento River risk region. The risk region encompasses the southwest portion of Yolo County and the eastern portion of Solano County.

Figure 2. Upper San Francisco Estuary study area and risk regions delineated in it.

The Sacramento risk region is directly east and adjacent to the North Delta region, sharing its western border, the Sacramento Deep Water Ship Canal, with it. Its east border extends south along the Legal Delta Boundary and terminates at the northern boundary of the Central Delta risk region. This risk region encompasses the southeastern portion of Yolo County, the southwestern portion of Sacramento County and the southeastern portion of Solano County.

The Central Delta risk region borders the Confluence to the west and the study site boundary to the east. Its southern boundary includes the Clifton Court Forebay, Union Island, and Robert's Island-Trapper Slough watersheds that delineate the northern border of the South Delta risk region. The Central subregion northern border is delineated by the Threemile Slough, South Mokelumne River, and Hog Slough watershed that forms the southern border of the Sacramento risk region. The risk region encompasses the southwestern portion of Sacramento County, the northeastern portion of Contra Costa County and the eastern portion of San Joaquin County.

The South Delta risk region shares its northern border with the Central Delta region, whereas its east, south, and western borders are delineated by the Legal Delta Boundary's southeastern, south, and southwestern boundaries. The risk region encompasses the southwestern portion of San Joaquin County and the northeastern portion of Alameda County.

The Confluence is bordered west by the Suisun Bay risk region, on the north and south by the Legal Delta Boundary, and east by the Central Delta risk region. The eastern border originates in the south at the Lower Marsh Creek watershed border and extends north to the beginning of the Sacramento Deep Water Ship Canal. The region encompasses the southwestern portion of Sacramento County and the northeastern section of Contra Costa County.

The Suisun Bay risk region was delineated on its north, south and west borders by the Suisun Boundary. It shares its eastern border with the Confluence risk region that originates south near Shore Acres and extends northeast to the south edge of the Lucol-Hollow watershed near Montezuma Hills. Most of the region is in the southeastern section of Solano County with the Contra Costa County along its southern border.

Sources of Stressors

Land Use Practices

Land use activities including agriculture, construction of roads, railways, levees, dams, channels, and urban development have resulted in significant losses in natural wetlands, forests, rangelands, and riparian habitat in the study area over the last 130 years. It is estimated that in some areas, habitat losses have been up to 90% (SFEI and ASC 2014, Data Basin 2020).

These land uses have caused water challenges in the region resulting in groundwater loss, land subsidence, and saltwater intrusions. They have also served as sources of chemical contaminants and other stressors to the region that have adversely impacted valued aquatic and marine organisms, water quality and quantity, and ecological services.

Today, land use in the Central Valley is predominantly agricultural and though it comprises 1% of farmland in the United States, it produces 25% of the food in the United States (**Figure 3**) (Livingston 2015). It also provides critical habitat to fish and waterfowl, as well as supports growing urban development.

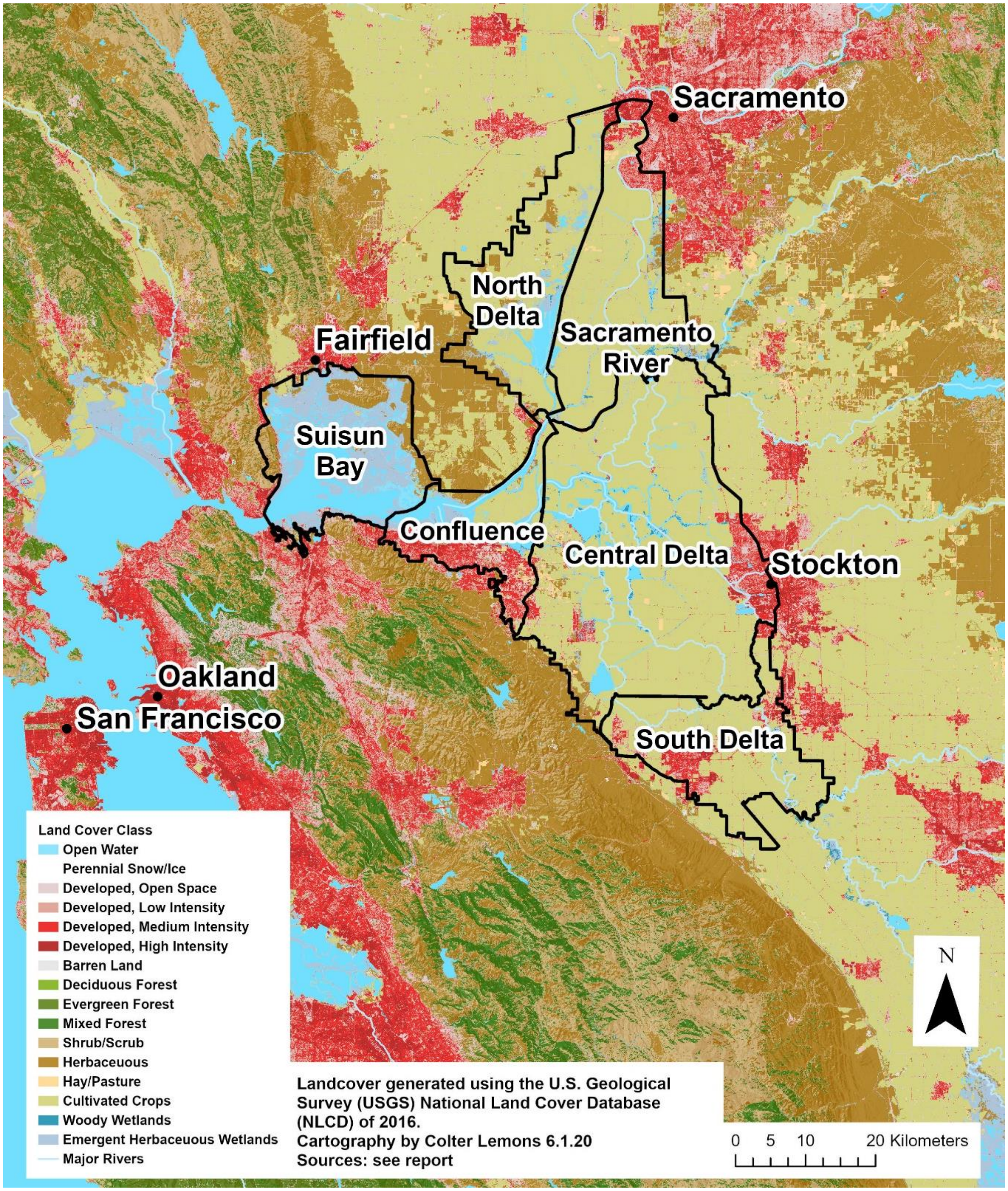


Figure 3. Land cover in the study area and the risk regions.

The Delta region of the Central Valley includes approximately 2,023 km^2 of waterways, levees, and farmed lands extending over five counties: Solano, Yolo, Sacramento, San Joaquin, and Contra Costa (Delta Protection Commission 2010). Waterways comprise of more than 1,609 km of rivers and sloughs that transect the region. They provide crucial habitat for aquatic species, as well as for amphibians, reptiles, mammals, and birds in the surrounding watershed.

The Delta is also a very popular destination site for recreational activities, including fishing, boating, hunting, swimming, and hiking (Delta Protection Commission 2010).

Zoning within the Delta region is predominantly for agriculture and related activities followed by wildlife habitat, and public facilities, with limited areas for commercial, industrial, and rural residential development (Delta Protection Commission 2010). The two Delta ports at Sacramento and Stockton also own hundreds of kilometers of land along their respective shipping channels, of which some are used for dredge material disposal, as well as for habitat mitigation sites (Delta Protection Commission 2010).

Most of the urban development in the region is occurring around the periphery of the Delta. Demand for additional developable land to meet growing residential and commercial needs has resulted in the loss of agricultural lands (Delta Protection Commission 2010). Impacts due to land use practices in the region, however, are still primarily from agriculture and agriculturally supported commercial and industrial uses, followed by urban development and historical mining activities.

Other sources of stressors include NPDES (National Pollutant Discharge Elimination System) facilities, primarily municipal wastewater treatment plants, as well as some industrial and commercial facilities that are permitted to discharge pollutants into waterways. Most of the municipal wastewater plants are located around the periphery of the Delta where most urban development is located (**Figure 4**). Discharges include organic matter, as well as metals and organic contaminants.

Additional sources include the Sacramento and Stockton Shipping Channels, and the Suisun Bay Reserve Fleet that generate chemical contaminants including antifouling agents, paint, metals, and petroleum fuels to the water column and sediments, as well as impacts to fish from lights and engine noise, and to shorelines from wake-generated turbulence. Associated with keeping shipping channels open is ongoing dredging operations as well that cause loss of sediment habitat for benthic macroinvertebrates and fish spawning habitat.

Other natural sources of stressors not addressed in this phase of the ecological risk assessment were floods, sea level rise from climate change, droughts, and saltwater intrusions.

Stressors

Land Use

Stressors generated by agricultural land use practices that are transported via stormwater runoff and irrigation drainage to impact the surrounding land and water resources include a plethora of chemical contaminants to control pests, nitrates and phosphates from fertilizers to increase crop production, soil particles from erosion due to plowing, wind, and erosional processes, and groundwater depletions resulting in land subsidence and saltwater intrusions.

Stressors associated with urbanized areas include metals, particles, pesticides, pet waste, and other organic materials that are transported into the surrounding watershed via untreated stormwater runoff from impervious (roofs, roads, driveways) and semi-pervious (lawns, compacted soils) surfaces.

Commercial and industrial sourced stressors are regulated under the NPDES program however, they have permits that allow them to discharge organic and inorganic pollutants into the environment.

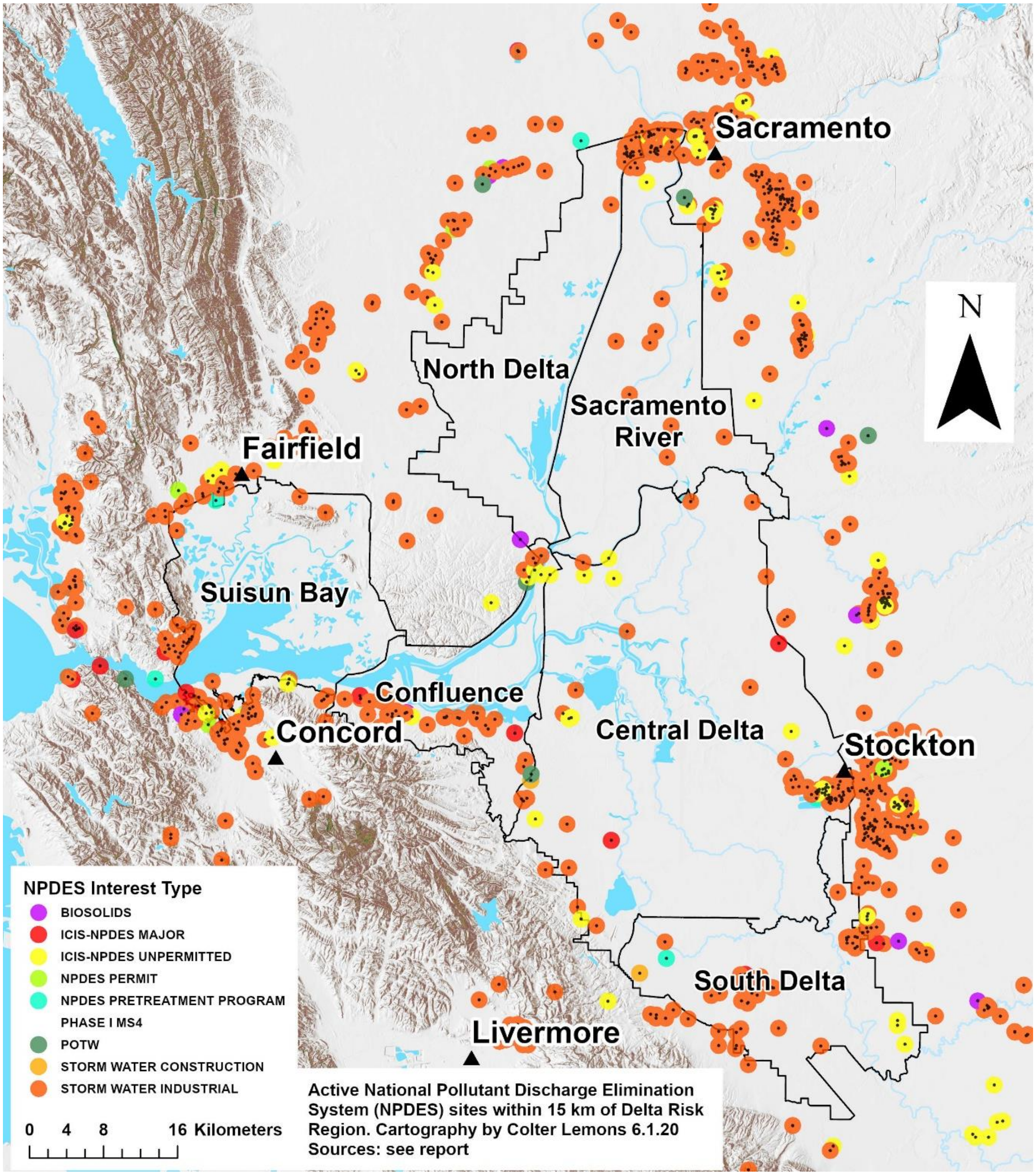


Figure 4. Location of NPDES permitted facilities in the study area.

Pesticides
In 2017, more than 93 million kilograms of pesticides were applied in California, with 92% used for production agriculture, 1% for post-harvest treatment, 1.7% for structural pest control, 0.8% for landscape maintenance, and 5.1% for all other non-agricultural applications (CDPR 2020). The highest use of pesticides was in the San Joaquin valley for agricultural production (CDPR 2020). According to the California Department of Pesticide Regulation (CDPR) (2020), pesticides with both fungicidal and insecticidal properties (e.g., sulfur) had the highest use in 2017. Insecticides, fumigants, herbicides, fungicides, and others (rodenticides, molluscicides, algaecides, repellents, antimicrobials, antifoulants, disinfectants, and biocides) and fumigants followed in use (CDPR 2020).

When applied, many of these types of pesticides may be present on soils and plants where they can be easily transported by wind, rain, or irrigation water into soils, surface waters, and groundwater. The chemical properties of the pesticides will determine whether it dissolves in water to be more bioavailable, absorb in or adsorb on suspended particles, bed sediments, or organic matter, or are readily transported across cellular membranes to elicit an adverse effect.

The risks posed by these different types of pesticides to non-target organisms will depend on the amounts used and the toxicity of the active ingredient in the specific pesticide formulation. For example, sulfur, petroleum and mineral oils, 1,3-dichloropropene, glyphosate, and potassium N-methyldithiocarbamate were the active ingredients used in the highest amount in 2017 (CDPR 2020). The active ingredients used to treat the highest cumulative area, however were glyphosate, sulfur, petroleum and mineral oils, abamectin, and copper (CDPR 2020). Abamectin, lambda-cyhalothrin, and chlorantraniliprole were not used, however in high amounts, have low toxicity to mammals and fish, and are not considered a significant risk. Conversely, some high use, higher toxicity organophosphate and neonicotinoid insecticides such as chlorpyrifos, malathion, and imidacloprid, as well as herbicides glyphosate and propanil, and fungicides copper and sulfur do pose risks (Michael Ensminger, personal communication, June 10. 2020).

Due to the prolonged use of these types of pesticides in the USFE agricultural and urban regions, many are detected in the water, soils, and sediments. Some chemicals have been detected at concentrations that can cause deleterious effects on non-target organisms. Based on guidance from the Metropolitan Water District of California and the California Department of Pesticide Regulation select groups of pesticides and specific chemicals were identified for consideration in this risk assessment of the USFE. A description of their physiochemical properties, intended uses, mode of action, and potential non-target toxicological effects follows.

<u>*Organochlorine Insecticides*</u>
Organochlorine pesticides (OCs) are ubiquitous, persistent, and broad-use chemicals that are structurally classified as having one or more covalently bonded chlorine molecules on aromatic hydrocarbon rings (Ali et al. 2014). DDT (dichlorodiphenyltrichloroethane) is a potent and persistent OC insecticide, along with its metabolites DDD (dichlorodiphenyldichloroethane) and DDE (dichlorodiphenyldichloroethylene). In the USFE study area, they are still detected, though DDT was banned in the United States in 1972. Other OCs detected in each of the study’s risk regions include endosulfan, exosulfan, and endosulfan sulfate (CDPR 2019).

Organochlorine insecticides target the nervous system of organisms and interfere with nerve impulses by depolarizing nerve membranes or inhibiting the gamma-aminobutyric acid (GABA) gated chloride channel complex (Zaffer et al. 2016). The result is uncontrolled nerve impulses that cause tremors, arrhythmias, and death (Zaffer et al. 2016). Some OCs like DDT are also endocrine disruptors, targeting hormone receptors. They are highly lipid soluble and due to their persistence, are bioaccumulative, resulting in deleterious effects throughout trophic food webs (Zaffer et al. 2016).

Organophosphate Insecticides
Organophosphate insecticides (OPs) are acutely toxic, broad-use pesticides that contain a central phosphate group and ester groups (Greaves and Letcher 2017). OPs largely replaced OC compounds due to their relatively low persistence in the environment and became the most widely used insecticides, primarily in agriculture, as well as in urban/residential areas and medical practices (USEPA, 2013). In 2001 the U.S. EPA banned most residential uses of them due to their acute and subacute toxicity to humans, as well as non-target organisms in the environment. They are still permitted for agricultural use OPs that were detected in all of the risk regions were diazinon, malathion, dichlorvos, and chlorpyrifos (CDPR 2019).

OPs function through the irreversible inhibition of the acetylcholinesterase enzyme (AChE) in the synapses between neurons, preventing it from breaking down acetylcholine (ACh) neurotransmitters. As a result, nerve impulses continue to be transmitted across synapses causing uncontrolled muscle spasms, paralysis, and death (USEPA 2013, Greaves and Letcher 2017, Adeyinka and Pierre 2020).

Pyrethroids
Pyrethroid insecticides are a group of synthetic chemicals similar in structure to the natural pesticide pyrethrum produced by chrysanthemum flowers (IDPH 2007). They are widely used in agriculture and constitute the majority of commercial insecticides used in urban environments to control insects including mosquitos, ants, and spiders, as well as lice and fleas on pets.

Pyrethroids interfere with the voltage-gated sodium channels in target insect nerve membranes by preventing them from closing. As a result, electrical signals continue to propagate along the nerve causing paralysis and then death of the organism (Soderlund 2012). Voltage-gated sodium channels are highly conserved between insects and mammals and, as a result pyrethroids can also be toxic to non-target organisms including invertebrates and humans (Soderlund 2010). Ligocki et al. (2019) also found that pyrethroids cause mortality to and behavioral effects on fish.

Pyrethroid insecticide use has increased dramatically in California over the last 20 years and as of 2009, totaled 161,025 kg/year for agricultural uses and 287,187 kg for all other uses (Weston and Lydy 2009). Concurrent with its increased use, declines in several pelagic fish populations in the Delta have reached record lows (Weston and Holmes 2007). Specific fish species included Delta smelt, striped bass, longfin smelt, and threadfin shad (Weston and Holmes 2007). Initial studies found pyrethroids in surface waters at concentrations toxic to aquatic life. Weston et al. (2004, 2005) also found one in five sediment samples from agricultural dominated waterbodies and two of three samples from urban dominated waterbodies contained pyrethroid concentrations at acutely toxic levels. Eight commonly used pyrethroid insecticides were identified in the study area (Western and Holmes 2007) and prioritized for future monitoring and analyses: bifenthrin, cyfluthrin, cupermethrin, esfenvalerate, lambda-cyhalothrin, deltamethrin, fenpropathrin, and permethrin.

Since then, a number of studies have investigated the exposure-response relationships between various pyrethroid compounds and Delta smelt (Connon et al. 2009, Jeffries et al.

2015), whereas others have focused on fathead minnow (Floyd et al. 2008, Heath et al. 1994), and various macroinvertebrate species including the epibenthic amphipod *Hyalella azteca* (Amweg et al. 2005, Reynaldi and Liess 2005, Hasenbein et al. 2015a, 2015b). The compounds most commonly studied in those toxicological studies included permethrin, bifenthrin, lambda-cyhalothrin, deltamethrin, esfenvalerate, and cyfluthrin. Many of these chemicals have been detected in water and sediment samples collected in the study area.

Neonicotinoids - Imidacloprid
Imidacloprid is the most commonly used neonicotinoid insecticide in both agriculture and non-agriculture applications. It is applied to over 100 different agricultural crops and is also used for pest control in commercial and residential areas on landscapes (gardens, turf, trees) structures, and as a spot-on flea control for pets (Gervais et al. 2010). It is a systemic broad-spectrum insecticide that targets sucking and chewing insect pests. It can be applied as a spray or seed treatment, or injected into trees or soil. When applied to plants, it is translocated rapidly throughout the tissues to the leaves, fruit, pollen, and nectar of the plant (Wu-Smart and Spivak 2016).

Imidacloprid functions by binding irreversibly to specific insect nicotinic acetylcholine receptors to interfere with the transmission of signals in the central nervous system (NPIC 2020a). Once binding occurs, nerve impulses are immediately propagated at first along the nerve, followed by failure of the neuron to propagate any signal (NPIC 2020a) leading to paralysis and death (Buckingham et al. 1997). As a systemic insecticide, imidacloprid impacts not only pest insects, but non-target beneficial insects as well, including honeybees, beetles, and wasps (Wu-Smart and Spivak 2016). It is also slightly toxic to some freshwater fish and algae, as well as highly toxic to macroinvertebrates, and algae (NPIC 2020a). It can also cause sublethal effects in *Daphnia magna*, resulting in impaired predator response, growth, and reproduction (NPIC 2020a).

Fipronil
Fipronil is a broad use insecticide used for controlling pests in agricultural crops and seeds, as well as in urban areas (gardens, turf, homes and on pets). In California, it is for non-agricultural uses only, predominantly for structural applications (Dan Wang, personal communication June 9, 2020, Michael Ensminger, personal communication June 10, 2020). It disrupts the insect's central nervous system by blocking GABA-gated and glutamate-gated chloride (Glu-Cl) channels (Raymond-Delpech et al. 2005). Hyperexcitation of the nerves and muscles occurs and leads to muscle paralysis and death. It is highly toxic to marine and freshwater fish and macroinvertebrates, some bird species and honeybees (NPIC 2020b).

Imidacloprid and fipronil (and its degradates fipronil sulfone, sulfide, desulfinyl, and amide) were recently detected in the influents and effluents of the SFE's municipal wastewater treatment plants (Sadaria et al. 2017). The source was linked to household applications of flea and tick treatments on pets. Analyses of raw and treated sewage found that regardless of treatment technologies, 93 ± 17% of imidacloprid and 65 ± 11% total fiproles remained in the wastewater discharged into the estuary (Sadaria et al. 2017). Fipronil and its degradates have been flagged as chemical of moderate concern in the SFE due to their high toxicity to fish, crustaceans, and invertebrates, and presence in concentrations in sediments that are toxic to aquatic organisms (Sadaria et al. 2017).

Herbicides
Herbicides are chemicals formulated to control unwanted plants by disrupting specific biochemical processes in plants. They may affect grasses, broadleaf or sedge plants differentially, however those used routinely that have the same mode of action may account for the development of weed resistance to them. To prevent or delay resistance, multiple herbicides with different modes of action may be used within a given year or alternated over several years.

Frequent herbicide use can result in contamination of surface waters via stormwater and irrigation water runoff. In the Central Valley, high use herbicides such as diuron, hexazinone, simazine, propanil, thiobencarb, paraquat, oxyfluorfen, 2,4-D, and glyphosate can be detected in the Delta (Kuivila et al. 1999, WSSA 2020). Several of these (atrazine, diuron, linuron, oxyfluorfen, paraquat dichloride, thiobencarb) were detected at concentrations that exceed USEPA Aquatic Life Benchmarks (Kuivila et al. 1999, CDPR 2019, USEPA 2020a).

These commonly used and detected herbicides have several distinct modes of action, such as inhibiting photosynthesis, disrupting membranes, inhibiting amino acid synthesis, or interfering with cell growth and elongation. Herbicides that inhibit photosynthesis (diuron, hexazinone, propanil, and simazine) are of particular concern in aquatic systems for their potential to inhibit phytoplankton primary productivity, alter phytoplankton species composition, and cause deleterious impacts on aquatic food webs (Kuivila et al. 1999). Kuivila et al. (1999) found that concentrations of photosynthetic inhibitor herbicides in the Delta varied spatially and temporally. Highest concentrations are detected in May through June, with spikes reoccurring in November. These times coincide with highest reported use, and in May and June, with the highest biological productivity.

Fungicides
Fungicides kill or prevent the growth of fungi and their spores that damage plants, such as rusts, mildews, and blights, as well as control mold and mildew (NPIC 2020c). Their mode of action depends on their chemical properties as follows: 1) Contact fungicides remain on the outside of the plant and protect it from new infection, 2) Localized penetrants form a protective barrier on the plant’s surface and permeate into the plant tissue where applied to provide some curative benefits, 3) Acropetal penetrants form a protective barrier, permeate into the plant, and are transported up the xylem into the plant tissues. These protect the plant, new growth, and provide good curative activity, and 4) Systemic penetrants provide the same protections as the acropetal penetrants, but are transported both up the xylem and down the phloem throughout the plant (Jung et al. 2010).

In the Central Valley, the active ingredients applied to the greatest area in 2017 were copper, followed by azoxystrobin, pyraclostrobin, fluopyram, and propiconazole (CDPR 2020). Copper acts by permeating the plant tissues and deactivating fungal enzyme systems, as well as preventing fungal spores from germinating. Azoxystrobin, pyraclostrobin, fluopyram, and propiconazole are acropetal penetrants, however they vary in terms of their target site of action and are classified using the Fungicide Resistance Action Committee (FRAC) code (IPMF 2020).

Azoxystrobin and pyraclostrobin are FRAC 11 fungicides that inhibit fungal mitochondrial respiration by binding to the cytochrome b complex III at the Q_0 site (IPMF 2020). Fluorpryam is a FRAC 7 fungicide that inhibits complex II of fungal mitochondrial respiration by binding to succinate dehydrogenase in the mitochondria and blocking electron transport (IPMF 2020). Propiconazole is a FRAC 3 demethylation inhibitor fungicide. They work by inhibiting the biosynthesis of ergosterol which is a major component of the plasma membrane of certain fungi and needed for fungal growth (IPMF 2020). Several of the fungicides detected in water and suspended sediment samples in the study area included azoxystrobin (FRAC 11), boscalid, fluopyram, and fluxapyroxad (FRAC 7), carbendazim (FRAC 1), fenhexamid (FRAC 17), and propiconazole FRAC 3).

Inorganic (Metal) Contaminants
The legacy of the Gold Rush and mining in the Sierra Nevada mountains of northern California in the 1850s was the mobilization of metal contaminants, as well as sediment and debris throughout the Delta region. It is estimated 1.2 billion cubic meters of landscape in the Sierra Nevada mountains were hydraulically mined during that time and another 2.98 billion cubic meters of the landscape were affected by dredging operations (Regional San 2020).

Cadmium, Copper, and Zinc
Acid mine drainage containing cadmium, copper, and zinc from abandoned mines, was transported to the headwaters of the many tributaries of the Sacramento and San Joaquin rivers. Elevated concentrations of these metals were found to exceed water quality standards to protect aquatic life and were found to cause fish kills and population declines, especially in the upper Sacramento River watershed (SRTMDL Unit 2002). Subsequently, a TMDL (total maximum daily load) study was conducted to determine the maximum load a waterbody can receive and still meet water quality standards. It was completed in 2002. Of these metal contaminants, however, mercury was of greater ecological and human health concern.

Mercury and Methylmercury Contamination
Mercury (Hg) was actively mined in the California Coastal Range starting in the 1850s and used in hydraulic gold mining during the Gold Rush, as well as in dredge tailings operations (Regional San 2020). At its peak, there were over 200 known mercury mines that produced over 91 million kilograms of mercury over the last 130 years, of which an estimated 3.6 million kilograms of mercury ended up in the environment (Regional San 2020). The high organic content of soils and sediments in the Delta, as well as irrigation resulted in facilitating the production of methylmercury (MeHg) and its transport via drainage water into the channels. A completed Delta Methylmercury TMDL approved in 2011, identified sources of MeHg in wetlands, open water, inputs from tributaries, atmospheric wet deposition, NPDES facilities, agricultural drainage from island farms, and urban runoff (Wood et al. 2010, CVWB 2011).

The toxicity of Hg varies depending on its form and speciation. Cells absorb inorganic Hg slowly, making its toxicity less than organic forms. MeHg is the most toxic form to mammals, fish, and birds and the primary route of exposure to these organisms is via diet (Scheuhammer et al. 2007). It also bioaccumulates and biomagnifies in food webs, making it environmentally persistent even after the primary mercury source is eliminated (Scheuhammer et al. 2007, Flanders et al. 2010). MeHg can cause a wide range of deleterious effects in organisms including reduced hatching success and diminished egg health in avian species, as well as altered growth, survival and embryo viability in fish (Scheuhammer et al. 2007).

Selenium
Selenium contamination in the San Joaquin watershed resulted from weathering of marine sedimentary rocks in the California Coast Range, as well as from irrigating soils derived from rocks of marine origin that were high in selenium (Presser et al. 1994, RWQCB 2000). The selenium leached into the shallow groundwater aquifers where it became concentrated. Farmers periodically drained the groundwater to prevent the salts within it from reaching the active root zones of their crops. The water was discharged into nearby wetland supply

channels, other waterbodies in the watershed, and downstream resulting in elevated selenium concentrations deleterious to aquatic life (RWQCB 2000). A TMDL study was conducted and it was determined that about 121 km of wetland supply channels and 250 km^2 of wetland marshes were contaminated (RWQCB 2000). As a result of the TMDL, the discharge of subsurface drainage water into wetland supply channels was prohibited.

Similar to mercury, selenium is highly bioaccumulative and can be mobilized through the food web to cause acute and chronic toxicity in fish and wildlife (RWQCB 2000). Inorganic forms of selenium react with thiol compounds in tissues to generate reactive oxygen species that induces single and double strand breaks in DNA, damages RNA and proteins, and cause cell death.

Water Quality Parameters

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. Semi-diurnal tides 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. To prevent saltwater incursions into the Delta, 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).

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). The LSZ area with 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 zone has been strongly associated with several critical life stages of the Delta smelt (Moyle et al. 2016, Bennett 2005, Feyrer et al. 2007, Sommer et al. 2011). Upstream migration of adult Delta smelt generally occurs during winter and is associated with “first flush” events to their 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. See **Appendix B** for more information.

Nutrients

Phosphorus and nitrogen are the two drivers of biological productivity in waterbodies. The more nutrients that are available, the greater the rate of productivity. The higher the rate of productivity, the faster water quality deteriorates. When microorganisms and macrophytes rapidly utilize the nutrients to grow, they consume dissolved oxygen in the water column that can lead to anoxic conditions that kill fish and other aquatic organisms. Elevated biological productivity can also cause huge daily variations in water chemistry, not only in dissolved oxygen concentrations, but also in alkalinity and pH as well. These conditions favor more tolerant, undesirable and invasive species.

Excess nutrients can also cause shifts in phytoplankton, periphyton, and macrophyte community structures by enabling invasive or undesirable species to outcompete native species. This can lead to algal blooms, taste and odor issues in drinking water, clog water filtration systems, form huge decomposing mats on the surfaces of waterbodies, and produce toxins that can harm or kill wildlife, waterfowl, pets, and humans.

In the Delta, the main sources of nutrients are from agricultural runoff and effluents from municipal wastewater treatment plants (Chappelle 2015). Strategies to address these sources include upgrades to current wastewater treatment plants and wetland restoration to help sequester the excess nutrients. The Delta Nutrient Research Plan approved in July 2018 outlines actions that will be taken in the coming years to help address these stressors to the Delta ecosystem.

Turbidity

Sediment transport is a dynamic process within the Delta. Tides, waves, and freshwater inflows, as well as the slope, elevation, and morphology of the streambeds, sub-basins, and their watersheds in the Delta affect sediment deposition and erosional processes. These processes in turn will affect concentrations of toxic substances that adsorb and absorb to suspended sediment particles, as well as the quantity and quality of habitat for fish and benthic organisms, and amount of light available to phytoplankton and submerged macrophytes for photosynthesis.

Delta smelt larvae require some amount of turbidity to see their prey (Hassenbein et al. 2016) and Ferrari et al. (2014) found that higher turbidity also increased their survival rates by reducing the predation. Conversely, Chinook salmon and other species require less turbidity that otherwise can abrade gills, clog membranes, and smother organisms. As with many ecological systems, conflicting or competing needs for ecological services can challenge resource managers to find solutions.

Temperature

Water temperature within the Delta is influenced by riverine inputs, atmospheric forcing, and tidal dispersion (Monismith et al. 2008, Wagner et al. 2011). Wagner et al. (2011) found that long-term trends in water temperatures within the Delta were primarily driven by air temperatures, whereas short-term temperature flux was significantly impacted by peaks in riverine inputs. Delta smelt and Chinook salmon have shown sensitivity to thermal ranges during various life stages that coincide with seasonal variations in water temperatures. For example, water temperatures within the Delta influences the timing of Delta smelt spawning (Bennet 2005). The thermal tolerance range for Delta smelt was found to be between 7.5±1.2 °C and 25.4±1.7 °C and the thermal maxima for Chinook salmon smolts was 26-27°C (Swanson et al. 2000). Elevated water temperatures have been found to increase rates of predation on out-migrating juvenile Chinook salmon and other forage fish (Michel et al. 2015). Water temperatures and season also play an important role in determining the assemblages and abundance of macroinvertebrates in streams (Hawkins et al. 1997).

Water Flow Dynamics

Delta Inputs

The hydrodynamics of the Delta have been highly altered due to the construction of a complex network of channels, levees, dikes, and islands for agricultural, navigational/commercial, and urban uses (Monsen et al. 2007). The primary hydrologic drivers within the Delta are: 1) tides and 2) riverine inputs from the Sacramento and San Joaquin rivers, their tributaries, and their watersheds. Forty percent of the land area of California drains into waterways that discharge into the Delta via runoff. In total, the Delta receives about 75% of its water from the Sacramento River and its tributaries, approximately 15% from the San Joaquin River system, and about 10% from precipitation and from the Delta's eastern tributaries (CDWR and CDWF 2015). To a lesser extent, other hydrologic drivers include: 3) flood control devices, 4) local municipal and agricultural inputs and exports, and 5) meteorological.

The flows through the Delta are dominated by water export and containment operations. Dam operations reduce flows in the winter when precipitation and snowmelt result in higher freshwater stream flows into the Delta. Conversely, dam operations increase flows in the summer when water demand for irrigation, drinking water, and fish passage is higher. The primary goals of flow management within the Delta is to reduce salinity intrusion, reduce flooding by mitigating peak flow events within the Central Valley, and supply fresh water for agricultural and municipal uses when it is needed most (CDWR and CDWF 2015).

In 1997 there were at least 2,209 water diversions within the legal Delta boundary and at least 366 water diversions within Suisun Marsh (Herren and Kawasaki 2001). The large-scale municipal, state, and federal pumping plants are located in the southern Delta and include: 1) the Contra Costa Water District's Contra Costa Canal, Old River, and Middle River pumping stations, 2) the State of California's State Water Project's (SWP) Banks Pumping Plant, and 3) the Federal government's Central Valley Project (CVP) Jones Pumping Plant. The SWP and CVP large-scale pumping stations can divert enough water to effectively reverse water flows in the southern to central Delta region. Lastly, the Berkshire Slough pump operates in the northern region near the Cache Slough complex (CDWR and CDWF 2015).

Seasonal Diversions

Also complicating Delta flow dynamics are the seasonally operated hydraulic flow structures that include the Delta Cross Channel (DCC), and four southern Delta temporary barriers. The DCC on the Sacramento River diverts water into the Mokelumne River. The DCC directs flow from the Sacramento River to the southern Delta pumps via the central Delta (Monsen et al. 2007). Typically, the DCC gates are kept open to facilitate freshwater flows across the Delta. During late summer to autumn the DCC is closed to encourage migrating salmonids to stay within the main branches of the Sacramento River. Closing the DCC gates also corresponds to seasonal decreases in river flow rates and increases in salinity intrusion (CDWR and CDWF 2015).

The South Delta Temporary Barriers project (SDTB) has four locations in the southern Delta where seasonal barriers to flow and or fish migrations can be constructed. These temporary barriers are located at the head of the Old River, the OHR station at Tracy, the Middle River, and the Grant Line Canal. These temporary barriers consist of rock placements within the channel to increase upstream water levels and to act as a barrier to fish passage (CDWR and CDWF 2015).

Other diversion projects include the placement of temporary barriers, such as at the head of the Old River. This barrier is used to keep migrating salmonids within the San Joaquin River in the spring, as well as to keep flow rates in the Stockton Deep Water Ship Channel elevated in the autumn to reduce occurrences of hypoxia. The Delta, however, is such a highly managed system that these regulatory actions can sometimes be in conflict. Actions aimed at maintaining water quality standards, such as rates of salinity intrusion low, may at the same time increase the likelihood that migrating fish reach the central Delta where survivorship is generally decreased (Monsen et al. 2007).

Mixing

The primary riverine sources of water into the Delta are the Sacramento River from the north and the San Joaquin River from the south (Monsen et al. 2007). The eastern tributaries that provide riverine inputs to a lesser degree include the Consumnes, Mokelumne, and Merced Rivers, and Dry Creek. The central Delta acts as a mixing zone for these rivers and tributaries. The water of the San Joaquin River receives more agricultural runoff and is less desirable for water exports than that of the Sacramento River. Conversely, the Sacramento River provides a source of good quality, low conductivity water that can be diverted through the Delta to the large-scale pumping plants in the southern Delta for distribution to State, local, and federal municipalities. Diversion of water from the Sacramento River through the interior of the Delta can cause rapid changes in water quality characteristics and flushing times as the ratio of riverine inputs changes (Monsen et al. 2007). For example, when the CVP and SWP pumping plants are operating at high capacity, water quality parameters in the Old and Middle Rivers of the Southern Delta become more similar to those in the Sacramento River.

Habitat Selection and Descriptions

Habitats included in the ecological risk assessment are those specifically associated with those utilized by the assessment endpoint species. In this ERA, habitats specific to Delta smelt, Chinook salmon, and macroinvertebrate communities were identified: marshes, sloughs, open channels including riffles and pools of rivers, sediments, and aquatic vegetation (rooted - submerged and emergent, and floating). These habitats may be used by all the endpoints depending on their life stage, time of year, and environmental conditions and are therefore not unique to each for providing food, water, shelter, and space to survive and thrive.

Marshes

Marshes are a type of wetland that is nutrient-rich and dominated by herbaceous species of plants. They are found around the periphery of lakes and streams, forming a transition zone between aquatic and terrestrial ecosystems. Brackish marshes are the dominant type of marsh in the study area and are tidally influenced by coastal water inputs from the west, as well as by freshwater inputs from the Sacramento and San Joaquin rivers from the east. Location and salinity are the primary factors influencing the range, scope, and diversity of the species that utilize these marshes. Larval and juvenile fish use the edges of marshes to feed and avoid predation by larger fish and is therefore crucial habitat for the Delta smelt and Chinook salmon endpoints. They also provide habitat and nutrients for benthic and epifaunal macroinvertebrate communities, as well as larval and immature insect species.

Sloughs

Sloughs are a type of tidal wetland, usually a swamp, shallow lake, or side channel and are often a backwater to a larger body of water. The water is usually stagnant or slow flowing. Open water sloughs have both submerged and floating vegetation that is utilized by diverse species of fish to prey on zooplankton, epifaunal macroinvertebrates, worms, and mollusks.

Open Channels/Rivers

Natural channels provide fish with areas of refuge and feeding in the pools and riffle areas of the stream bed, as well as routes by which to in- and out-migrate in the study area. Larger juvenile and adult fish utilize these open waterways, however residence time in them is transitory depending on season, temperature, flow, and water quality conditions. Chinook salmon utilize this habitat, as well as other predatory fish. Eggs deposited by fish spawning in the headwaters of the rivers will be carried downstream to entrapment areas (marshes, sloughs) where they will hatch and feed in the nutrient-rich habitats on zooplankton and other macroinvertebrates.

Sediments
Sediments in the study area are predominantly soft bottom and consist primarily of mud (Cohen 2000). Fine particulate matter in runoff from the surrounding agricultural lands, as well as inputs from the Sacramento and San Joaquin rivers and their tributaries discharging into the Delta are the major sources. Worms, clams, crabs, anemones, amphipods, snails, and other benthic organisms predominate. These organisms serve as prey to bottom-feeding fish that, in turn, serve as prey to higher trophic level predators including fish, birds, and small mammals. This habitat is present in marshes, sloughs, and open channels.

Aquatic Macrophyte Vegetation (rooted and floating)
Aquatic plants create important habitat and food sources for fish, waterfowl, and wildlife. They also play key roles in filtering or trapping suspended particles and absorbing nutrients from runoff, as well as in providing substrates for periphytic and insect larvae to attach.

Rooted emergent plants are found near the water's edge and along the banks of rivers. These vascular plants often have deep, dense roots that stabilize the shallow soils at the water's edge. They also provide important habitat for birds, insects, and other animals living near water.

Floating plants have leaves and flowers that float on the water surface. Their roots may be attached in the substrate or floating in the water column. They are generally found in water less than 1.5 m deep. Though several species are invasive in the Delta, studies have found that they do provide shelter and food for macroinvertebrates in the water column.

Submersed macrophytes are also rooted to the bottom, however their leaves grow entirely underwater. They tend to grow to greater depths than emergent and floating plants, dependent on the water clarity. Submersed macrophytes create valuable habitat for fish and small invertebrates, as well as food for ducks and aquatic mammals. When they become too abundant, they may interfere with boat propellers, modify flows in moving water, and may cause large day to night swings in dissolved oxygen and pH.

Endpoints

Chinook Salmon (out-migrating juvenile abundance)
There are four runs of Chinook salmon (*Oncorhynchus tshawytscha*) that navigate through the waters of the USFE to reach their natal spawning grounds in the watersheds throughout the Central Valley (Yoshiyama et al. 1998). The runs are named based on when they migrate upstream: spring-, fall-, late-fall-, and winter-run. These are further sub-divided into Sacramento River and San Joaquin River runs. Although general timing of runs may be similar in the two rivers, the larger basin and hydrology of the Sacramento River watershed play an important role in determining the specific life-history traits of the different Chinook salmon runs there. Seasonal influences also affect each run and sub-run differently (Yoshiyama et al. 1998).

Notable declines in Central Valley salmon have been described since 1851, with the first protective fisheries legislature being recommended in 1871 (Yoshiyama et al. 1998). Spawning habitat for each run has been reduced due to construction of dams and highly altered flow regimes to the Sacramento and San Joaquin Rivers and their tributaries over the years (Yoshiyama et al. 1998). Historically, the major streams that constituted the Chinook range in the Sacramento River watershed included (from north to south), the Upper Sacramento, McCloud, Pit, Feather, Yuba, and American Rivers, as well as Battle, Mill, Deer, and Butte creeks. The Chinook range in the San Joaquin watershed was composed of (from south to north) the Upper San Joaquin, Merced, Tuolumne, Stanislaus, Mokelumne, and Consumnes rivers (Yoshiyama et al. 1998).

Delta Smelt Abundance

Delta smelt (*Hypomesus transpacificus*) is a small pelagic fish endemic to the USFE and is listed as an endangered species both statewide and federally (USBR 2019). They live one to two years with most adults completing their life cycle in one year (Moyle et al. 2016). The population is thought to be panmictic (randomly mating) because of the connectivity of the Delta, the historical size of the population, and because most spawning likely occurs in the same location (Fisch et al. 2011). The historical distribution of the Delta smelt was largely associated with LSZ regions ranging from San Pablo Bay and Suisun Marsh to the upper reaches of the Delta. Since Delta smelt have a relatively short life-span (1-2 years), the distribution of individuals is highly dependent on season and life-stage, though some individuals have been found year-round in the Cache Slough Complex (Moyle et al. 2016).

Four surveys take place in the Delta each year that focus on different sizes of the fish to provide information about varying life stages. In general, adults migrate upstream in the winter to spawn in freshwater. The life-cycle progress from egg to the larval stage occurs in March to May, and to the juvenile stage in June to July. The older life stages then move into the brackish waters of Suisun Bay and Suisun Marsh to rear and grow into adulthood (Moyle et al. 2016, USBR 2019). Adults can grow up to 120 mm (standard length). Delta smelt are considered semi-anadromous, but year-to-year distributions are heavily influenced by regional hydrodynamics (Moyle et al. 2016). Annual abundance estimates are published by the U.S. Fish and Wildlife (USFW 2020).

The ecological niche of Delta smelt is described by interactions of temperature, salinity, turbidity, and predation (Moyle et al. 2016). Most wild-caught Delta smelt are found in water <22°C though lab-reared fish can tolerate temperatures to 28°C (Nobriega et al. 2008, Komoroske et al. 2014). They are primarily found in brackish to fresh water with salinities ranging from 0-7 practical salinity units (PSU) (Bennett et al. 2005; Moyle et al. 2016). Turbidity and “first flush” riverine events are correlated with fish migration events. Trawl surveys rarely find Delta smelt at turbidities less than 18 NTU (Brown et al. 2013). The turbidity helps the larvae see their prey and can also increase their survival rates by reducing the effectiveness of visual predation (Ferrari et al. 2014, Hasenbein et al. 2016).

Macroinvertebrate Community Structure

Macroinvertebrates are commonly used as indicators of the biological conditions in aquatic and marine ecosystems. They play a key role in planktonic and detrital based food webs, feeding on algae, bacteria, and other microorganisms, as well as organic matter (particles, leaves, woody debris). They also serve a key role as a food source for other species including insects, birds, and juvenile and adult fish. They occupy every niche in aquatic habitats: the water column (daphnia, copepods) and the sediment (worms, clams, amphipods), as well as attached to rocks, submerged and floating aquatic vegetation, logs, and other submerged debris (snails, insect larvae, beetles). They have limited mobility, are easy to collect and identify, are relatively long-lived (some for over a year) and have varying tolerances to contaminants and water quality conditions, depending on the species. Together, they therefore serve as resident bioindicators of their surrounding environmental conditions.

Several macroinvertebrate community-based metrics have been developed that use taxa richness, diversity, abundance, and composition in a waterbody to provide information on potential chemical contaminants, DO issues, nutrients, and habitat quality and quantity. The metrics used in the study region were based on total taxa richness and EPT (Ephemeroptera – mayfly, Plecoptera – stonefly, and Trichoptera – caddisfly) taxa richness. An assessment of the Sacramento River watershed was conducted from 2000 – 2002 and in the San Joaquin River watershed in 2001 (de Vlaming et al. 2004, 2005). Hartman et al. (2019) conducted a follow-up study of macroinvertebrate communities in the Delta a decade later.

De Vlaming et al. (2005) found that metal concentrations (copper, lead, and zinc), riparian zone quality, total organic carbon (TOC), total nitrogen, and amount of organic wastes were determinants of benthic macroinvertebrate (BMI) communities and biological condition in agriculture dominated waterways (ADWs). Sites with lower concentrations and intact riparian zones had more diverse BMI communities, whereas sites adjacent to the highest intensities of agricultural and urban land uses had the least (de Vlaming et al. 2004). Seasonal differences were also found to have an effect on BMI communities with noticeable declines from spring to fall.

BMI Bioassessment Advantages and Limitations

Over the last two decades these BMI bioassessments have helped to prioritize tidal wetland restoration projects in the Delta and other areas of the USFE. Providing habitat that supports diverse and abundant macroinvertebrate communities, in turn, helps to provide habitat and quality food sources for at-risk fish species, including Delta smelt and Chinook salmon.

De Vlaming et al. (2005) cautioned that it is impossible to establish cause and effect using solely this bioassessment procedure. Furthermore, that caution should be used in interpreting the results due to the small size of the dataset they had and limited water quality data. They emphasized that a combination of physical habitat (in-stream and riparian), hydrology (flow regimes), and water quality factors interact to determine BMI integrity in the Central Valley.

Another metric used is the California Stream Condition Index (CSCI) which is a process that uses macroinvertebrate counts, as well as other types of species to compare streams within the state as to estimate impairment (Mazor et al. 2014). It is based on the classic index of biotic integrity, an index derivation commonly used that has a number of drawbacks in a risk assessment scenario (Rehn et al 2015). However, the collections done in support of the effort do provide insight into the macroinvertebrate community structure in California streams. There are CSCI sites within the Sacramento, Eastside, Central Delta and South Delta risk regions. We plan to use those data in a multivariate analysis similar to that of Hartman et al. (2019).

Data Sources: Criteria, Analyses

A variety of data sources, databases, state and federal government websites, technical reports, and peer-reviewed articles in the scientific literature were consulted to evaluate the quality and quantity of data that could be used in this ERA. Among the data sources consulted were: the Surface Water Database (SURF) (CDPR 2019), the California Environmental Data Exchange Network (CEDEN) datasets (SFEI and ASC 2019), the California Department of Water Resources datasets (CDWR 2020b), monitoring station data, GIS datasets, USGS water gage station's datasets, site specific water temperature data, and NPDES effluent data. More detailed information about data sources can be found in **Appendix C**.

Data relevant to the sources of stressors, stressors, habitats, and assessment endpoints that were identified during meetings with project officers and other stakeholders were prioritized for consideration. Data specific to the assessment endpoints, Chinook salmon (*Oncorhynchus tshawytscha*), Delta smelt (*Hypomesus transpacificus*), and macroinvertebrate community structure, as well as for individual and classes of chemical contaminants in each risk region were evaluated for quality and quantity. Toxicological data specific to the organisms or their surrogates to the selected classes of chemicals were derived from both site-specific data and the scientific literature. This evaluation was key in preparing the final Conceptual Model that will be used to construct the BN-RRM models in Phase 2 of this study.

Pesticide Data

The SURF (https://www.cdpr.ca.gov/docs/emon/surfwtr/surfcont.htm) and CEDEN (https://ceden.waterboards.ca.gov/AdvancedQueryTool) datasets contain data on the presence or absence of pesticides in California's surface waters and sediments (CDPR 2019, SFEI and ASC 2019). Aqueous pesticide data from 2010 to 2020 were extracted from both databases and then sorted by the sampling site location to identify chemical contaminants and their concentrations in each risk region. The 10-year aqueous concentration data for each chemical in each risk region was then compared to USEPA's Office of Pesticide Program's Aquatic Life Benchmarks for Freshwater Species (USEPA 2020a). The benchmarks are based on aquatic toxicity tests from scientific studies and used to assess the effects of chemical contaminants in surface waters on aquatic life. The benchmarks are typically based on the most sensitive of the available aquatic toxicity data for each taxon and are estimates of the concentrations below which pesticides are not expected to represent a risk of concern for aquatic life (USEPA 2020a). Those chemicals that exceeded the benchmark concentrations were flagged as having a higher probability of causing adverse effects on aquatic organisms in that risk region. Those chemicals therefore will be considered for inclusion on the BN-RRM risk assessment in Phase 2 of this study. In Year 2, sediment data will also be extracted for each risk region and analyzed for exceedances to sediment quality criteria.

Water Quality Data

The CEDEN and CDWR datasets contain information about California's surface waters including water quality, aquatic habitat, and wildlife data (SFEI and ASC 2019, CDWR 2020b). Similar to the SURF data, CEDEN data from 2010 to 2020 were extracted and sorted by risk region. Data included water quality measurements, chemical contaminant concentrations, species abundance data for algae, cyanobacteria, annelids, crustaceans, mollusks, and other benthic and water column organisms, and habitat data for marshlands, open channel, and bank/riparian areas.

Chinook, Delta Smelt Trawl Data

Several fish sampling and monitoring surveys take place throughout the USFE and the Delta by the U.S. Fish and Wildlife Service and the California Department of Fish and Wildlife (CDFW 2020a, 2020b, 2020c). The various surveys were established to record the abundance of different species of fish, however there is much overlap between target and non-target species.

In the 1970's, the Delta Juvenile Fish Monitoring Program was established to specifically record the abundance of salmonid species within the San Francisco Bay, Estuary, and Delta. The scope of this program has since been expanded to include surveys that specifically monitor the abundance of the Delta smelt, as well as other species associated with pelagic organism decline (POD): Chinook, steelhead, striped bass, threadfin shad, and longfin smelt (USFW 2020). The Kodiak and Midwater trawl surveys use either a Kodiak or Midwater trawl net with varying mouth opening and mesh sizes. Beach seining operations use a 15.2 m beach seine net (USFW 2020).

The sampling operations include the 20 mm survey, the Kodiak Trawls, the Midwater Trawls, and beach seining. The 20 mm survey targets post-larval and juvenile Delta smelt within the USFE and is operated on a biweekly basis for 16 to 20 weeks since 2002 (CDFW 2020a). The Kodiak Trawl operates from January to May and samples at 40 different sites (CDFW 2020c). The Kodiak Trawls target adult, spawning Delta smelt. The Midwater Trawl is the longest running of the fish monitoring trawls, being operated since 1967. Initially comprised to map the abundance and distribution of striped bass, the Midwater Trawl now provides data on the relative abundance of POD species (CDFW 2020b). There are 122 stations that make up the network surveyed by the Midwater Trawl, that are sampled monthly from September to December. Beach seine surveys are conducted at 58 sites throughout the USFE to map juvenile pelagic fish abundances.

The USFWS combines multiple trawl surveys to provide fish abundance estimates (USFWS 2020). Of these surveys, three specific trawling locations that use either the Kodiak and/or the Midwater methodology take place to capture salmonid and other fish movements throughout the Delta. These trawls take place at Chipps Island slightly downstream of the confluence of the Sacramento and San Joaquin rivers, Mossdale Crossing, slightly southeast of the Delta on the San Joaquin River, and at Sherwood Harbor near Sacramento, slightly upstream of the Delta on the Sacramento River. Each of these trawling locations are recorded within the datasets of the Delta Juvenile Fish Monitoring Program (https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm) (USFW 2020).

Macroinvertebrate Data

Studies conducted in the SFE by de Vlaming et al. (2004, 2005) and Hartman et al. (2019) will be the primary source of site-specific data on macroinvertebrate abundances and community structure. Other data sources will include the benthic macroinvertebrate (BMI) assessments that are based on total taxa richness and EPT taxa richness, as well as CSCI data collected in the study area. Additional data sources will be investigated in Year 2 of the study to capture data that may still be in the process of being collected in the region.

USGS Gage Stations

The U.S. Geological Survey operates an extensive network of at least 50 stream gages throughout the USFE including 36 stations within the Delta to monitor flows, salinity, turbidity, conductivity, water levels, temperature, sediment transport and other biotic and abiotic measures (Burau et al. 2016). Many of these stations deliver data in real time at 15-minute intervals. Measurements vary depending on the station and not all stations include the same analytes.

The USGS gages measure water depth and translates it to flow rate using a fitted curve. The curve is based on field samples using acoustic velocity samplers or mechanical samplers. The curve is then shifted to reflect the empirical measurements so that scour or fill taking place at

the water depth orifice reflects the true discharge rate. The records for each gage are then checked at the end of water year and published according to USGS standards.
Not all gages are for discharge or discharge only. Sediment, temperature, and other water quality parameters are measured at certain stations. The analytes measured reflect what the cost-sharing operator wanted at the specific site.

Net Delta Outflow and Water Exports
The net Delta outflow is quantified once per water year based on flow monitoring stations throughout the Delta and is published by the California Department of Water Resources as Dayflow (CNRA 2020a). This estimate of net Delta flow is prepared by several agencies, including State, Federal, and local municipalities. Dayflow provides a quantitative assessment of all riverine inputs, diversions, and large-scale water exports to and from the Delta.

Toxicity Datasets
Based on SURF and CEDEN chemical monitoring data, a group of contaminants were selected to evaluate for inclusion in the risk assessment. The contaminants selected belonged to major chemical classes present in the Delta, including representative organochlorine, organophosphate, and pyrethroid insecticides, imidacloprid and other high use neonicotinoids, fipronil and its degradants, some herbicides, fungicides, metals, and nutrients. Because risk assessment is probabilistic, one of the goals was to calculate the probability of toxicological effects on assessment endpoints from chemical stressors. Those chemicals known to interact synergistically and bioaccumulate will be evaluated for their potential toxicological effects on the assessment endpoints as mixtures.

The first step was to conduct a search of the scientific literature, including supplementary data, technical reports, and state and federal government websites for toxicological studies that focused on the organisms and contaminants prioritized for inclusion in this risk assessment. Studies that used similar species or similar classes of contaminants were also included in the search. The second step was then to evaluate all the compiled materials to determine whether the information was sufficient to inform the risk assessment. To accomplish this, curve-fitting in R (R Core Team 2020) was used to test various nonlinear regression models and calculate exposure-response equations from the toxicological studies. Confidence and prediction intervals were also calculated for the exposure-response curves to gauge the quality of the data in terms of applicability to risk assessment.

Literature Search and Data Acquisition Methods
Google Scholar was used to conduct a search of the scientific literature using search terms listed in **Appendix C**. Studies that investigated dose- or concentration- response relationships between the chemicals and species selected for this risk assessment were used. These dose-response curves were then used to evaluate whether toxicity data were adequate or inadequate for the risk assessment, those data reporting methods that could be improved to better inform the risk assessment were highlighted.

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 for one study 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. If there were multiple studies for a contaminant-organism, only the study that was

most compatible with the BN-RRM was used. Factors considered included experimental design, methods, data availability, and reporting.

To determine the suitability of the 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.

Three dose-response curves were then plotted and evaluated for their usefulness in the risk assessment. Additional details about the toxicity data analyses are in **Appendix C**.

GIS Data Sources

Water and sediment pesticide data from 2009 to 2019 were obtained from the SURF and CEDEN databases (CDPR 2019, SFEI and ASC 2019). Water quality, habitat, benthic macroinvertebrate, toxicity, and metals data from the same time period were obtained from the CEDEN database (SFEI and ASC 2019), as well as water quality data from the CDWR database CDWR 2020b). The data were then filtered to Contra Costa, Sacramento, San Joaquin, Solano, and Yolo county locations using latitude and longitude coordinates. Data were then clipped to the risk region boundary, individual sub regions, and a 15 km buffer to analyze the data. The buffer was established to include data collected at sampling stations adjacent to each of the risk regions. An adjustment to the risk region delineations will be reevaluated in Year 2 to include more data in the risk assessment calculations.

Other data sources used were as follows: 1) Water body shapefiles used to visualize locations in situ were obtained from the California Natural Resource Agency (CNRA 2020b), 2) NPDES data were obtained from USEPA (2020c) and sites were clipped to risk region with a15 km buffer and interest type for analysis, 3) ArcGIS Pro tools utilized for analysis and cartography were obtained from ESRI (2020), 4) land cover data were obtained from the National Land Cover Database (NLCD 2016), and 5) the National Hydrography Dataset (NHD) for major rivers and streams was obtained from USGS (2020a). Other sources such as USEPA's StreamCat and LakeCat databases will be consulted in Year 2 of the study to capture land use and other watershed characteristics not included in the other data sources.

Acquisition of Additional Data

The extensive datasets available to describe the USFE describe a number of endpoints and interactions. However, gaps do occur in almost every study. A gap is caused when the available data to describe a variable or interaction results in uncertainty so that the distributions in the nodes or the conditional probabilities are poorly described. Poorly described means that the distributions have very long tails or what are termed even distributions, so that the information available is too low to estimate risk. There are a number of methods available to reduce this uncertainty:

1) Additional data from other sources: We often put out a call to stakeholders describing the data gaps that are in the model. Data often show up from unusual circumstances. In one

case, a paper from the 1940s provided key information in the fertility at age of Pacific herring. In another instance, the State of Virginia sent surveys of fisherman's creels from the South River, VA study area to us so that we could determine the kinds of fish being eaten locally.

2) Laboratory/experimental data are particularly useful in describing toxicity, the interaction of multiple chemicals, biomagnification in microcosms, and other studies. The issue is of extrapolation from smaller scale experimental systems to areas as large as the USFE.
3) Similar or model systems: It is possible to extrapolate interactions from field studies of other similar systems, especially the interaction pathways and trophic dynamics. This is particularly useful in determining the lines of influence in the conceptual model and later in the Bayesian network.
4) Computational Models: It is possible to use mathematical models to describe effects due to populations and communities, hydrology, fate and transport of contaminants, and nutrients to name a few. We have used models of Pacific herring and Chinook salmon population dynamics to predict risk and to estimate future trends. The Delta smelt model may be useful in the USFE. As always, care must be taken in the extrapolation.
5) Expert elicitation: Expert elicitation is another tool for obtaining information. There are a number of techniques that can be used in these circumstances. Expert elicitation works with a clear communication as to how the information will be used, a careful design of the survey tool, and careful analysis. In some instances, individuals are interviewed with specific questions. There is also extensive literature available as to the utility of such processes and data analysis. We have used such approaches in the past.

RESULTS

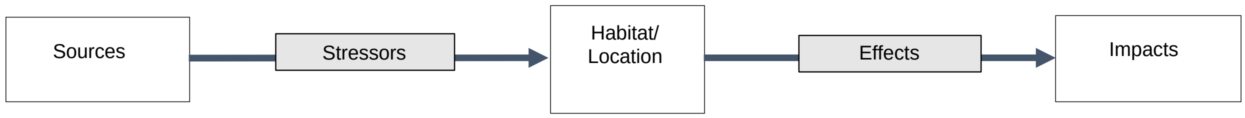
The conceptual model was somewhat modified from the incarnations as presented in September and then at the Society of Environmental Toxicology and Chemistry North America meeting in November in Toronto (**Figure 5**). The endpoints were made more specific. The importance of the Suisan Bay and Suisun Marsh as transition zones to the Delta regions of the study area was also noted. As will be apparent in the following sections, sufficient information and data were available to start the parameterization of the risk assessment for the study area.

The next sections present the evaluations of the various data sources available to take the step of turning the conceptual model into a series of Bayesian networks to calculate risk.

Data Sources Evaluation

Aqueous Pesticide Data
Pesticide data in water samples collected from 2010 to 2020 in the study area were compiled and sorted by the sampling site location to identify chemical contaminants and their concentrations in each risk region (**Appendices D, E, and I**). The data for each chemical in each risk region was then compared to USEPA's Office of Pesticide Program's Aquatic Life Benchmarks for Freshwater Species (USEPA 2020a). Those chemicals that exceeded the benchmark concentrations to cause acute or chronic adverse effects in fish and invertebrates, or acute effects in vascular or nonvascular plants in each risk region were then tabulated (**Table 1**).

Conceptual model for the USFE



Central Valley agriculture **Effluents** Wastewater and Industrial treatment **Land use types** Agriculture Residential Commercial Industrial **Non-point sources, Stormwater** **Transportation** Trains, Cars, Roads **Marine shipping/transportation** Sacramento Ship channel	**Pesticides (Includes all toxic agricultural and urban applied materials** Measured occurrence in the rivers just before and after the boundary of the study area. **Metals and other legacy materials** Hg and MeHg concentration Biosynthesis of MeHg Other metals PCBs, TCDDs, PBDEs and other POPs. PAHs. **Water characteristics** Water levels and flows (natural and with human intervention). Nutrients, Water quality variables, DO, temperature, salinity, hardness, total suspended solids and organic carbon. Retention times in different segments of the delta and marsh. **Landscape alteration** Dredging, breaching of levees, channel alteration.	**Delta smelt critical area** **Chinook Salmon critical area** **Macroinvertebrate areas** **Estuary to freshwater gradients** **Rivers** **Riverine areas** **Marshlands** **Suisan Bay transition**	**Habitat Effects** Alteration in habitat location, quality, blockage to migration, spawning and rearing regions, and occurrence of aquatic plants. **Fish** Direct effects - egg, larval, adult mortality Indirect effects - behavioral, sensory, neurotoxicity, immuno-suppression, disease as measured with an exposure-response. **Population scale** Change in age structure, species abundance and diversity, trophic structure and function. **Community structure** Changes invertebrate community structure, change in phytoplankton biomass, change in trophic transfer of nutrients/energy, eDNA. Alteration of food and habitat resources for valued endpoints.	**Endpoints** **Chinook Salmon,** Four runs-survivorship through the region. **Delta Smelt**-Endangered. No loss of habitat or population. **Aquatic community metrics** Macroinvertebrate community structure as measured by current sampling sites and the CSCI.

Figure 5. Revised conceptual model for the USFE. Slight changes were made to make the model more specific to the data available for the region.

Toxicity Data Analysis

Table 2 shows the results of our evaluation for each chemical contaminant for data availability. In summary, we found adequate exposure-response information for most compounds, however, because of how many studies reported toxicity results, many exposure-response models required additional statistical and modeling assumptions. These assumptions affected uncertainty calculations and the interpretation of exposure-response curves for many of the evaluated chemicals.

Trawl Data: Chinook Salmon and Delta Smelt

Data representing Chinook and Delta smelt abundance throughout the study area comes primarily from the Delta Juvenile Fish Monitoring Program and includes the Kodiak trawls, Midwater trawls, and beach seines conducted by the U.S. Fish and Wildlife Service and the California Department of Fish and Wildlife (USFW 2020).

<u>Chinook Salmon Data</u>

The Kodiak Trawls provided continuous data within the Sacramento River risk region and the South Delta risk region for the last ten complete water years. The Midwater Trawls provided continuous records of Chinook abundance for the Confluence risk region and the Sacramento risk region for the last ten complete water years. Beach seine monitoring provided data for the Central Delta, Confluence, North Delta, Sacramento River, and South Delta risk regions for the last ten complete water years (**Figure 6**) (**Appendix G**).

The dataset that includes the trawl data and beach seines over the last ten complete water years included 15,836 unique sampling occurrences, at 56 different locations, with a total of 107,037 individual Chinook sampled.

Over a ten-year period, the Kodiak Trawls sampled 5,568 times with a total catch of 31,033 Chinook. The Midwater Trawls sampled 6,991 times with a total catch of 51,032 Chinook. There were 3,278 beach seine samples that netted 24,972 total Chinook.

There were 349 samples taken in the Central Delta risk region with 1,953 total Chinook caught over a ten-year period. There were 5,170 samples in the Confluence risk region with a total catch of 36,445 Chinook. Eighty-one samples took place within the North Delta risk region, catching 380 Chinook. The Sacramento River risk region had a total of 5,661 samples with 36,540 fish caught. A total of 3,077 samples collected within the South Delta risk region with a total of 3,077 Chinook sampled over the last ten complete water years. See **Appendix G** for a breakdown of fall, late fall, spring, and winter run Chinook sampled per water year per risk region.

<u>Delta Smelt Data</u>

The Kodiak Trawls, Midwater Trawls, and beach seine surveys comprise the dataset for Delta smelt abundance throughout the Central Delta, Confluence, North Delta, Sacramento River, and South Delta risk regions for the last ten complete water years (USFW 2020). There were 1,536 total Delta smelt surveys for water years 2009 to 2019 throughout the study area with 2,667 individual Delta smelt sampled (**Figure 7**).

The Kodiak Trawls provided 36 separate surveys with 48 Delta smelt caught over a ten-year period. The Midwater Trawls sampled 2,280 Delta smelt in 1,362 surveys in the last ten complete water years. Beach seining occurred on 138 occasions and netted 339 Delta smelt. The Central Delta region had 8 surveys with 9 Delta smelt caught. There were 1,410 surveys within the Confluence risk region with a total of 2,434 individuals counted. There were 9 surveys in the North Delta risk region and 11 fish sampled. The Sacramento River risk region had a total of 72 surveys with 164 sampled. The South Delta risk region had one survey with one fish caught. See **Appendix G** for a complete description of fish counts by region by year. The US Fish & Wildlife Service provides estimates of Delta smelt abundance through their Enhanced Delta Smelt Monitoring reports that are published daily (USFW 2020).

Water Quality and Metals Data

<u>Nitrogen</u>

Measurements of nitrate in various forms retrieved from CEDEN showed that coverage of data for risk regions varied by water year and region over the ten-year period (**Table 3, Appendix F and I**). Measurements of total nitrate + nitrite as N had continuous coverage in the Sacramento risk region for the last ten complete water years. The North region had coverage for water years 2010-2015 and 2017-2019. The Central and South Delta risk regions had measurements of nitrate + nitrite as N, for water years 2010-2018. There were no samples recorded in the Suisun risk region for the period of study.

Table 1. Pesticide exceedances, based on SURF and CEDEN aqueous sample data, causing acute or chronic effects in fish (FA, FC) and invertebrates (IA, IC), respectively or acute effects in vascular plants (VP) or nonvascular plants (NVP). (Historical indicates exceedances occurred five or more years prior to 2020.)

	Risk Regions					
Pesticides Classes	**North Delta**	**Sacramento River**	**Central Delta**	**South Delta**	**Confluence**	**Suisun Bay**
Benzoylureas						
Diflubenzuron						IA, IC
Fipronil	IC				IC – Historical	
Fungicides						
Chloropicrin		FA, VP				
Chlorothalonil			IC			
Herbicides						
Atrazine	NVP		IC			IC
Diuron			NVP			
Linuron						IC
Oxyfluorfen		NVP				
Paraquat Dichloride			NVP			
Thiobencarb	IC					
Neonicotinoids						
Clothianidin		IC				
Imidacloprid	IC			IC		
Organo-chlorines						
Endosulfan			FA, FC, IC			
Pyridaben		FA, FC, IA, IC				
Organo-phosphates						
Azinophos methyl						FA, FC, IA, IC
Chlorpyrifos		FA, FC, IA, IC	FA, FC, IA, IC	FC, IA, IC		FA, FC, IA, IC
Diazinon		FC, IA, IC	FC, IA, IC			FC, IA, IC
Dimethoate		IC	IC			IC
Dichlorvos (DDVP)		IA, IC				IA, IC
Malathion		FA, IA, IC				FA, IA, IC
Methidathion						FA, IA, IC

Table 1 continued.

	Risk Regions					
Pesticides Classes	**North Delta**	**Sacramento River**	**Central Delta**	**South Delta**	**Confluence**	**Suisun Bay**
Naled						IA, IC
Phorate						FA, FC, IA, IC
Pyrethroids						
Bifenthrin	IC	FC, IA, IC	FA, FC, IA, IC		FA, FC, IA, IC	IC
Cyfluthrin		FC, IA, IC	FA, FC, IA, IC		FC, IA, IC - Historical	FC, IA, IC
Deltamethrin		FC, IC				FC, IC
Esfenvalerate		IA, IC	FA, FC, IA, IC			FC, IA, IC
lambda-Cyhalothrin	IA, IC	FC, IA, IC	FA, FC, IA, IC			IA, IC
Permethrin	IC - Historical	FA, FC, IA, IC	FA, FC, IA, IC			FC, IA, IC

Measurements for dissolved nitrate as N within the study area show that the Central Delta risk region had data for 2011-2012 and 2014. The Confluence data covered 2010-2014 and 2018. The Sacramento risk region data covers 2012-2013 and 2015. The South Delta risk region had measurements during 2013 and 2015, and the Suisun region had data for water years 2010-2013. There were no measurements for nitrate as N within the North Delta risk region. See **Appendices F** and **I** for boxplots of nitrogen concentrations in each risk region.

Dissolved Oxygen
Measurements of dissolved oxygen have been recorded in CEDEN for each of the six risk regions with data gaps during some water years varying by region. The Central, Confluence, North, and Sacramento risk regions have complete data from water year 2010-2019. The South Delta risk region DO data covered water years 2010-2018. The Suisun region had data covering 2010-2013 and odd numbered water years thereafter.

Phosphorus
Data from CEDEN were analyzed for phosphorus (P) as orthophosphate (ORP), P, dissolved, and P, total. The dataset for P, dissolved had limited coverage with measurements for water year 2010 only in the Central Delta, North Delta, and Sacramento River risk regions. The most recent water year covered for dissolved phosphorus was 2018 and only in the Confluence risk region. The Suisun Bay risk region dissolved phosphorus data covered 2011 and 2012. There were data for phosphorus as P, total for all risk regions. Only the Central Delta, Confluence, North Delta, and Sacramento River risk regions had data representing at least one complete water year out of the last 5. See **Appendices F** and **I** for plots of phosphorus concentrations in each risk region over the last ten-year period.

Table 2. Availability of exposure-response data for chemical contaminants in the study area to be considered for inclusion in the BN-RRM risk assessment. Select chemicals were used to represent a chemical class. Chemicals were ranked A, B, or C from best to least preferred based on the quality of the exposure-response data. The rankings correspond to the examples of exposure-response

Class	Chemical	Freshwater Invertebrates	Estuarine Invertebrates	Delta Smelt (Fish)
Organophosphate	Chlorpyrifos	Hasenbein et al. 2015a (B); Steevens and Benson 2001 (B)	C	Maryoung et al. 2014 (B*)
Organophosphate	Malathion	Rider and Leblanc 2005 (A)	C	Laetz et al. 2013 (B*)
Organophosphate	Diazinon	Burkepile et al. 2000 (B)	C	Laetz et al. 2013 (B*)
Metal	Mercury	Tsui and Wang 2006 (B)	C	Dillon et al. 2010 (B*)
Metal	Methylmercury	Steevens and Benson 2001 (B)	C	Dillon et al. 2010 (B*)
Metalloid	Selenium	Ingersoll et al. 1990 (B)	Ward et al. 1981 (B)	Halter et al. 1980 (B*)
Pyrethroid	Bifenthrin	Hasenbein et al. 2015a (B)	C	C
Pyrethroid	Cyfluthrin	Hasenbein et al. 2015a (B)	C	C
Pyrethroid	Esfenvalerate	C	C	Connon et al. 2009 (B)
Pyrethroid	λ-Cyhalothrin	Barata et al. 2006 (B)	DeLorenzo et al. 2014 (B)	Kumar et al. 2007 (B*)
Pyrethroid	Permethrin	Hasenbein et al. 2015a (B)	DeLorenzo et al. 2014 (B)	Jeffries et al. 2015 (B)
Pyrethroid	Deltamethrin	Barata et al. 2006 (B)	DeLorenzo et al. 2014 (B)	Köprücü and Aydin 2004 (B*)
Neonicotinoid	Imidacloprid	Jemec et al. 2007 (B)	C	C
Triazine	Atrazine	Palma et al. 2009 (B)	Ward and Ballantine 1985 (B)	Xing et al. 2015 (B*)
Phenylpyrazole	Fipronil	Konwick et al. 2005 (B)	C	C
Organochloride	Endosulfan	Palma et al. 2009 (B)	Breteler et al. 1982 (B)	Ballesteros et al. 2007 (B*)

A = Ideal exposure-response information for BN-RRM risk assessment. Data were fully available and uncertainty could be calculated with minimal statistical and modeling assumptions; **B** = Adequate exposure-response information for risk assessment. Higher or underestimated mathematical uncertainty. Required more statistical and modeling assumptions than an A-ranking; **C** = Insufficient exposure-response information for BN-RRM risk assessment.

* Exposure-response study used model organism (fish) instead of delta smelt, the endpoint fish.

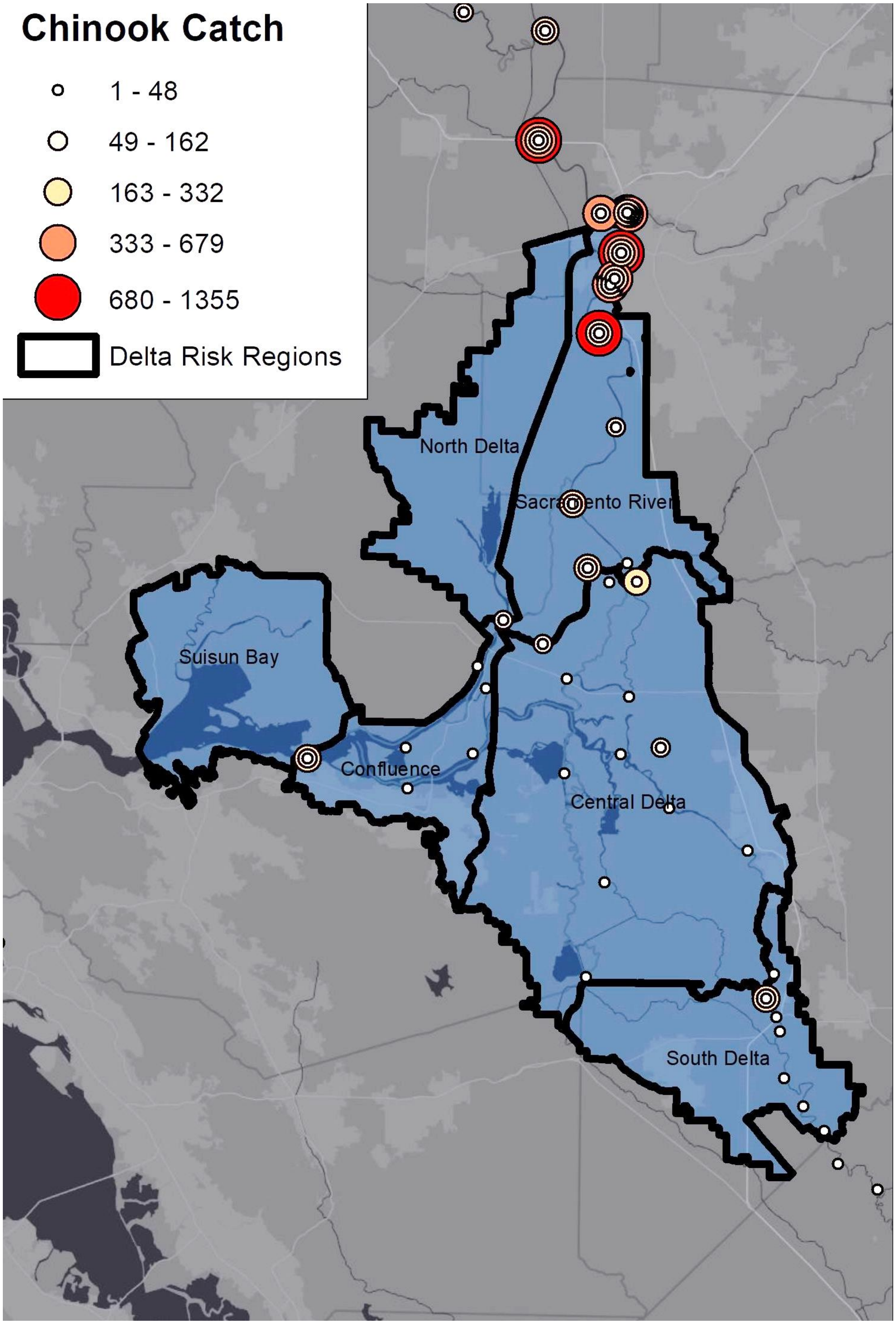


Figure 6. Chinook salmon trawl catch data for water years 2010 through 2019.

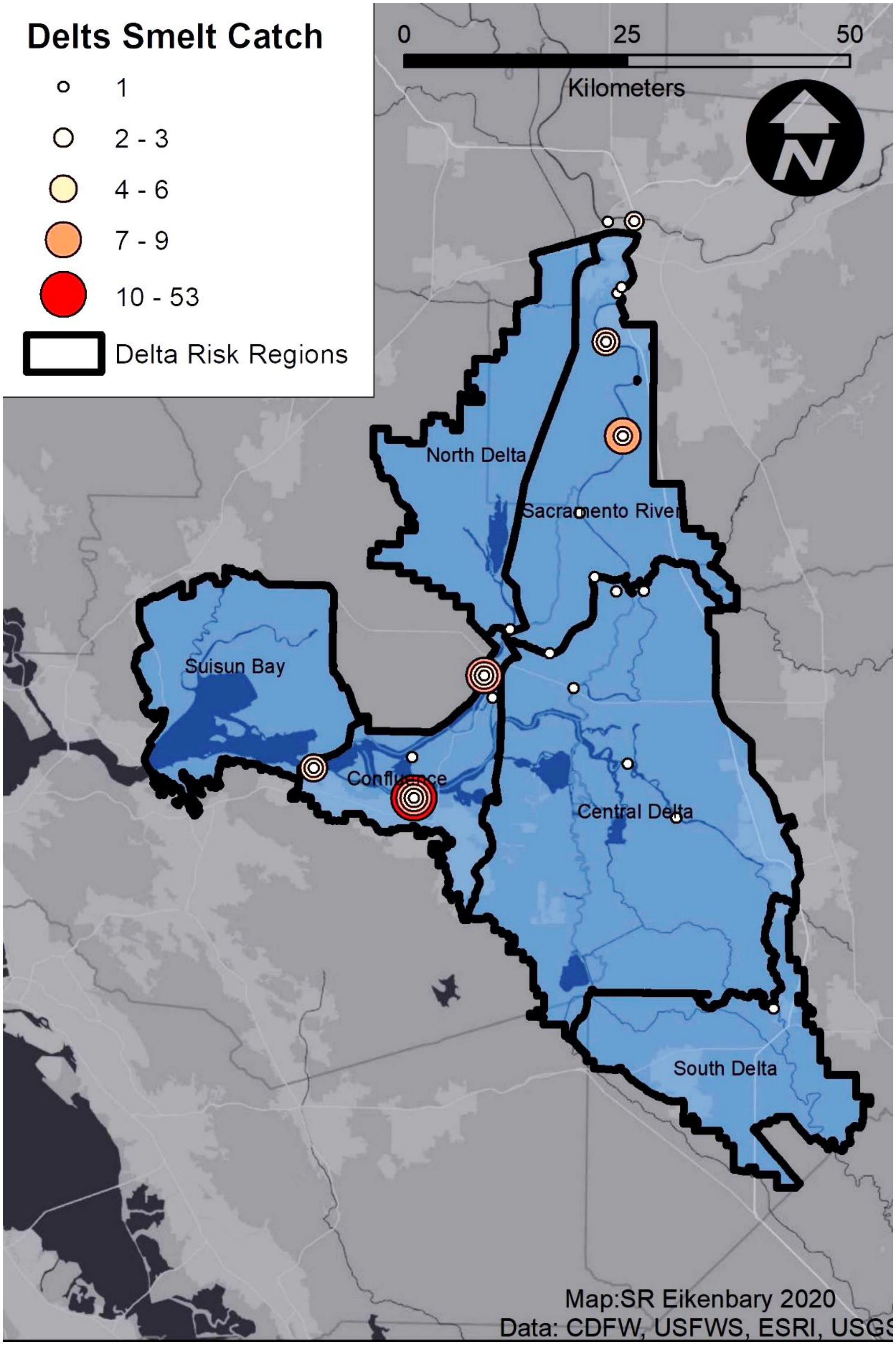


Figure 7. Delta smelt trawl catch data for water years 2010 through 2019.

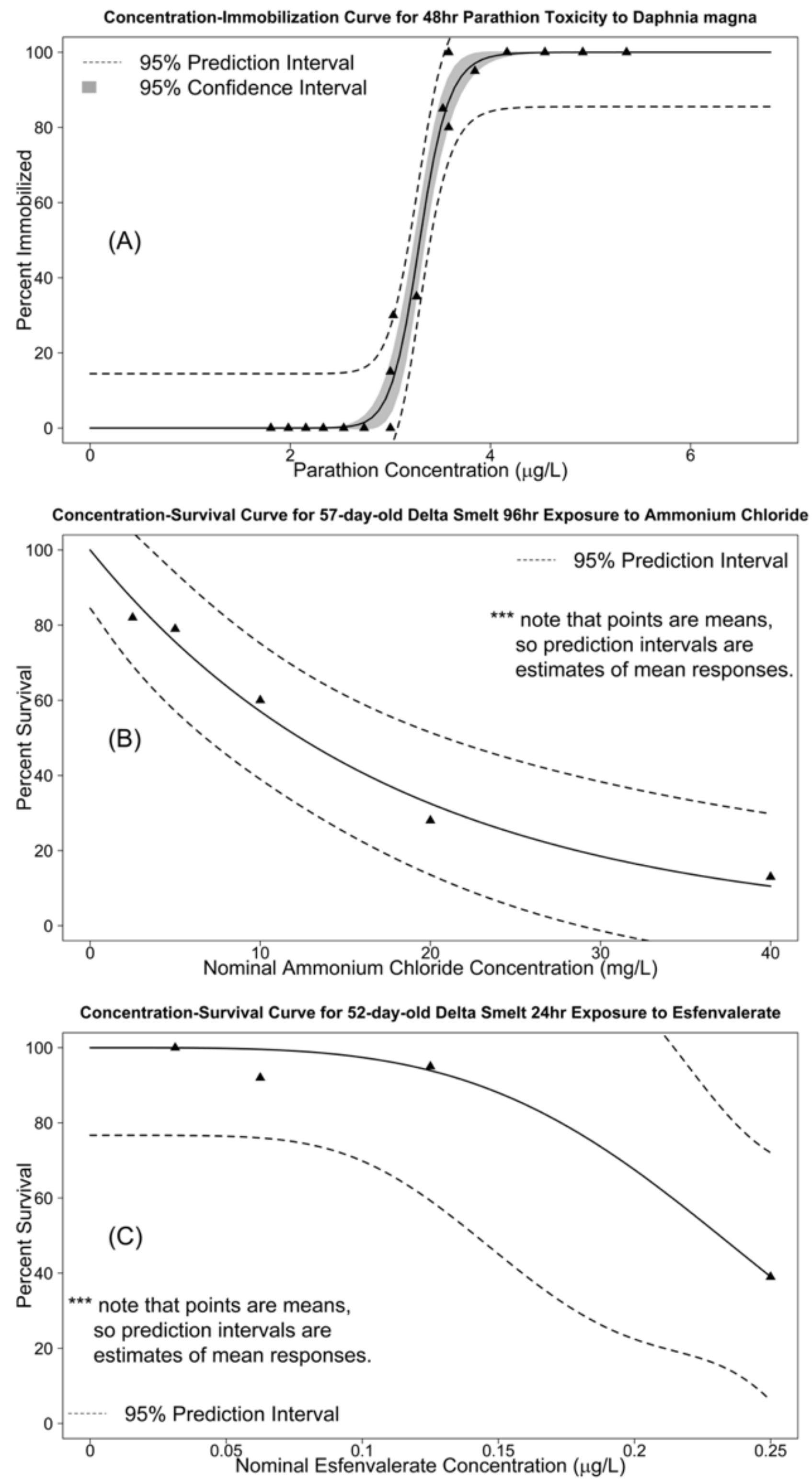


Figure 8. Examples of exposure-response curves and typical datasets. Curve A is the preferred type of exposure-response, Curve B is sufficient, and Curve C is insufficient. See **Appendix C** for more details.

Temperature
Temperature data retrieved from CEDEN covered all risk regions for the last 10 complete water years except the Suisun region. The Suisun region had temperature data only covering water years 2010-2013, 2015, and 2017. See **Appendices F** and **I** for plots of water temperatures in each risk region.

Table 3. Regional coverage of analytes by water year and risk region.

Analyte	**Region**	**WY Coverage**
Nitrate + Nitrite as N, Total	Central	2010-2018
Nitrate + Nitrite as N, Total	Confluence	NA
Nitrate + Nitrite as N, Total	North	2010-2015, 2017-2019
Nitrate + Nitrite as N, Total	Sacramento	2010-2019
Nitrate + Nitrite as N, Total	South	2010-2018
Nitrate + Nitrite as N, Total	Suisun	NA
Nitrate as N, Dissolved	Central	2011-2012, 2014
Nitrate as N, Dissolved	Confluence	2010-2014, 2018
Nitrate as N, Dissolved	North	NA
Nitrate as N, Dissolved	Sacramento	2012-2013, 2015
Nitrate as N, Dissolved	South	2013, 2015
Nitrate as N, Dissolved	Suisun	2010-2013
Oxygen, Dissolved, Total	Central	2010-2019
Oxygen, Dissolved, Total	Confluence	2010-2019
Oxygen, Dissolved, Total	North	2010-2019
Oxygen, Dissolved, Total	Sacramento	2010-2019
Oxygen, Dissolved, Total	South	2010-2018
Oxygen, Dissolved, Total	Suisun	2010-2013, 2015, 2017, 2019
Phosphorus as P, Dissolved	Central	2010
Phosphorus as P, Dissolved	Confluence	2010, 2011, 2012, 2018
Phosphorus as P, Dissolved	North	2010
Phosphorus as P, Dissolved		
Phosphorus as P, Dissolved	Sacramento	2010
Phosphorus as P, Dissolved	South	NA
Phosphorus as P, Total	Suisun	2011-2012
Phosphorus as P, Total	Central	2010-2014, 2018
Phosphorus as P, Total	Confluence	2010-2015, 2018
Phosphorus as P, Total	North	2010-2013, 2017-2019
Phosphorus as P, Total	Sacramento	2010-2015, 2018-2019
Phosphorus as P, Total	South	2010-2014
Temperature	Suisun	2010-2015, 2018
Temperature	Central	2010-2019
Temperature	Confluence	2010-2019
Temperature	North	2010-2019
Temperature	Sacramento	2010-2019

Table 3 continued

Analyte	Region	WY Coverage
Temperature	South	2010-2019
Turbidity, Total	Suisun	2010-2013, 2015, 2017
Turbidity, Total	Central	2010-2019
Turbidity, Total	Confluence	2010-2012, 2015, 2018, 2019
Turbidity, Total	North	2010-2019
Turbidity, Total	Sacramento	2010-2019
Turbidity, Total	South	2010-2018
Mercury, Total	Central	2016-2017
Mercury, Total	Confluence	2010-2014, 2017-2018
Mercury, Total	North	2016-2017
Mercury, Total	Sacramento	2010-2017
Mercury, Total	South	NA
Mercury, Total	Suisun	2010-2011, 2013
Methyl Mercury	Central	2016-2017
Methyl Mercury	Confluence	2010-2015, 2018
Methyl Mercury	North	2016-2017
Methyl Mercury	Sacramento	2010-2018
Methyl Mercury	South	2014-2015, 2017
Methyl Mercury	Suisun	2010-2015, 2018
Selenium, Total	Suisun	2010-2012
Selenium, Total	Central	2011-2014, 2017-2018
Selenium, Total	Confluence	2010-2015, 2017
Selenium, Total	North	2011, 2014-2015
Selenium, Total	Sacramento	2010-2011, 2013-2014
Selenium, Total	South	2010-2011, 2013-2014

Turbidity

Turbidity data reported in CEDEN showed that all risk regions, except Suisun Bay, had measurements for the last 5 complete water years, with some data gaps varying by region. The Central Delta, North Delta, and Sacramento River risk regions had complete turbidity data for the last 10 complete water years. The Confluence region had turbidity data from 2010-2012, 2015, 2018, and 2019. The South Delta risk region turbidity data covered water years 2010-2018, and the Suisun Bay risk region had data from 2010 only.

Mercury

Coverage of total mercury concentrations within the study area varied per region by water year. The confluence risk region had sample coverage for water years 2010 to 2014, and 2017 to 2018. The Central and North Delta risk regions had data from water years 2016 to 2017. The Sacramento risk region data covered water years 2010 to 2017. The Suisun risk region had data for water years 2010, 2011 and 2013 only, and the South risk region had no data for total mercury concentrations. See **Appendices D, F,** and **I** for distributions and concentrations of mercury in the study area.

Methylmercury
Data within the study area representing total methylmercury concentrations was derived from CEDEN. Results of spatial analysis showed that there are data covering all six of the risk regions, but with some gaps in water years and only data up to 2018. The Sacramento risk region is the only region with continuous methylmercury monitoring data for water years 2010 to 2018. The Central and North Delta risk regions have methylmercury measurements covering 2016 to 2017. The Confluence risk region methylmercury data covered water years 2010-2014 and 2017-2018 and the South Delta risk region data covered water years 2014-2015 and 2017. See **Appendices D, F,** and **I** for distributions and concentrations of methylmercury in the study area.

Selenium
Selenium data derived from CEDEN show measurements within each of the six risk regions, with coverage varying by water year by region. Only the Central, Confluence, North, and Suisun risk regions had measurements within the last 5 water years for total selenium concentrations. The most recent measurements within both the Sacramento and South Delta regions were from water year 2014. See **Appendices D, F,** and **I** for distributions and concentrations of methylmercury in the study area.

DISCUSSION AND SUMMARY

Data Quantity and Quality

Aqueous Pesticide Data Quantity
The SURF and CEDEN databases had many zeros in them indicating the concentrations were below the analytical detection limit or reporting limit. There were also several pesticides that were measured in 2010 through 2015, however there were no data for them after that. There is uncertainty as to whether the chemicals were not detected due to drought or their use was discontinued, or they were no longer analyzed for in the water samples. Clarification is needed to determine whether this is a data gap or not. Otherwise, data were sufficient to identify those classes of chemicals that exceed benchmarks for the protection of fish, invertebrates, and plants in each of the risk regions.

Toxicological Data Quantity
We found adequate exposure-response information for the toxicity of a wide variety of chemicals to both fish and invertebrates (**Table 2**). For all chemicals in **Table 2** with a B-rating or higher, we would be able to probabilistically evaluate their toxicity within a BN-RRM risk assessment. A small number of selected chemicals received a C-rating for either the fish or invertebrate endpoints due to the lack of adequate exposure-response information for BN-RRM risk assessment in our literature search.

Toxicological Data Quality
Out of all the compounds we evaluated in **Table 2**, only one A-rating was given to the one research study. It provided dose-response information ideal for BN-RRM risk assessment that required minimal statistical and modeling assumptions and provided probabilistic estimates of a chemical's toxicity over the entire exposure-response curve (EC_0-EC_{100}). Most chemicals received B-ratings for both endpoints in that there was adequate exposure-response information for BN-RRM risk assessment. The models generated by toxicity information that received a B-

rating, however, required more statistical and modeling assumptions and had a higher mathematical uncertainty associated with the exposure-response curve estimates.

Additional Toxicological Data Needs to Reduce Uncertainty
Although we found adequate exposure-response information for a large number of contaminants across both fish and invertebrate studies (**Table 2**), the high number of B-ratings and C-ratings suggested there are still knowledge gaps and areas in need of improvement in terms of toxicity data for BN-RRM risk assessment. Many of the studies to which we assigned B-ratings received those ratings due to a lack of complete data reporting for those toxicity tests. Generating exposure-response curves using treatment means is not ideal, as the uncertainty calculations generated by these analyses will underestimate the true variability of toxicity-related outcomes. If raw data were attained for some of these studies, it is possible that more A-ratings would be assigned. A number of researchers (Richard Connon, Juergen Geist, Sebastian Beggel, Inge Werner, Michelle Hladik) were contacted about obtaining raw data, however none have been received. Moreover, many of these studies are older and the raw data might be completely inaccessible at this point. Additional outreach to these authors and others will be conducted in Year 2.

Trawl and Beach Seine Datasets
Trawl and beach seine datasets do not include any sample locations that are within the Suisun Bay risk region. There are datasets, however, for sample locations south of the bay and north of the North and Sacramento risk regions that are not included in the study area. Minor adjustments to the risk region’s delineations should address this data gap.

Outside of the long-term fish monitoring trawls, sampling within the Delta for biotic and abiotic components is largely a patchwork of various multi-agency smaller temporal monitoring efforts aimed at locations in one specific region of the Delta and as such incurs data gaps when looking at the region over larger spatial and temporal scales. This presents a hurdle when attempting to examine concentrations over time for metals, nutrients, and other water quality constituents within the study region over many water years. Water quality measurements may be skewed toward on region versus another due to stakeholder investment within separate counties or regional municipalities. The USFE and Delta represent a large area with a diverse population that has differing values of cultural importance towards endpoints within the different regions. This can lead to monitoring efforts being prioritized in one region and not in another, presenting gaps in data between regions and between years.

The landscape variations within the study area switch from agricultural to densely populated urban centers, to major oil refineries, sometimes within the bounds of a single bridge. Because the risk regions are composed of sometimes drastically different landscapes, not all water quality constituents will be present in all regions, as is shown in the data.

The Conceptual Model

The data are comparable to or exceed the quantities available in our previous large-scale projects such as the South River or the Brisbane sites. Because the monitoring programs for the regions were not designed with an ecological risk assessment in mind it is expected that the coverage is not even and that not all parameters are sampled in each risk region.

There will be some slight changes to the risk regions to take advantage of some of the sampling locations. The next challenge is to turn the conceptual model into a Bayesian network relative risk model (BN-RRM) applicable to each risk region.

NEXT STEPS

This report is a summary of the project through the first year. Years 2 and 3 are directed towards the construction of the Bayesian network, the estimate of risk, the understanding of uncertainty and sensitivity, and finally the building of an adaptive management process. The next paragraphs outline these steps.

Next is the building of the BN-RRM and the risk calculation. **Figure 9** is a diagram of the transition as we did for the Brisbane (Graham et al. 2019). In this instance the conceptual model including the lines of influence is sketched out in the Netica software. As information is added to the nodes and the conditional probability tables are built the parameterized BN is constructed. In this example the node to the left designates the risk region for which the risk estimate is being calculated. Selecting the risk region selects the input dataset specific to that region to the used for the rest of the calculation. The next sets of nodes set the water quality parameters. In some instances (water temp) the node is independent of the previous nodes. Other parameters are derived from combinations of interactions of the nodes to the left. The last set of nodes in this example are the water quality and species diversity nodes that were the endpoints.

Another recent example is the calculation of risk due to organophosphates to the population size for Chinook salmon in the Puget Sound region (**Figure 10**). In this instance the inhibition of acetylcholinesterase inhibition is connected to water temperature and dissolved oxygen inputs. The change in the survivorship of the adults and juveniles is then linked to a population model for Chinook salmon. The results of this paper are detailed in Landis et al (2020).

Year 2 will be spent building the models and estimating risk for the USFE following similar approaches.

The final step in the research program will be integrating the BN-RRM into the adaptive management framework describe in Landis et al. (2017b). Adaptive management has been proposed as the management framework for the USFE.

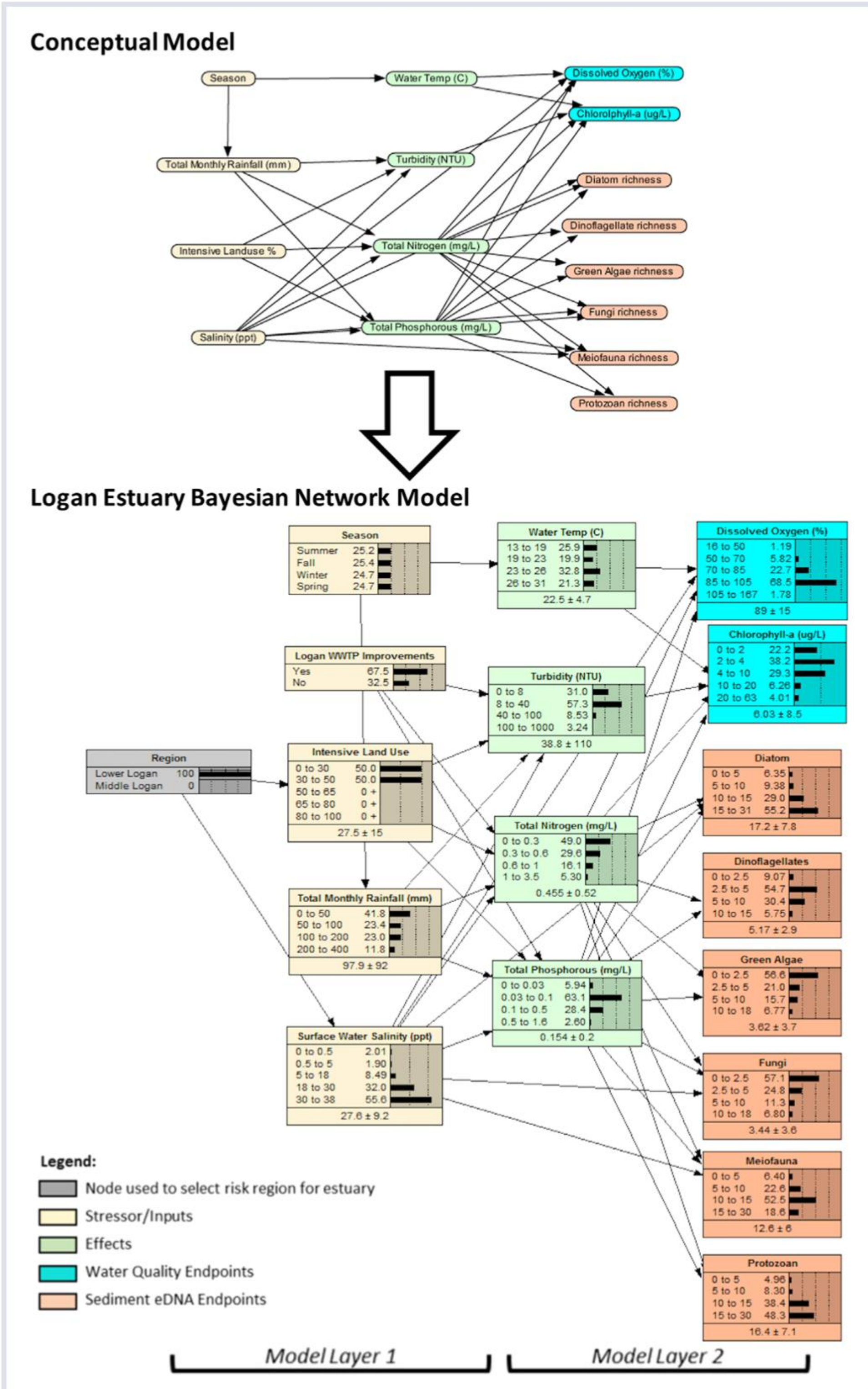


Figure 9. Example of the transition from conceptual model to Bayesian network for the estuaries near Brisbane, NSW (Graham et al 2019).

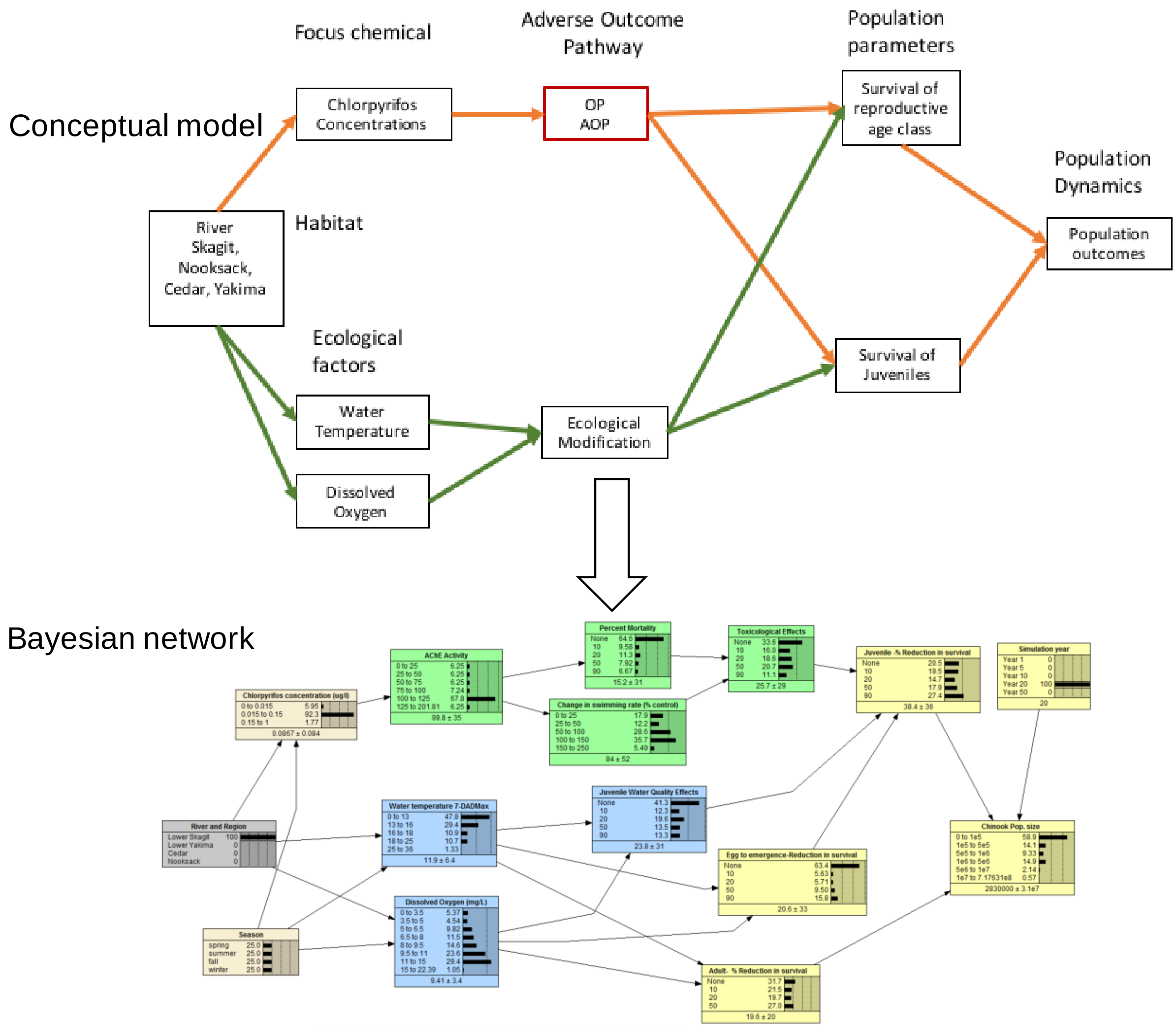


Figure 10. Transition from conceptual model for OP pesticide effects to Chinook populations and the derivative BN-RRM.

REFERENCES

Adeyinka A, Pierre L. 2020. Organophosphates. StatPearls Publishing LLC. https://www.ncbi.nlm.nih.gov/books/NBK499860/. Accessed 28 Apr. 2020.

Ali U, Syed JH, Malik RN, Katsoyiannis A, Li J, Zhang G, Jones KC. 2014. Organochlorine pesticides (OCPs) in South Asian region: A review. *Sci.Total. Environ.* 476-477:705-717.

Amweg EL, Weston DP, Ureda NM. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. *Environ. Toxicol. Chem.* 24(4):966-972.

Ayre KK, Landis WG. 2012. A Bayesian approach to landscape ecological risk assessment applied to the Upper Grande Ronde watershed, Oregon. *Hum. Ecol. Risk Assess.* 18(5):946-970.

Ayre KK, Caldwell CA, Stinson J, Landis WG. 2014. Analysis of regional scale risk to whirling disease in populations of Colorado and Rio Grande cutthroat trout using Bayesian belief network model. *Risk Anal.* 34(9):1589-1605.

Bennett WA. 2005. Critical assessment of the Delta smelt population in the San Francisco Estuary, California. *San Francisco Estuary and Watershed Science* 3.

Breteler RJ, Williams JW, Buhl RL. 1982. Measurement of chronic toxicity using opossum shrimp *Mysidopsis bahia*. *Hydrobiologia* 93:189-194.

Brown LR, Bennett WA, Wagner RW, Morgan-King T, Knowles N, Feyrer F, Schoellhamer DH, Stacey MT, Dettinger M. 2013. Implications for future survival of Delta smelt from four climate change scenarios for the Sacramento–San Joaquin Delta, California. *Estuaries Coast* 36:754-774.

Buckingham SD, Lapied B, Le Corronc H, Grolleau F, Sattelle DB. 1997. Imidacloprid actions on insect neuronal acetylcholine receptors. *J. Exp. Biol.* 200: 2685-2692.

Burau J, Ruhl C, Work PA. 2016. Innovation in monitoring: The US Geological Survey Sacramento–San Joaquin River Delta, California, flow-station network (No. 2015-3061). US Geological Survey.

Burkepile DE, Moore MT, Holland MM. 2000. Susceptibility of five nontarget organisms to aqueous diazinon exposure. *B. Environ. Contam. Tox.* 64:114-121.

CDFW [California Department of Fish and Wildlife]. 2020a. 20mm Survey. Available from: http://www.dfg.ca.gov/delta/projects.asp?ProjectID=20mm. Accessed 20 May 2020.

CDFW [California Department of Fish and Wildlife]. 2020b. Fall Midwater Trawl. Available from https://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT. Accessed 20 May 2020.

CDFW [California Department of Fish and Wildlife]. 2020c. Spring Kodiak Trawl. Available from http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SKT. Accessed 20 May 2020.

CDPR [California Department of Pesticide Regulation]. 2019. Surface Water Database (SURF). https://www.cdpr.ca.gov/docs/emon/surfwtr/surfdata.htm. Accessed 3 Dec 2019.

CDPR [California Department of Pesticide Regulation]. 2020. Summary of Pesticide Use Report Data - 2017. https://www.cdpr.ca.gov/docs/pur/pur17rep/17sum.htm#trends . Accessed 19 Apr 2020.

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

CDWR [California Department of Water Resources]. 2020a. DWR Atlas. http://atlas-dwr.opendata.arcgis.com/datasets/legal-delta-boundary. Accessed 8 May 2020.

CDWR [California Department of Water Resources]. 2020b. CNRA Open Data Home. https://data.cnra.ca.gov/organization/dwr/portal/home. Accessed 21 May 2020.

Chappelle C. 2015. The Great Nutrient Pollution Challenge. Public Policy Institute of California, 10 Nov 2015. https://www.ppic.org/blog/the-great-nutrient-pollution-challenge. Accessed 30 May 2020.
CNRA [California Natural Resources Agency]. 2020a. Dayflow. Suisun Marsh branch: California Natural Resources Agency. Available from https://data.cnra.ca.gov/dataset/dayflow. Accessed 30 May 2020.
CNRA [California Natural Resources Agency]. 2020b. Water Body Data: California Natural Resources Agency. Available from https://data.cnra.ca.gov/dataset. Accessed 30 May 2020.
Cohen A. 2000. An Introduction to the San Francisco Estuary. Save the Bay, San Francisco Estuary Project, San Francisco Estuary Institute. 44p. https://sfestuary.org/wp-content/uploads/2012/12/Intro-to-SF-Estuary-PDF.pdf. Accessed 30 May 2020.
Connon RE, Geist J, Pfeiff J, Loguinov AV, D'Abronzo LS, Wintz H, Vulpe CD, Werner I. 2009. Linking mechanistic and behavioral responses to sublethal esfenvalerate exposure in the endangered delta smelt; *Hypomesus transpacificus* (Fam. Osmeridae). *BMC Genomics* 10:608.
CVWB [Central Valley Water Board]. 2011. Central Valley Water Board Final Basin Plan Amendment– Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Methylmercury and Total mercury in the Sacramento-San Joaquin Delta Estuary, Resolution No. R5-2010-0043. https://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/delta_hg/2011_1020_deltahg_bpa.pdf. Accessed 30 Apr 2020.
Data Basin. 2020. Basemap: Land Use in the Sacramento and San Joaquin Delta and Suisun Marsh Area, California, USA. https://databasin.org/datasets/0e12d52982234872bef0bcca9626ca39. Accessed 29 May 2020.
DeLorenzo ME, Key PB, Chung KW, Sapozhnikova Y, Fulton MH. 2014. Comparative toxicity of pyrethroid insecticides to two estuarine crustacean species, *Americamysis bahia* and *Palaemonetes pugio*. *Environ. Toxicol.* 29(10):1099-1106.
Delta Protection Commission. 2010. Land Use and Resource Management Plan for the Primary Zone of the Delta, adopted February 25, 2010.
de Vlaming V, Markiewicz D, Goding K, Holmes R. 2004. Macroinvertebrate assemblages in agriculture- and effluent-dominated waterways of the lower Sacramento River watershed. Sacramento, CA, USA: Central Valley Regional Water Quality Control Board. Prepared by University of California, Davis Aquatic Toxicology Laboratory for the Central Valley Regional Water Quality Control Board. 149pp.
de Vlaming V, Markiewicz D, Goding K, Morrill A, Rowan J. 2005. Macroinvertebrate Assemblages of the San Joaquin River Watershed. Central Valley Regional Water Quality Control Board. Prepared by University of California, Davis Aquatic Toxicology Laboratory for the Central Valley Regional Water Quality Control Board. 64pp.
Dillon T, Beckvar N, Kerns J. 2010. Residue-based mercury dose-response in fish: an analysis using lethality-equivalent test endpoints. *Environ Toxicol Chem* 29:2559-2565.
ESRI [Environmental Systems Research Institute]. 2020. ArcGIS Pro tools utilized for analysis and cartography. Digital Elevation Model (DEM). https://elevation.arcgis.com/arcgis/services/WorldElevation/Terrain/ImageServer. Accessed 31 May 2020.
Ferrari MC, Ranåker L, Weinersmith KL, Young MJ, Sih A, Conrad JL. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. *Environ. Biol. Fishes* 97(1):79-90.

Feyrer F, Nobriga ML, Sommer TR. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. *Can J Fish Aquat Sci* 64:723–734. doi: http://dx.doi.org/10.1139/f07-048. Accessed 17 May 2020.
Fisch KM, Henderson J, Burton RS, May B. 2011. Population genetics and conservation implications for the endangered delta smelt in the San Francisco Bay-Delta. *Conserv. Genet.* 12(6):1421-1434.
Flanders JR, Turner RR, Morrison T, Jensen R, Pizzuto J, Skalak K, Stahl R. 2010. Distribution, behavior, and transport of inorganic and methylmercury in a high gradient stream. *Appl Geochem* 25:1756-1769.
Floyd EY, Geist JP, Werner I. 2008. Acute, sublethal exposure to a pyrethroid insecticide alters behaviors, growth, and predation risk in larvae of the fathead minnow (*Pimephales promelas*). *Environ. Toxicol. Chem.* 27(8):1780-1787.
Gervais JA, Luukinen B, Buhl K, Stone D. 2010. Imidacloprid technical fact sheet. National Pesticide Information Center, Oregon State University Extension Services, Corvallis, OR, USA. Available from http://npic.orst.edu/factsheets/archive/imidacloprid.html. Accessed 17 May 2020.
Graham SE, Chariton AA, Landis WG. 2019. Using Bayesian networks to predict risk to estuary water quality and patterns of benthic environmental DNA in Queensland. *Integr. Environ. Assess. Manag.* 15:93-111.001: 10.1002/ieam.4091.
Greaves Ak, Letcher RJ. 2017. A review of organophosphate esters in the environment from biological effects to distribution and fate. *Bull. Environ. Contam. Toxicol*. 98(1):2-7.
Grimaldo LF, Sommer T, Van Ark N, Jones G, Holland E, Moyle PB, Herbold B, Smith P. 2009. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: can fish losses be managed? *N. Am. J. Fish. Manag.* 29:1253-1270.
Halter MT, Adams WJ, Johnson HE. 1980. Selenium toxicity to *Daphnia magna, Hyalella azteca*, and the fathead minnow in hard water. *B. Environ. Contam. Tox.* 24:102-107.
Hartman R, Sherman S, Conteras D, Furler A, Kok R. 2019. Characterizing macroinvertebrante community composition and abundance in freshwater tidal wetlands of the Sacramento-San Joaquin Delta. *PLoS One* 14(11):e0215421. https://dx.doi.org/10.1371%2Fjournal.pone.0215421. Accessed 17 May 2020.
Hasenbein S, Connon RJ, Lawler SP, Geist J. 2015a. A comparison of the sublethal and lethal toxicity of four pesticides in *Hyalella azteca* and *Chironomus dilutus*. *Environ. Sci. Pollut. Res.* 22:11327-11339.
Hasenbein S, Lawler SP, Geist J, Connon RE. 2015b. The use of growth and behavioral endpoints to assess the effects of pesticide mixtures upon aquatic organisms. *Ecotoxicology* 24:746-759.
Hasenbein M, Fangue NA, Geist J, Komoroske LM, Truong J, McPherson R, Connon RE. 2016. Assessments at multiple levels of biological organization allow for an integrative determination of physiological tolerances to turbidity in an endangered fish species. *Conserv. Physiol.* 4.
Hawkins CP, Hogue JN, Decker LM, Feminella JW. 1997. Channel morphology, water temperature, and assemblage structure of stream insects. *J. North Am. Benthol. Soc.* 16:728-749.
Heath S, Bennett WA, Kennedy J, Beitinger TL. 1994. Heat and cold tolerance of the fathead minnow, *Pimephales promelas*, exposed to the synthetic pyrethroid cyfluthrin. *Can. J. Fish. Aquat. Sci.* 51:437-440.
Herbold, B, Jassby, AD, Moyle, PB. 1992. Status and trends report on aquatic resources in the San Francisco Estuary. Report to the EPA San Francisco Estuary Project. 257pp.
Herren JR and Kawasaki SS. 2001. Inventory of water diversions in four geographic areas in California's Central Valley. *Fish Bull.* 179:343-355.

Herring CE, Stinson JM, Landis WG. 2015. Evaluating nonindigenous species management in a Bayesian networks derived relative risk framework for Padilla Bay, WA, USA. *Integr. Environ. Assess. Manag.* 11:640–652.

Hines EE, Landis WG. 2014. Regional risk assessment of the Puyallup River Watershed and the evaluation of low impact development in meeting management goals. *Integr. Environ. Assess. Manag.* 10:269–278.

IDPH [Illinois Department of Public Health]. 2007. Pyrethroid Insecticides. Environmental Health Fact Sheet. Springfield, IL. http://www.idph.state.il.us/envhealth/factsheets/pyrethroid.htm. Accessed 30 Apr 2020.

Ingebritsen SE, Ikehara ME, Galloway DL, Jones DR. 2016. Delta Subsidence in California; the Sinking Heart of the State. U.S. Geological Survey Fact Sheet 005-00. 4pp. https://pubs.usgs.gov/fs/2000/fs00500/pdf/fs00500.pdf. Accessed 17 Apr 2020.

Ingersoll CG, Dwyer FJ, May TW. 1990. Toxicity of inorganic and organic selenium to *Daphnia magna* (Cladocera) and *Chironomus riparius* (diptera). Environ. Toxicol. Chem. 9(9):1171-1181.

IPMF [Integrated Pest Management of Florida]. 2020. FRAC Code List 1: Fungicides sorted by FRAC Code. University of Florida Institute of Food and Agriculture Integrated Pest Management Program. https://ipm.ifas.ufl.edu/resources/success_stories/t&pguide/pdfs/Appendices/Appendix6-FRAC.pdf. Accessed 10 June 2020.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecol. Appl.* 5:272-289.

Jeffries KM, Komoroske LM, Truong J, Werner I, Hasenbein M, Hasenbein S, Fangue NA, Connon RA. 2015. The transcriptome-wide effects of exposure to a pyrethroid pesticide on the critically endangered Delta smelt *Hyposmesus transpacificus*. *Endangered Species Research* 28:43-60.

Jemec A, Tišler T, Drobne D, Sepčić K, Fournier D, Trebše P. 2007. Comparative toxicity of imidacloprid, of its commercial liquid formulation and of diazinon to a non-target arthropod, the microcrustacean *Daphnia magna*. *Chemosphere* 68:1408-1418.

Johns AF, Graham SE, Harris MJ, Markiewicz AJ, Stinson JM, Landis W. 2017. Using the Bayesian network relative risk model risk assessment process to evaluate management alternatives for the South River and upper Shenandoah River, Virginia. *Integr. Environ. Assess. Manag.* 13:100-114.

Jung G, Popko J, Dicklow B, Wick R. 2010. Chemical Classes and Modes of Action of Fungicides Registered for Use on Turfgrasses. University of Massachusetts-Amherst. Department of Plant, Soil, and Insect Sciences. https://www.doyourownpestcontrol.com/SPEC/technical-bulletin/UMassfungicide_class_mode.pdf. Accessed 29 May 2020.

Kimmerer WJ. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? *Mar. Ecol. Prog. Ser.* 243:39-55.

Komoroske LM, Connon RE, Lindberg J, Cheng BS, Castillo G, Hasenbein M, Fangue NA. 2014. Ontogeny influences sensitivity to climate change stressors in an endangered fish. *Conserv. Physiol. 2*(1):1-13. doi:10.1093/conphys/cou008.

Kuivila KM, Barnett HD, Edmunds JL. 1999. Herbicide Concentrations in the Sacramento-San Joaquin Delta, California. In U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999, Water-Resources Investigations Report 99-4018 B, Volume 2 of 3, Contamination of hydrologic Systems and Related Ecosystems. 504pp.

Laetz CA, Baldwin DH, Herbert V, Stark JD, Scholz NL. 2013. Interactive neurobehavioral toxicity of diazinon, malathion, and ethoprop to juvenile Coho salmon. *Environ. Sci. Technol.* 47:2925-2931.
Landis W and Wiegers J. 1997. Design considerations and a suggested approach for regional and comparative ecological risk assessment. *Hum Ecol Risk Assess* 3:287-297.
Landis W and Wiegers J. 2005. Introduction to the regional risk assessment using the relative risk model. In: Landis W (ed), Regional Scale Ecological Risk Assessment Using the Relative Risk Model, pp 11-36. CRC Press, Boca Raton, FL, USA.
Landis WG and Wiegers JK. 2007. Ten years of the relative risk model and regional scale ecological risk assessment. *Hum. Ecol. Risk Assess.* 13: 25-38.
Landis WG, Ayre KK, Johns AF, Summers HM, Stinson J, Harris MJ, Herring CE, Markiewicz AJ. 2017a. The Multiple Stressor Ecological Risk Assessment for the Mercury Contaminated South River and Upper Shenandoah River Using the Bayesian Network-Relative Risk Model. *Integr. Environ. Assess. Manag.* 13:85-99.
Landis WG, Markiewicz AJ, Ayre KK, Johns AF, Harris MJ, Stinson JM, Summers HM. 2017b. A general risk-based adaptive management scheme incorporating the Bayesian network Relative Risk Model with the South River, Virginia, as case study. *Integr Environ Assess Manag.* 13:115-126.
Landis WG, Chu VR, Graham SE, Harris MJ, Markiewicz AJ, Mitchell CJ, von Stackelberg KE, Stark JD. 2020. Integration of chlorpyrifos acetylcholinesterase inhibition, water temperature, and dissolved oxygen concentration into a regional scale multiple stressor risk assessment estimating risk to Chinook salmon. *Integr. Environ. Asses*. 16(1):28-42.
Ligocki IY, Munson A, Farrar V, Viernes R, Sih A, Connon RE, Calisi RM. 2019. Environmentally relevant concentrations of bifenthrin affect the expression of estrogen and glucocorticoid receptors in brains of female western mosquitofish. *Aquatic Toxicology* 209:121-131.
Livingston A. 2015. Land Use and Conservation in the Central Valley: Challenges and Opportunities for Land Trusts in California's Heartland. Sequoia Riverlands Trust, Southern Sierra Partnership. Presentation for the 2015 California Council of Land Trusts Conference. https://www.calandtrusts.org/wp-content/uploads/2015/03/Land-Use-and-Conservation-in-the-Central-Valley.pdf. Accessed 11 May 2020.
Maryoung LA, Lavado R, Schlenk D. 2014. Impacts of hypersaline acclimation on the acute toxicity of the organophosphate chlorpyrifos to salmonids. *Aquatic Toxicology* 152: 284-290.
Mazor RD, Rehn AC, Ode PR, Engeln M, Schiff KC, Stein ED, Gillett DJ, Herbst DB, Hawkins CP. 2016. Bioassessment in complex environments: designing an index for consistent meaning in different settings. *Freshw. Sci.* 35:249–271
Michel CJ, Ammann AJ, Lindley ST, Sandstrom PT, Chapman ED, Thomas MJ, Singer GP, Klimley AP, MacFarlane RB. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. *Can. J. Fish. Aquat. Sci.* 72:1749-1759.
Monismith SG, Hench JL, Fong DA, Nidzieko NJ, Fleenor WE, Doyle LP, Schladow SG. 2009. Thermal variability in a tidal river. *Estuaries Coast* 32:100-110.
Monsen NE, Cloern JE, Burau JR. 2007. Effects of flow diversions on water and habitat quality: Examples from California's highly manipulated Sacramento–San Joaquin Delta. *San Franc. Estuary Watershed Sci.* 5.
Moyle PB, Brown LR, Durand JR, Hobbs JA. 2016. Delta smelt: life history and decline of a once-abundant species in the San Francisco Estuary. *San Franc. Estuary Watershed Sci.* 14(2) Article 7. https://ca.water.usgs.gov/pubs/2016/Brown_delta-smelt-life-decline_2016.pdf. Accessed 3 May 2020.
NLCD [National Land Cover Database]. 2016. 2016 Land Cover, The Multi-Resolution Land Characteristics Consortium (MRLC). https://www.mrlc.gov/data. Accessed 31 May 2020.

Nobriga ML, Sommer TR, Feyrer F, Fleming K. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. *San Franc. Estuary Watershed Sci. 6*(1).
NPIC [National Pesticide Information Center]. 2020a. Imidacloprid General Fact Sheet. http://npic.orst.edu/factsheets/archive/imidacloprid.html. Accessed 5 May 2020.
NPIC [National Pesticide Information Center]. 2020b. Fipronil General Fact Sheet. http://npic.orst.edu/factsheets/fipronil.html. Accessed 7 May 2020.
NPIC [National Pesticide Information Center]. 2020c. Fungicides. http://npic.orst.edu/ingred/ptype/fungicide.html. Accessed 18 May 2020.
O'Brien GC, Dickens C, Hines E, Wepner V, Stassen R, Quayle L, Fouchy K, MacKenzie J, Graham PM, Landis WG**.** 2018. A regional-scale ecological risk framework for environmental flow evaluations. *Hydrol. Earth Syst. Sci.,* 22, 957–975.
R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/. Accessed 24 Apr 2020.
Raymond-Delpech V, Matsuda K, Sattelle BM, Rauh JJ, Sattelle DB. 2005. Ion channels: molecular targest of neuroactive insecticides. *Invertebrate Neuroscience* 5(3-4):119-133. doi:10.1007/s10158-005-0004-9.
Regional San. 2020. Mercury in the Central Valley. https://www.regionalsan.com/post/mercury-central-valley. Accessed 30 Apr 2020.
Reynaldi S, Liess M. 2005. Influence of duration of exposure to the pyrethroid fenvalerate on sublethal responses and recovery of *Daphnia magna* Straus. *Environ. Toxicol. Chem.* 24(5):1160-1164.
RWQCB [Regional Water Quality Control Board]. 2000. Selenium TMDL for Grasslands Marshes. Staff Report of the California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region. 14pp. https://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/grasslands_se/grasslands_se_tmdl.pdf. Accessed 5 May 2020.
Rehn AC, Mazor RD, Ode PR. 2015. The California Stream Condition Index (CSCI): A New Statewide Biological Scoring Tool for Assessing the Health of Freshwater Streams. SWAMP Technical Memorandum SWAMP-TM-2015-2. https://www.waterboards.ca.gov/water_issues/programs/swamp/bioassessment/docs/csci_tech_memo.pdf. Accessed 29 May 2020.
Rider CV, LeBlanc GA. 2005. An integrated addition and interaction model for assessing toxicity of chemical mixtures. *Toxicol. Sci.* 87(2):520-528.
Ritz C, Streibig JC. 2020. Analysis of dose-response curves. Package "drc" version 3.0-1. Available at https://github.com/DoseResponse/drc. Accessed 22 Apr 2020.
Sadaria AM, Sutton R, Moran KD, Teerlink J, Brown JV, Halden RU. 2017. Passage of fiproles and imidacloprid from urban pest control uses through wastewater treatment plants in northern California, USA. *Environ. Toxicol. Chem*., 36(6):1473-1482.
Scheuhammer AM, Meyer MW, Sandheinrich MB, Murray MW. 2007. Effects of environmental methylmercury on the health of wild birds, mammals and fish. *Ambio* 36(1):12-18.
SFEI and ASC [San Francisco Estuary Institute and The Aquatic Science Center]. 2014. A Delta Transformed; ecological functions, spatial metrics, and landscape change in the Sacramento-San Joaquin Delta. A Report of the Delta Landscape Project: Management Tools for Landscape-Scale Restoration of Ecological Functions. Prepared for the California Department of Fish and Wildlife and Ecosystem Restoration Program. October 2014. 133p. https://www.sfei.org/sites/default/files/biblio_files/DeltaTransformed_SFEI_110414.pdf. Accessed 25 May 2020.

SFEI and ASC [San Francisco Estuary Institute and The Aquatic Science Center]. 2019. California Environmental Data Exchange Network (CEDEN). https://www.sfei.org/projects/california-environmental-data-exchange-network-ceden. Accessed 3 Dec 2019.

Soderlund DM. 2010. Chapter 77 - Toxicology and Mode of Action of Pyrethroid Insecticides. In Hayes' Handbook of Pesticide Toxicology (Third Edition). Academic Press. Pgs 1665-1686. https://www.sciencedirect.com/science/article/pii/B978012374367100077X. Assessed 5 May 2020.

Soderlund DM. 2012. Molecular mechanisms of pyrethroid insecticide neurotoxicity: recent advances. *Arch. Toxicol.* 86:165-181.

Sommer T, Mejia FH, Nobriga ML, Feyrer F, Grimaldo L. 2011. The spawning migration of Delta smelt in the upper San Francisco Estuary. *San Franc. Estuary Watershed Sci.* 9.

SRTMDL [Sacramento River TMDL] Unit. 2002. Upper Sacramento River TMDL for Cadmium, Copper, and Zinc. Final Report. April 2002. California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region. 207pp. https://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/upper_sacramento_cd_cu_zn/tmdl_final_rpt_apr2002.pdf. Accessed 30 Apr 2020.

Steevens JA, Benson WH. 2001. Toxicokinetic interactions and survival of *Hyalella azteca* exposed to binary mixtures of chlorpyrifos, dieldrin, and methyl mercury. *Aquat. Toxicol.* 51:377-388.

Swanson C, Reid T, Young PS, Cech Jr JJ. 2000. Comparative environmental tolerances of threatened Delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. *Oecologia* 123:384-390.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. *Trans. Am. Fish. Soc.* 101: 442-452.

USBR [U.S. Bureau of Reclamation]. 2019. Reinitiation of consultation on the coordinated long-term operation of the Central Valley Project and State Water Project: Final Biological Assessment. https://www.usbr.gov/mp/bdo/lto.html. Accessed 5 May 2020

USEPA [United States Environmental Protection Agency]. 2013. Chapter 5: Organophosphates. In Recognition and Management of Pesticide Poisonings: 6th Edition, JR Roberts and JR Reigart. USEPA Office of Pesticide Programs, EPA 735K13001, pgs 44-55. https://www.epa.gov/sites/production/files/documents/rmpp_6thed_ch5_organophosphates.pdf. Accessed 28 Apr 2020.

USEPA [United States Environmental Protection Agency]. 2020a. Aquatic Life Benchmarks and Ecological Risk Assessments for Registered Pesticides. USEPA Office of Pesticide Programs. https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/aquatic-life-benchmarks-and-ecological-risk. Accessed 28 Apr 2020.

USEPA [United States Environmental Protection Agency]. 2020b. Triazine Cumulative Risk Assessment and Atrazine, Simazine, and Propazine Decisions; June 22, 2006. https://web.archive.org/web/20130601222524/http://www.epa.gov/oppsrrd1/cumulative/triazine_fs.htm. Accessed 25 Apr 2020.

USEPA [United States Environmental Protection Agency]. 2020c. Data Downloads: NPDES. https://echo.epa.gov/tools/data-downloads. Accessed 25 Apr 2020.

USFW [U.S. Fish and Wildlife]. 2020. Delta juvenile fish monitoring program. Lodi, CA: U.S. Department of Interior. https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm, https://www.fws.gov/lodi/juvenile_fish_monitoring_program/djfmp/?dir=Metadata. Accessed 14 May 2020.

USGS [United States Geological Survey]. 2020a. National Hydrography Dataset (NHD); major rivers and streams. https://www.usgs.gov/core-science-systems/ngp/national-hydrography. Accessed 31 May 2020.

Wagner RW, Stacey M, Brown LR, Dettinger M. 2011. Statistical models of temperature in the Sacramento–San Joaquin Delta under climate-change scenarios and ecological implications. *Estuaries Coast* 34:544-556.

WEF [Water Education Foundation]. 2020a. Sacramento-San Joaquin Delta Land Use and Boundaries. https://www.watereducation.org/aquapedia/sacramento-san-joaquin-delta-land-use-and-boundaries. Accessed 14 May 2020.

Weston DP, You J, Lydy, MJ. 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. *Environ. Sci. & Technol*. 38: 2752-2759.

Weston, D.P., R.W. Holmes, J. You, and M.J. Lydy. 2005. Aquatic toxicity due to residential use of pyrethroid insecticides. *Environ. Sci. & Technol*. 39: 9778-9784.

Weston DP, Holmes RW. 2007. Monitoring Plan: Sources, Seasonality, and Toxicity of Pyrethroid Pesticides in the Sacramento-San Joaquin River Delta. Transport of Pyrethroid Pesticides in the in the Sacramento-San Joaquin River Delta: Sources, Seasonality, and Toxicity. 13pp. https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/workplans/0607_r5wpappx.pdf. Accessed 5 May 2020.

Ward GS, Hollister TA, Heitmuller PT, Parrish PR. 1981. Acute and chronic toxicity of selenium to estuarine organisms. *Northeast Gulf Sci.* 4(2):73-78.

Ward GS, Ballantine L. 1985. Acute and chronic toxicity of atrazine to estuarine fauna. *Estuaries* 8(1):22-27.

Wood ML, Foe CG, Cooke J, Louie SJ. 2010. Sacramento-San Joaquin Delta Estuary TMDL for Methylmercury. Staff Report. California Environmental Protection Agency, Regional Water Quality Control Board, Central Valley Region. 376pp.

WSSA [Weed Science Society of America]. 2020. WSSA-Herbicide Site of Action (SOA) Classification List. http://wssa.net/wp-content/uploads/WSSA-Herbicide-SOA-2020-5-12.xlsx. Accessed 20 Apr 2020.

Wu-Smart J, Spivak M. 2016. Sub-lethal effects of dietary neonicotinoid insecticide exposure on honey bee queen fecundity and colony development. *Sci. Rep.* 6:32108.

Yoshiyama RM, Fisher FW, Moyle PB. 1998. Historical abundance and decline of chinook salmon in the Central Valley region of California. *N. Am. J. Fish. Manag* 18(3):487-521.

Zaffer H, Irshad U, Pervez A, Naqvi TA. 2016. Mode of Action, Toxicity and Biodegradation of Organochlorine Pesticides: A Mini Overview. *J. Appl. Environ. Biol. Sci*. 6(8):1-6. https://www.researchgate.net/publication/306399965_Mode_of_action_toxicity_and_biodegradation_of_organochlorinated_pesticides_A_mini_review.

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 $1-\alpha$; 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

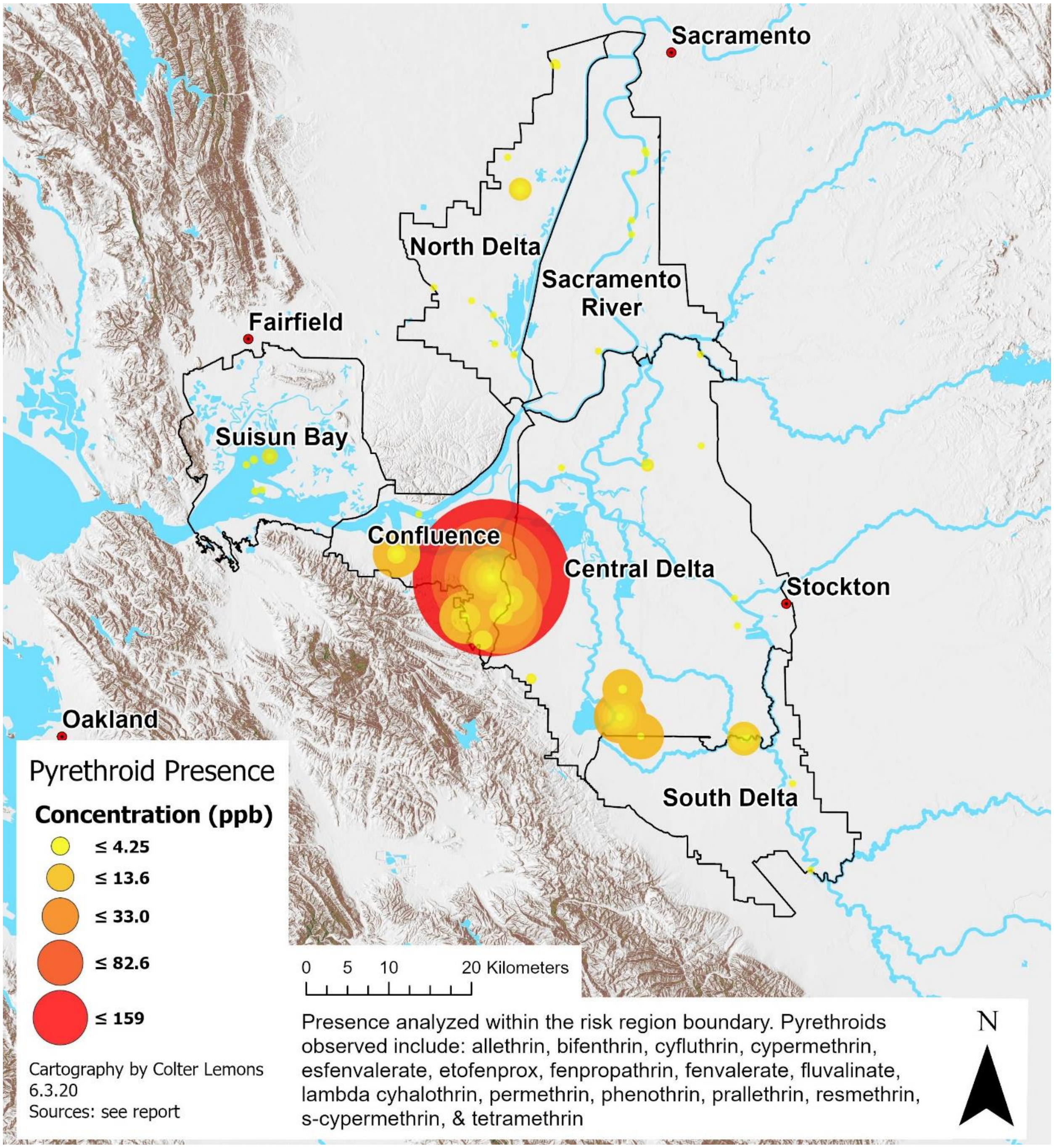


Figure D1 Pyrethroid pesticide distributions and concentrations within the study area.

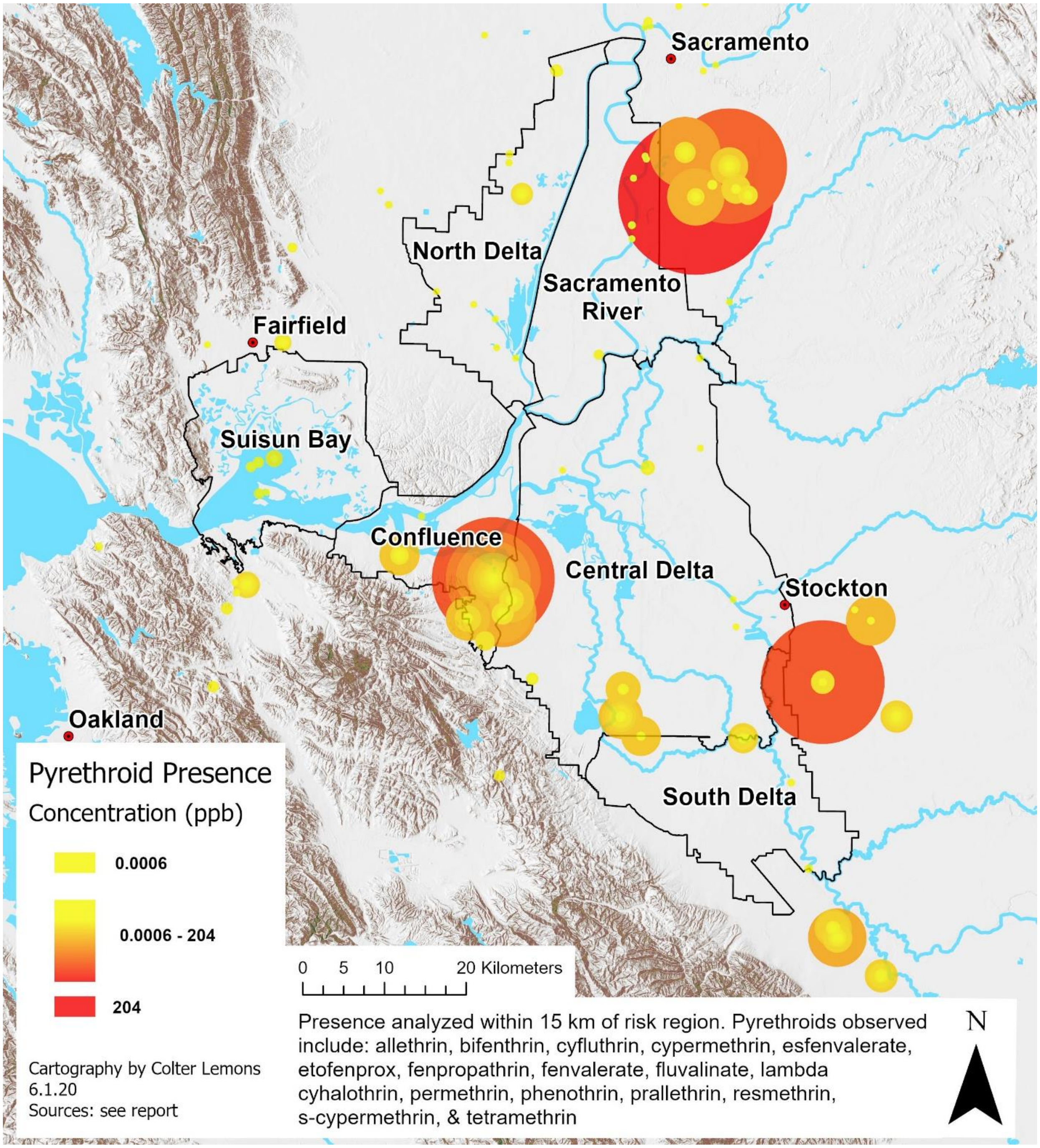


Figure D2 Pyrethroid pesticide distributions and concentrations within the study area and 15 km buffer outside the study area.

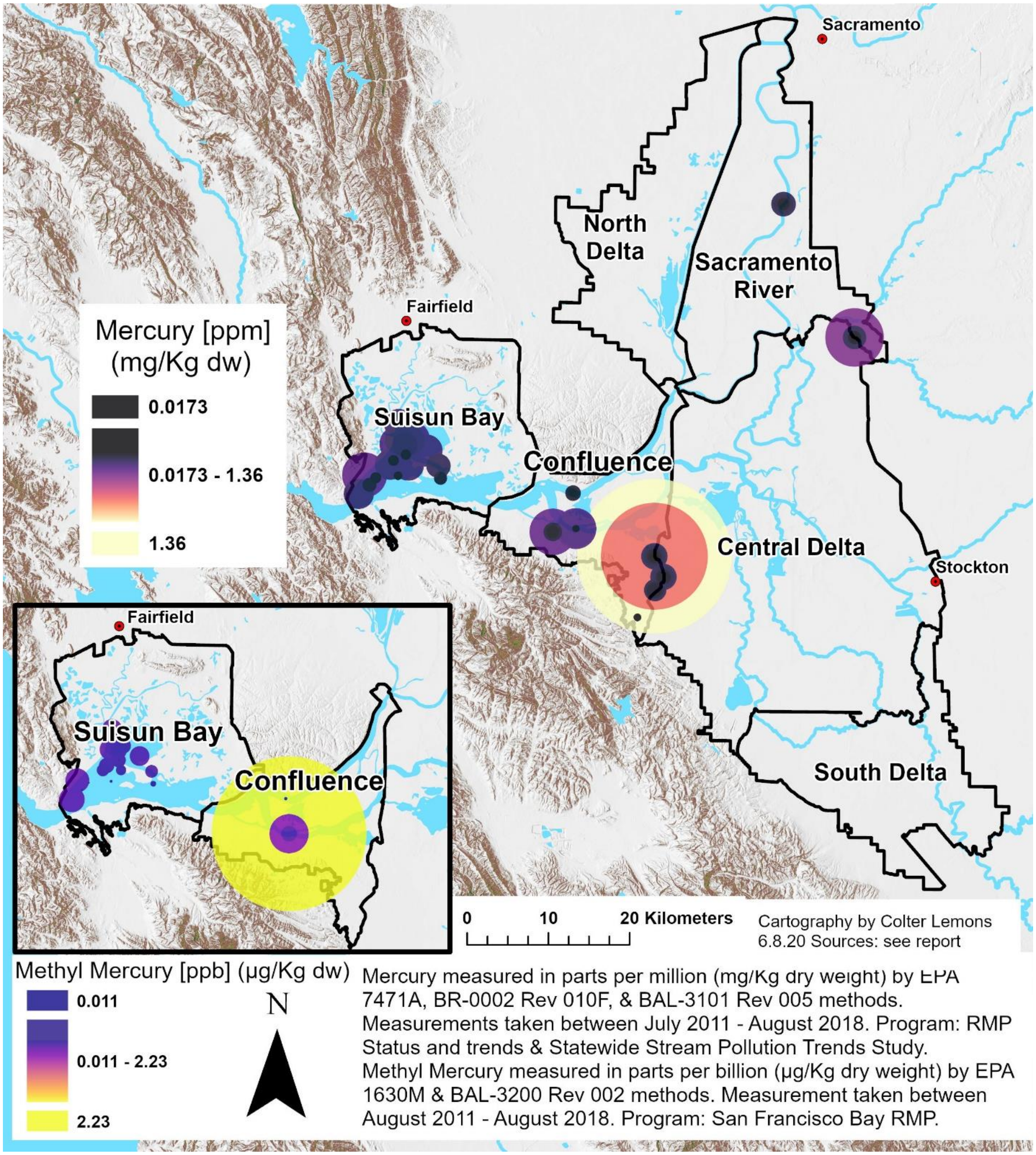


Figure D3 Mercury and methylmercury (dry weight) distributions and concentrations within the study area.

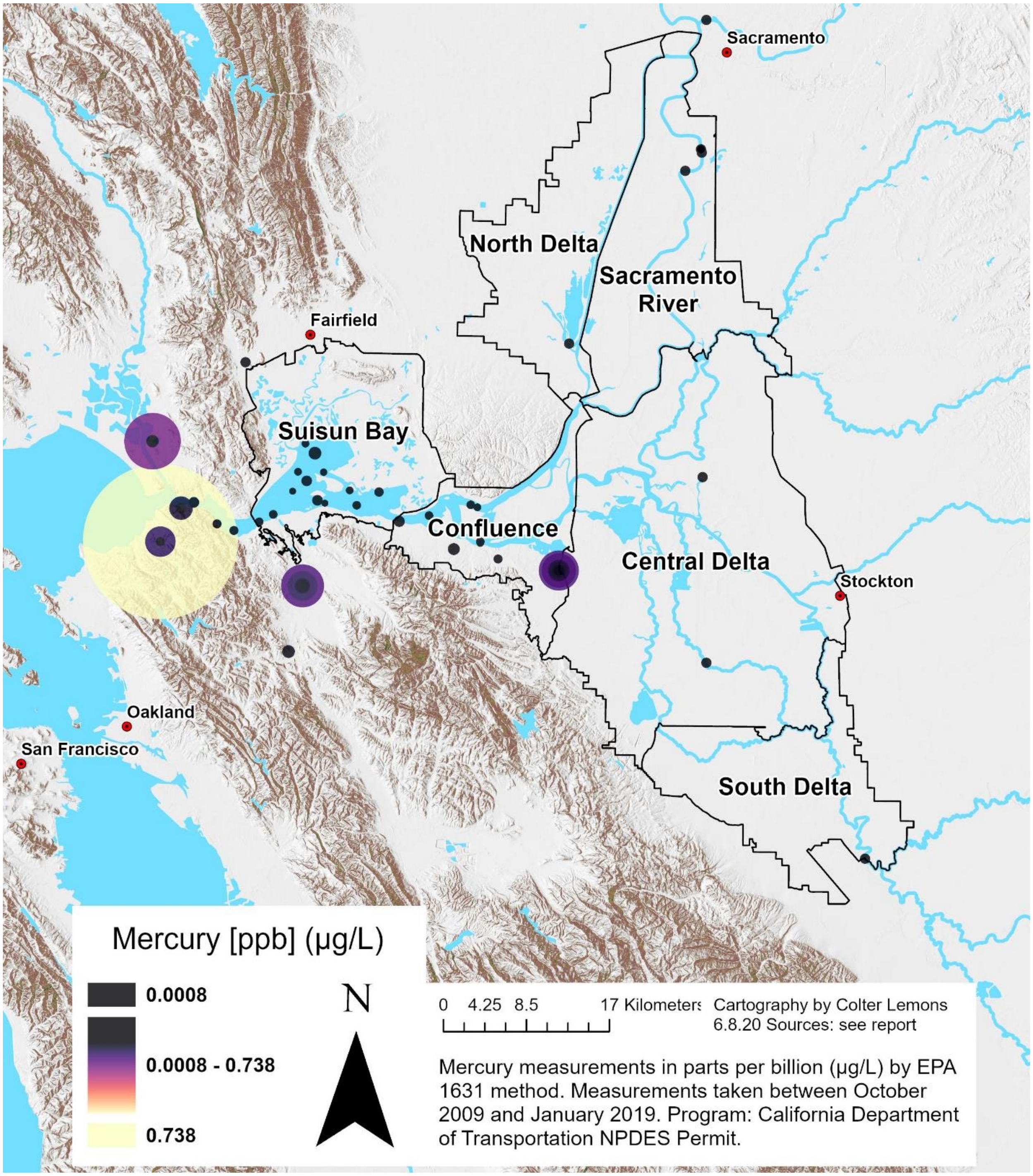


Figure D4 Mercury (Total) distributions and concentrations within the study area and 15 km buffer outside the study area.

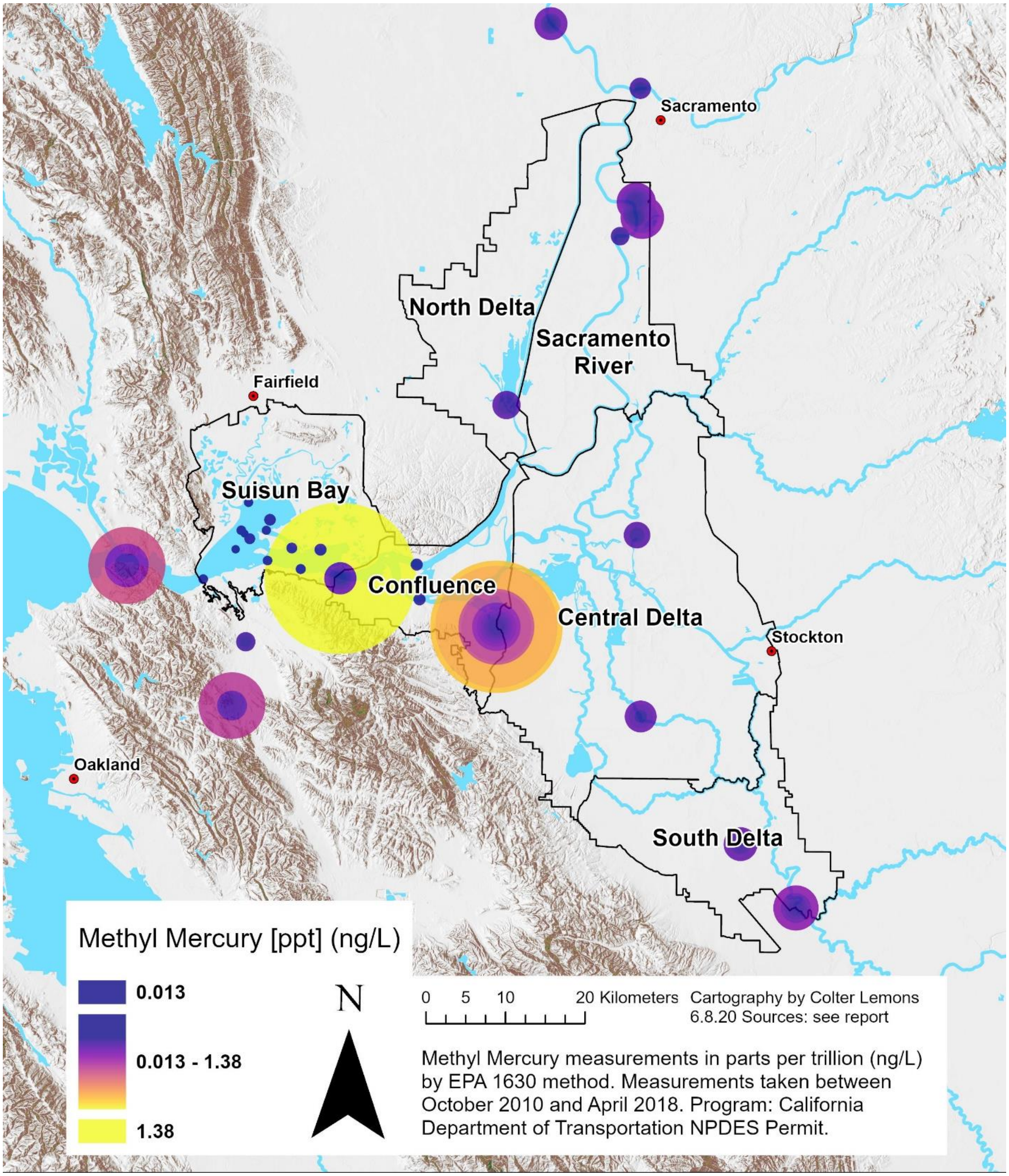


Figure D5 Methylmercury (Total) distributions and concentrations within the study area and 15 km buffer outside the study area.

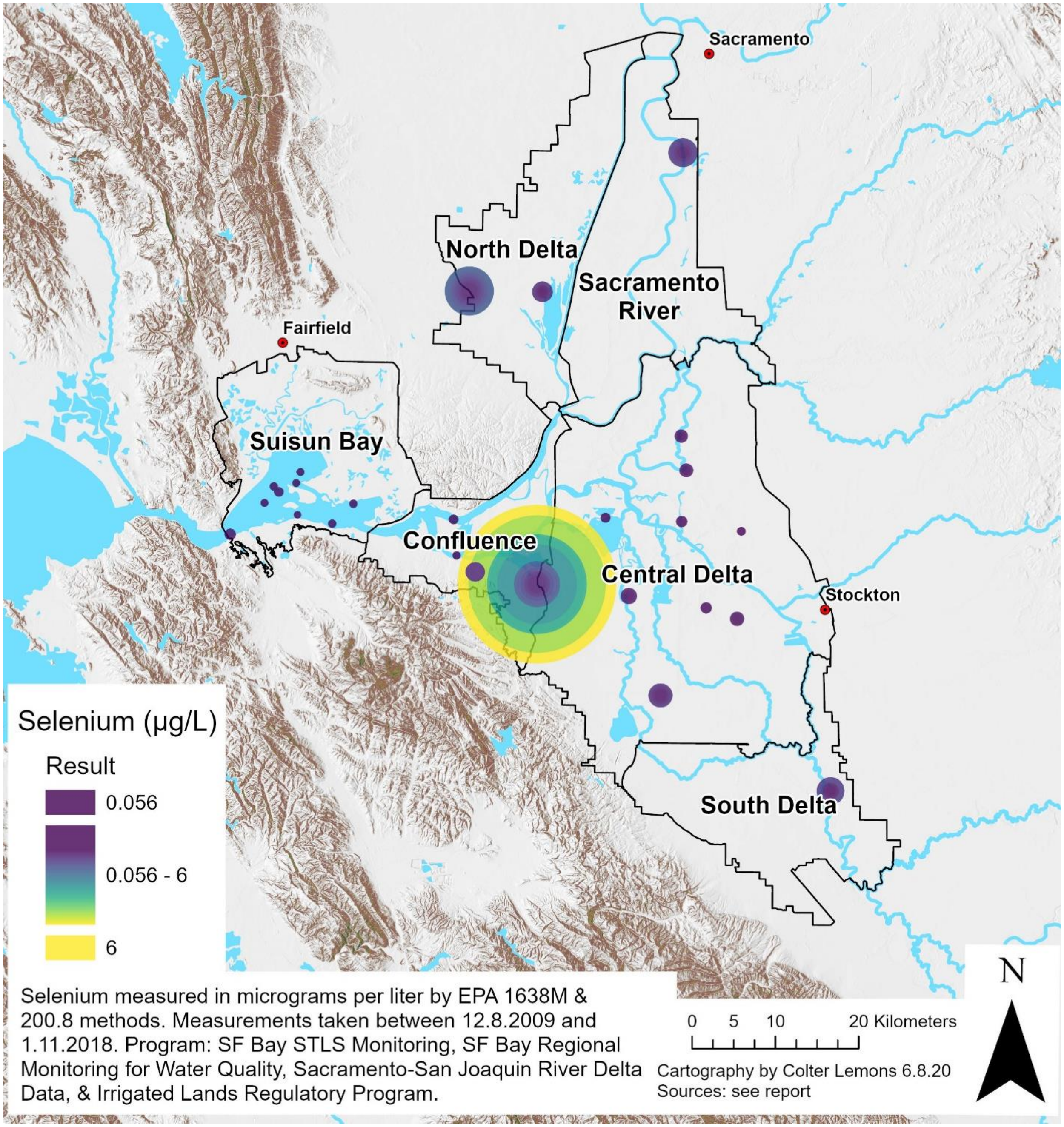


Figure D6 Selenium distributions and concentrations within the study area.

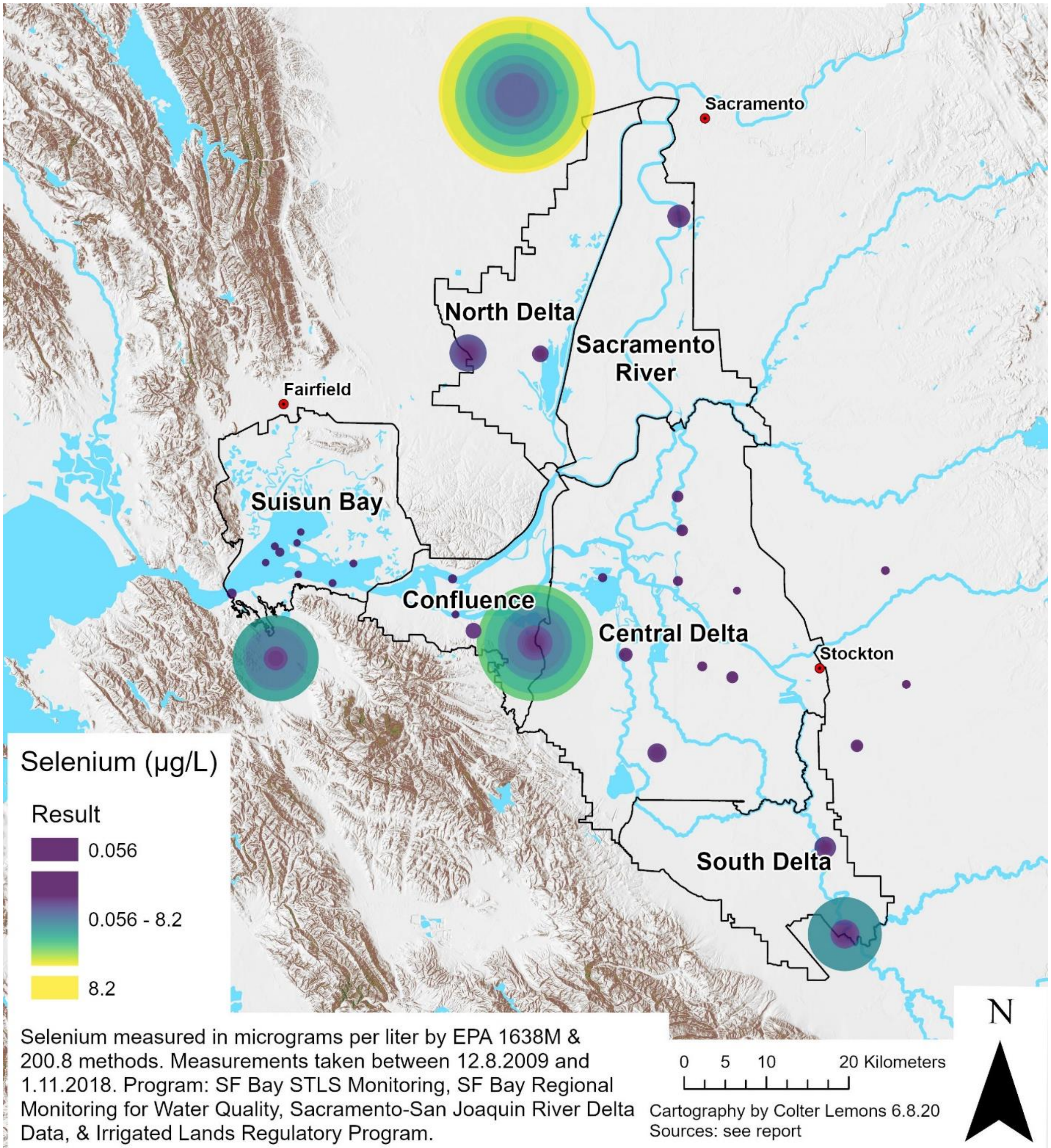
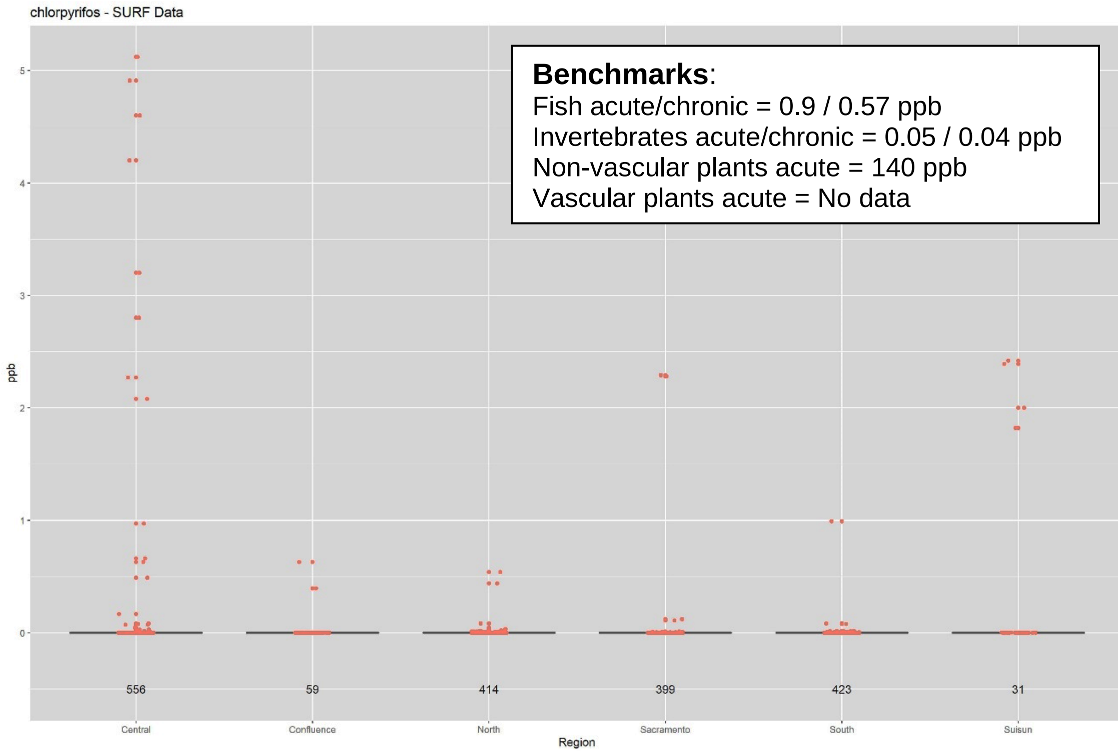
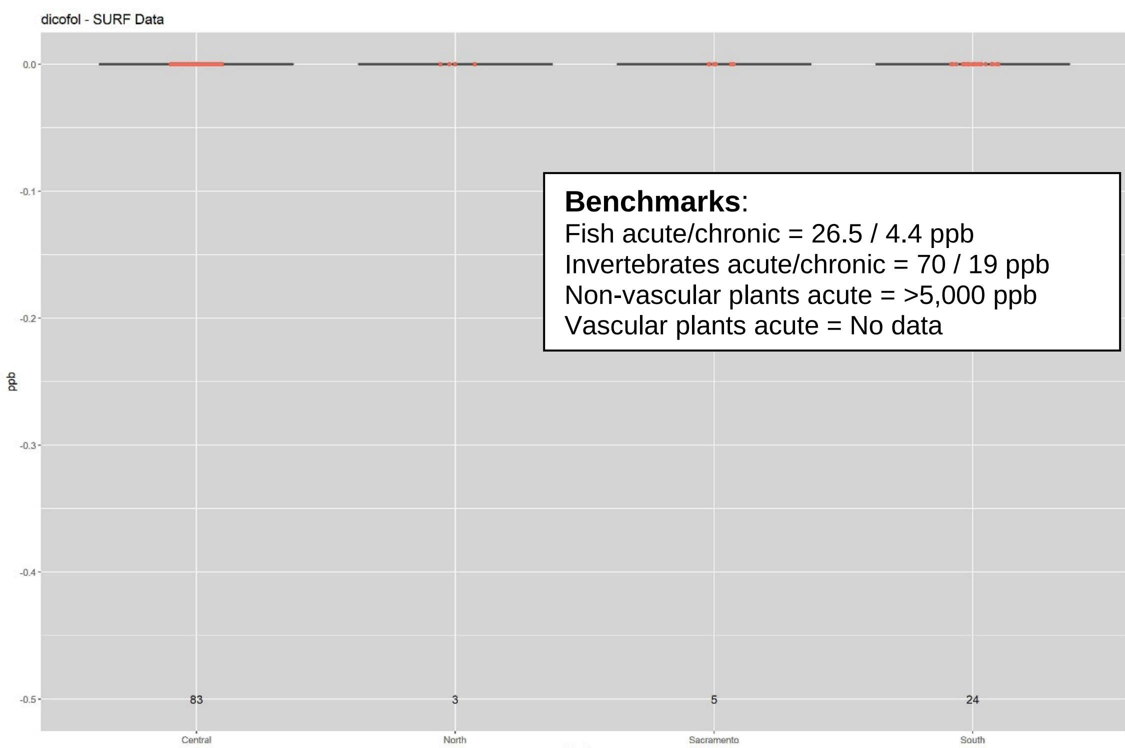
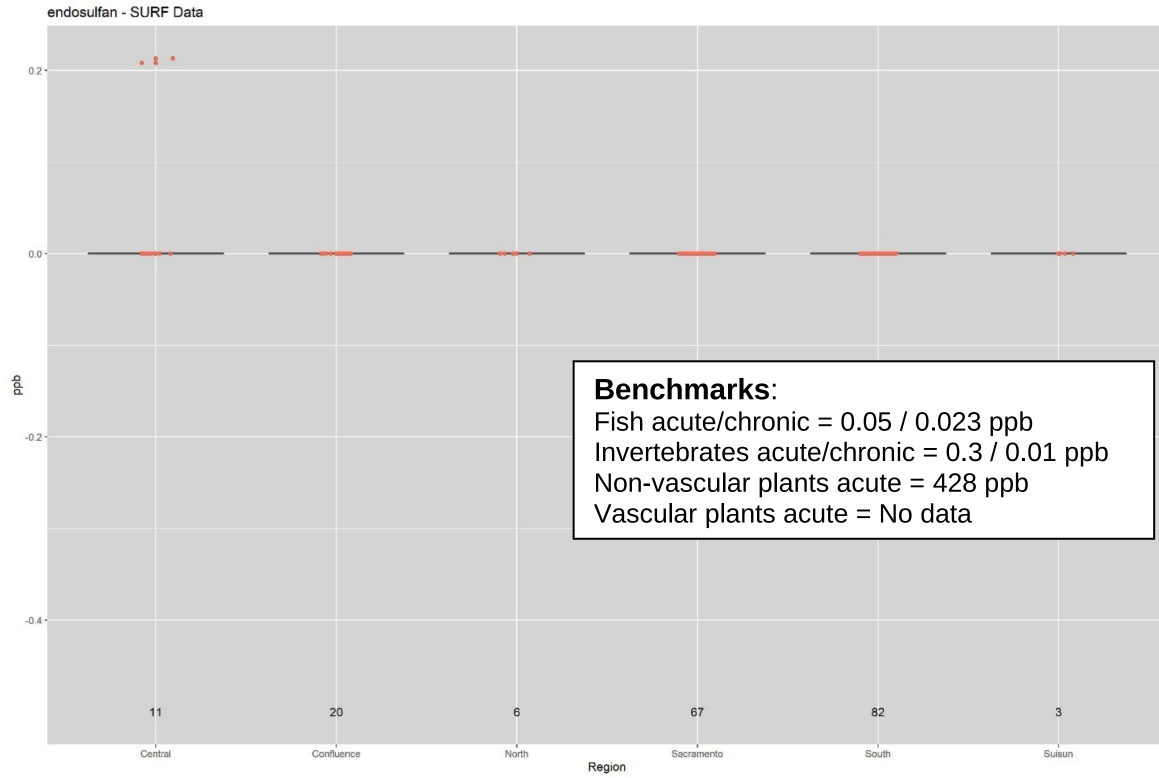


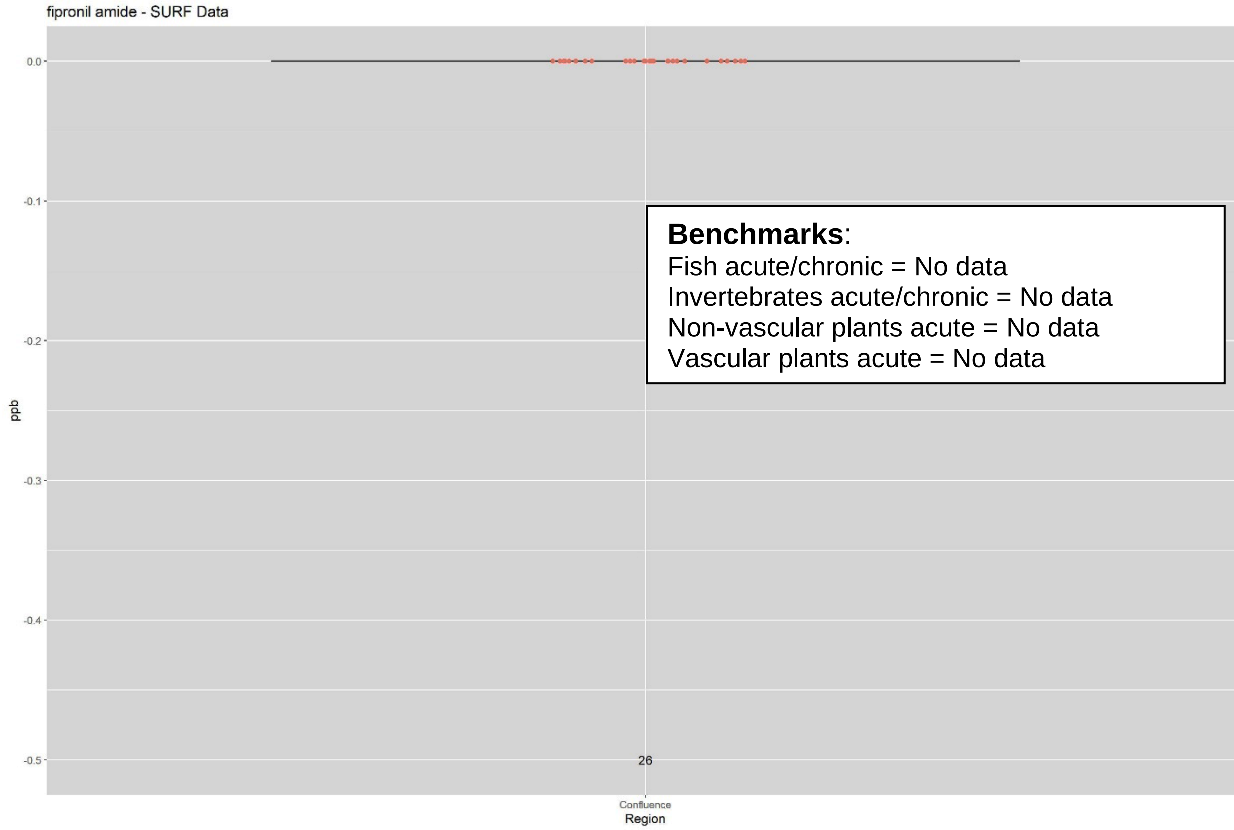
Figure D7 Selenium distributions and concentrations within the study area and 15 km buffer outside the study area

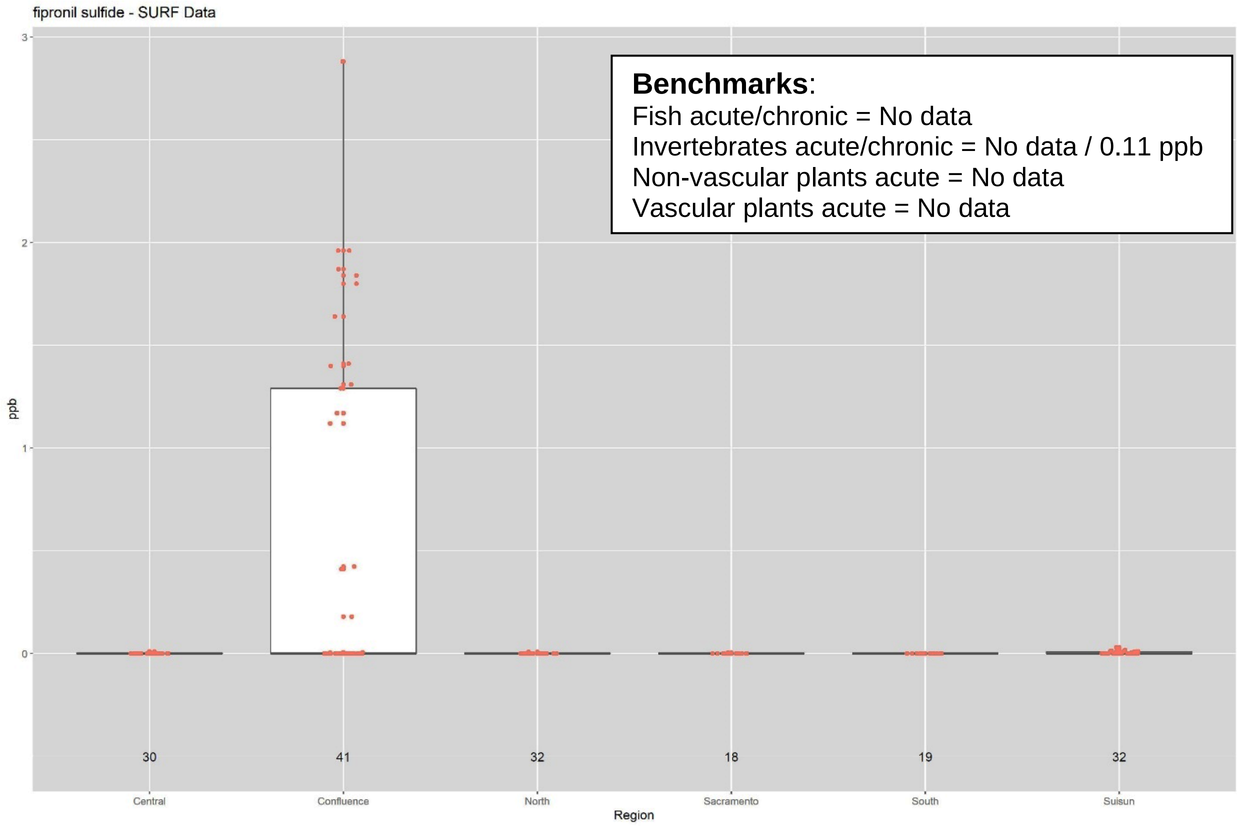
Appendix E. Boxplots of Risk Region Aqueous Pesticide Data from 2009 - 2019. (Data were obtained from the SURF database and plotted using R software). Plots are for chlorpyrifos, dicofol, endosulfan, fipronil amide, fipronil sulfide, fipronil sulfone, lambda cyhalothrin, lindane, malathion, permethrin,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

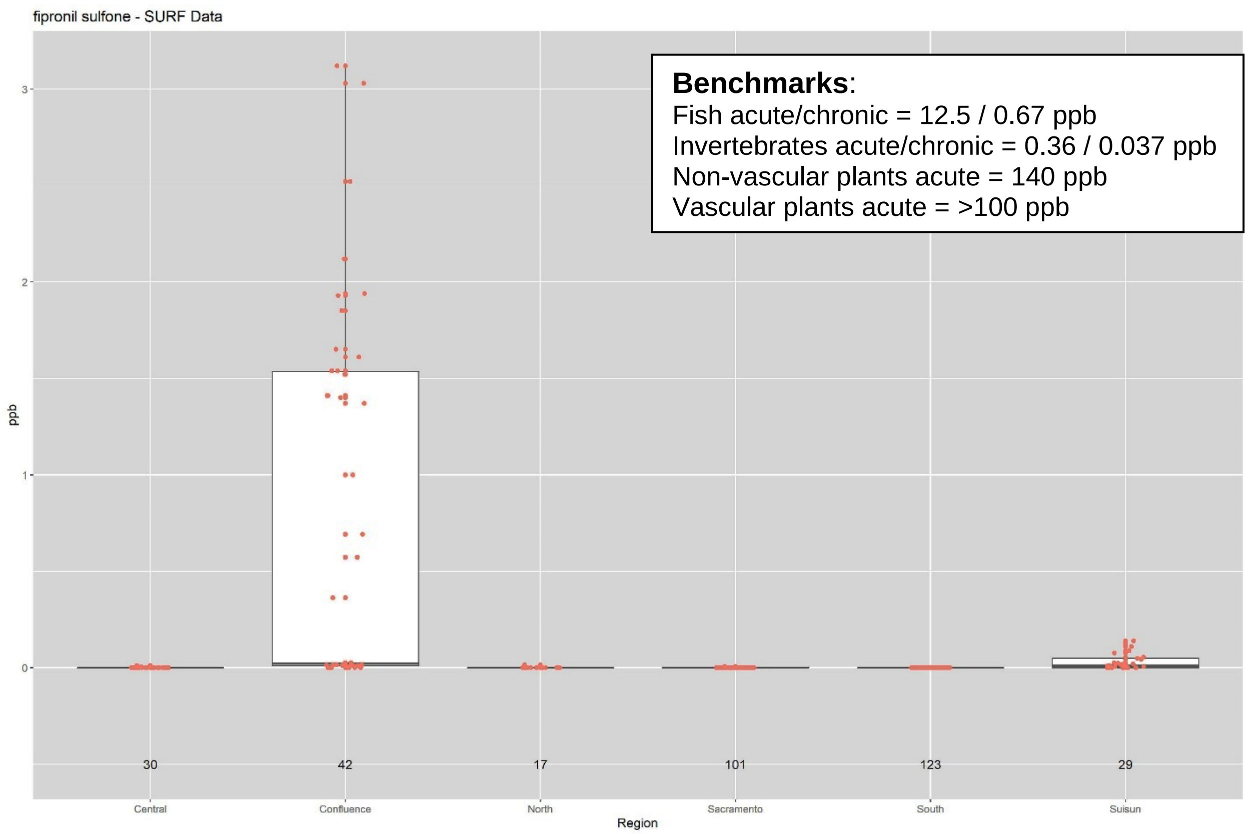


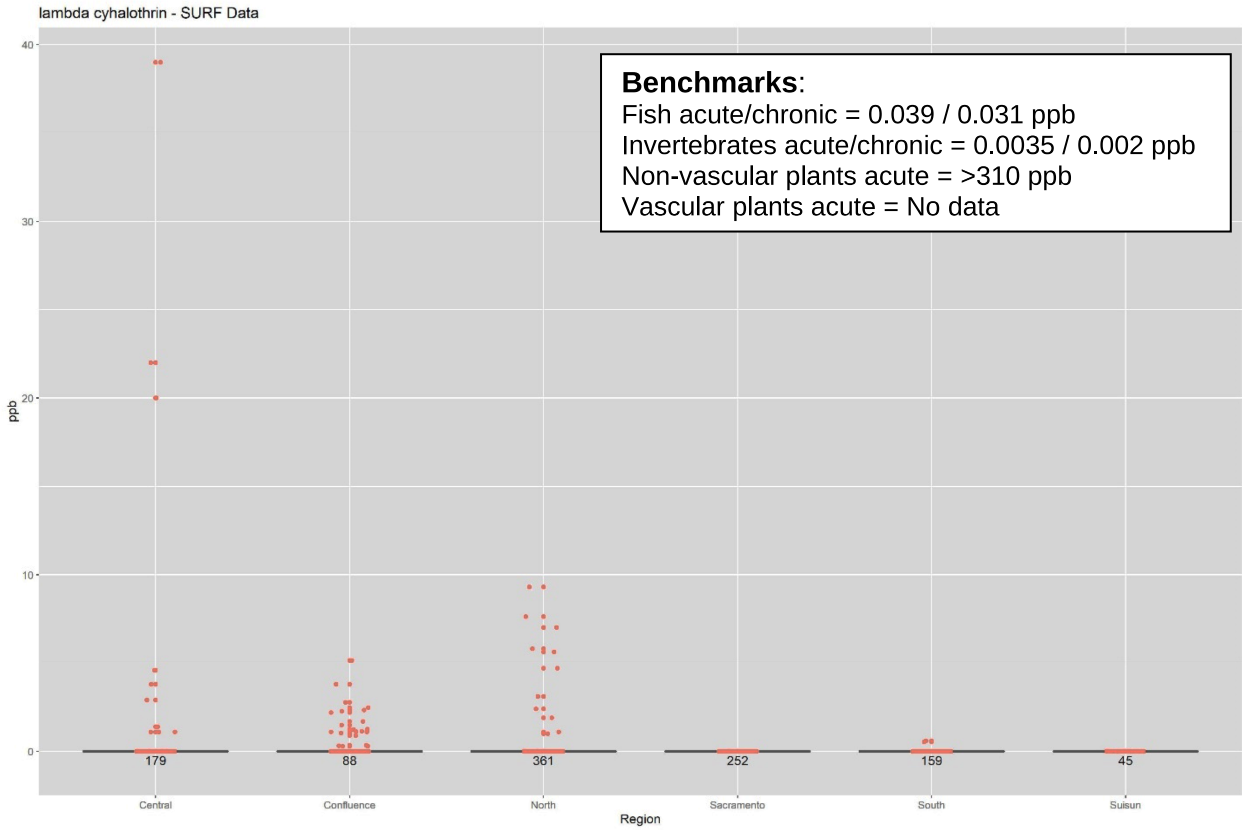


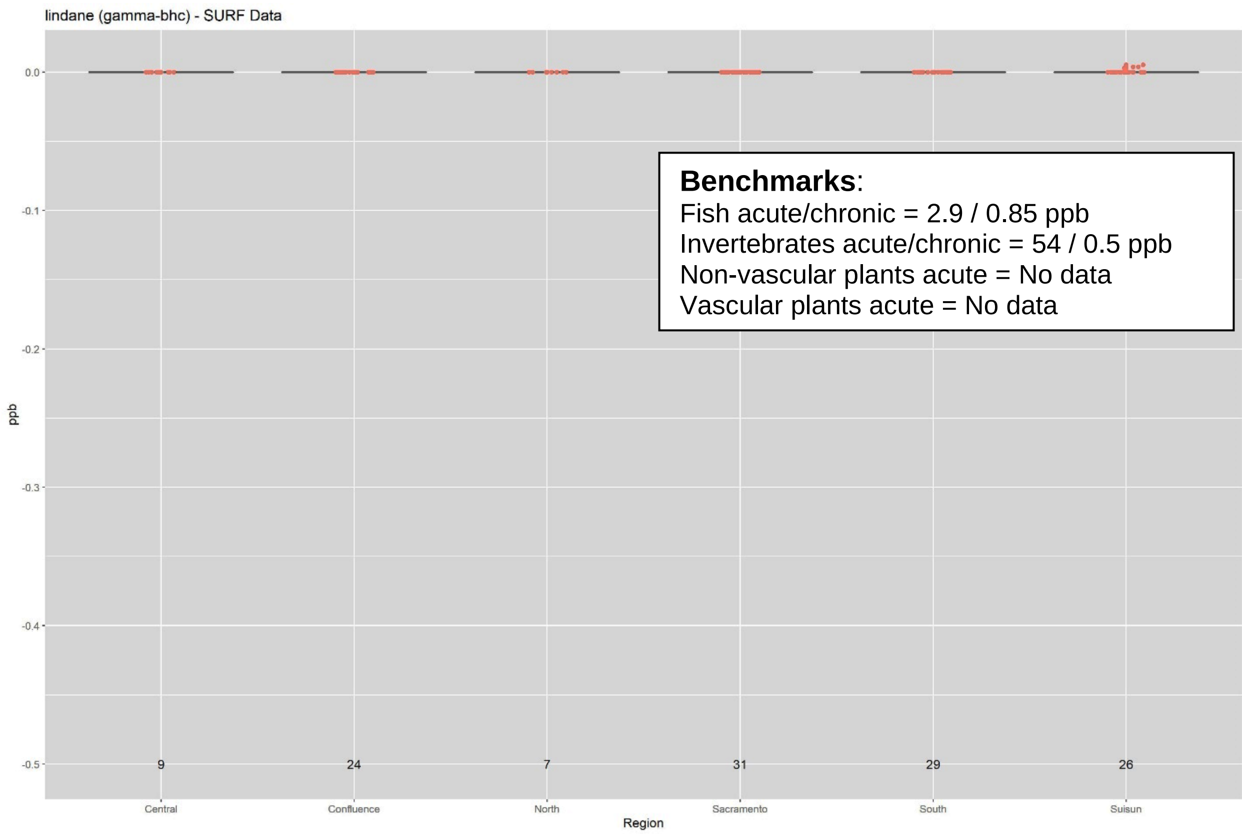

endosulfan - SURF Data
ppb
0.2
0.0
-0.2
-0.4
11
20
6
67
82
3
Central
Confluence
North
Sacramento
South
Suisun
Region
Benchmarks:
Fish acute/chronic = 0.05 / 0.023 ppb
Invertebrates acute/chronic = 0.3 / 0.01 ppb
Non-vascular plants acute = 428 ppb
Vascular plants acute = No data

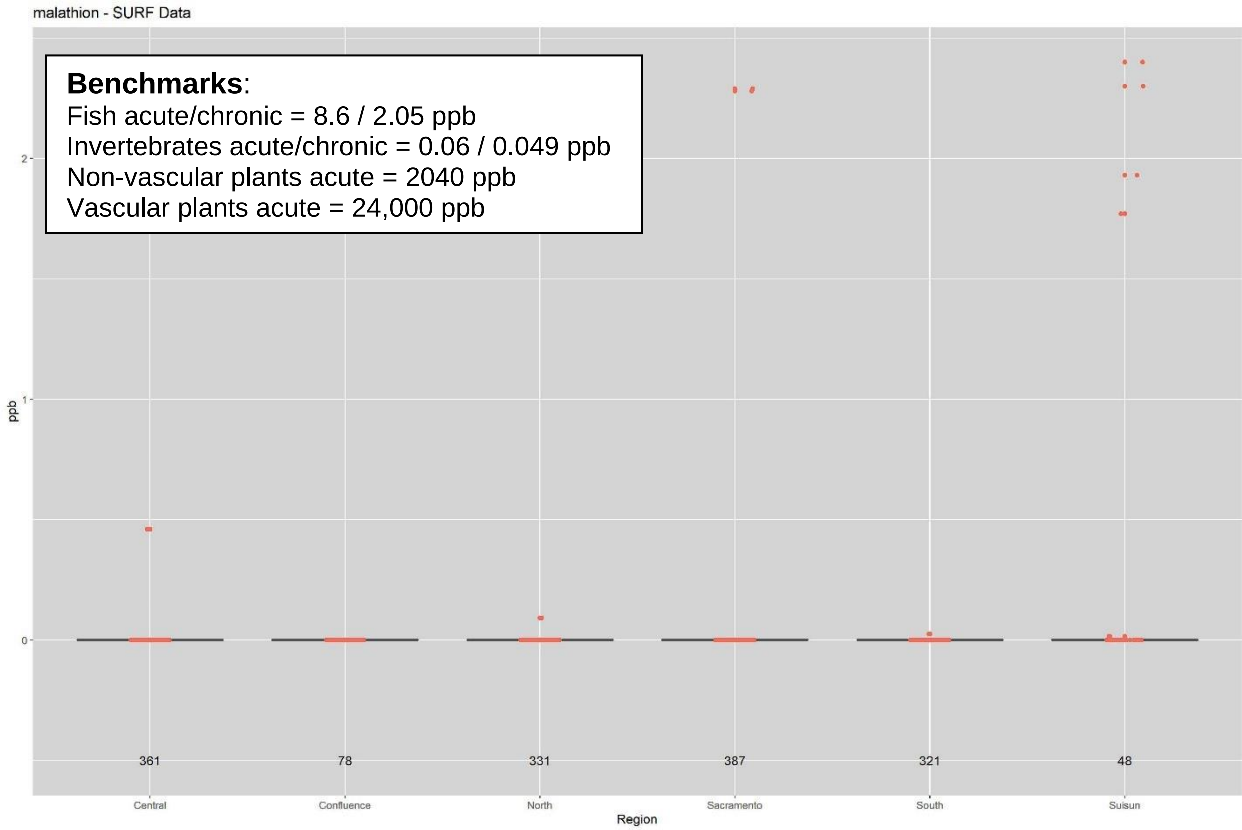

fipronil amide - SURF Data
ppb
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
26
Confluence
Region
Benchmarks:
Fish acute/chronic = No data
Invertebrates acute/chronic = No data
Non-vascular plants acute = No data
Vascular plants acute = No data

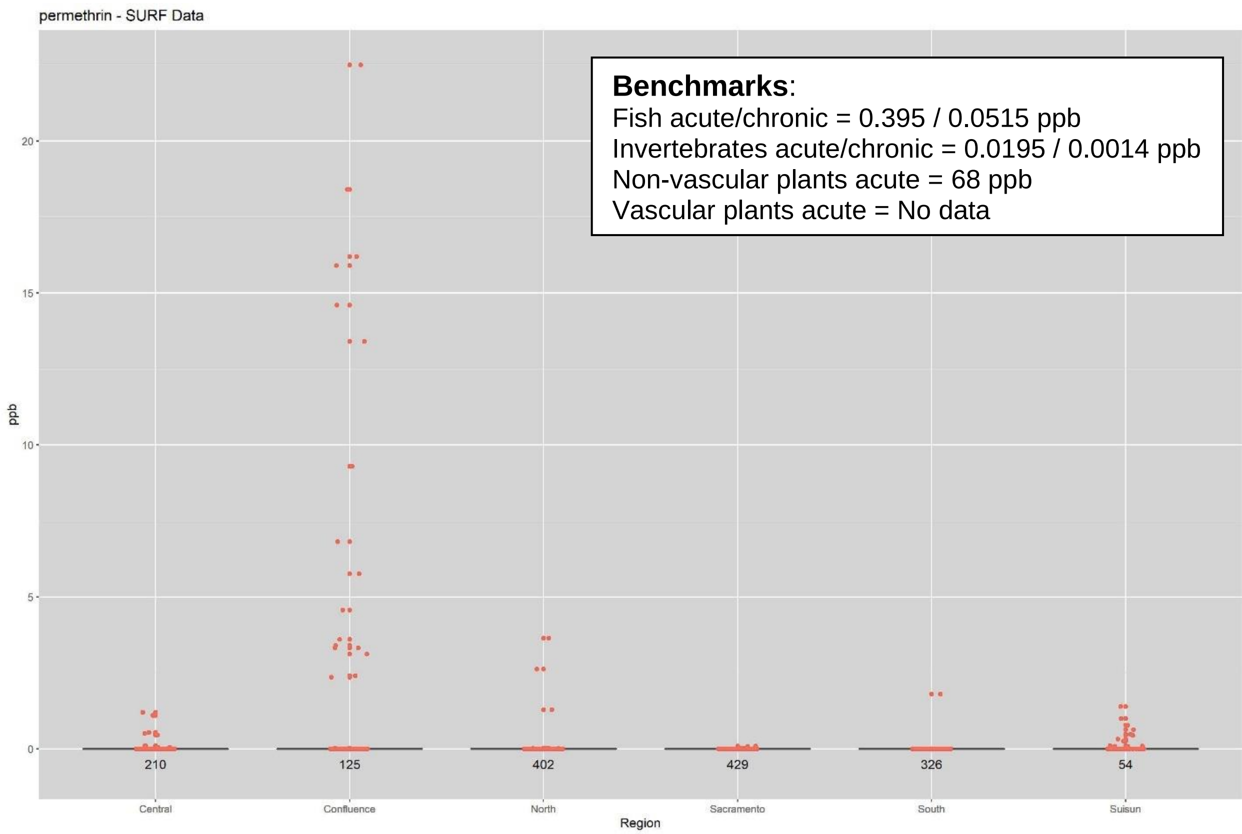

fipronil sulfide - SURF Data
Benchmarks:
Fish acute/chronic = No data
Invertebrates acute/chronic = No data / 0.11 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data
ppb
Region
Central
Confluence
North
Sacramento
South
Suisun
30
41
32
18
19
32

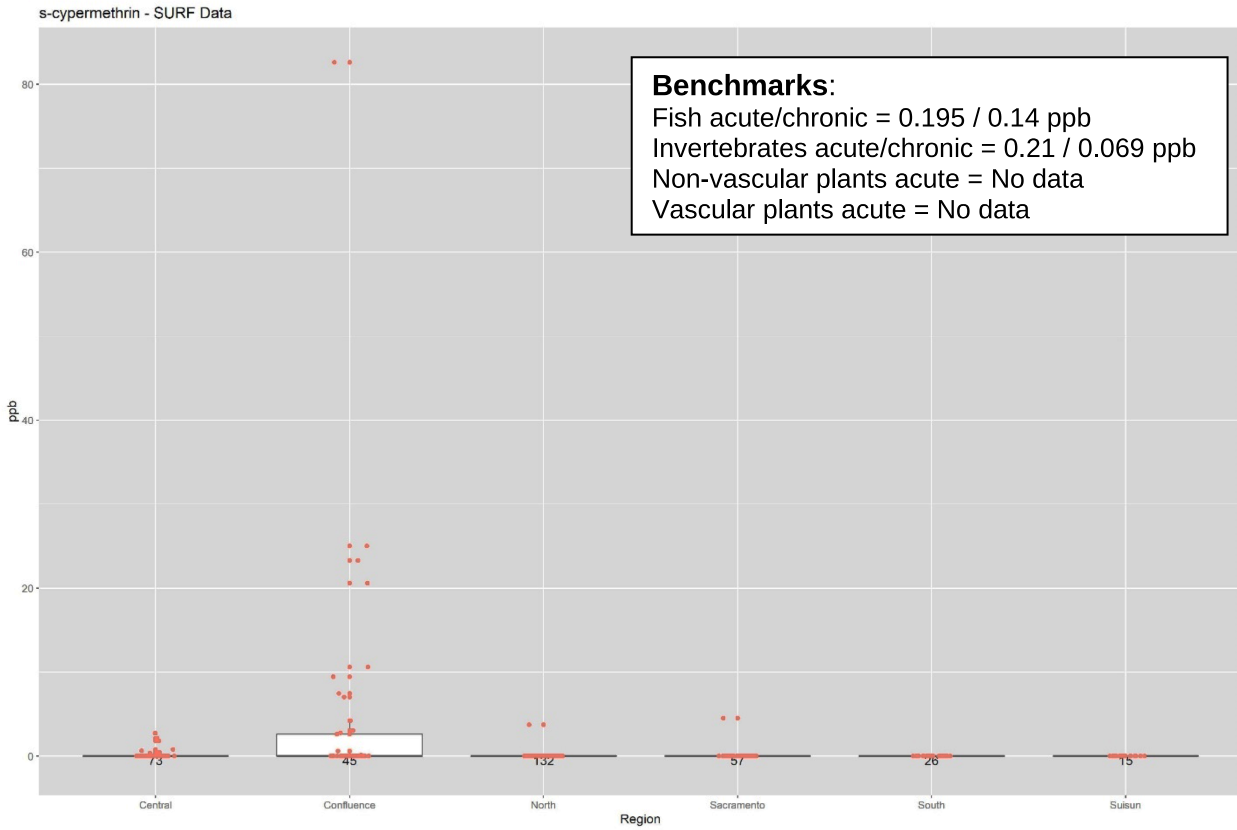

fipronil sulfone - SURF Data
Benchmarks:
Fish acute/chronic = 12.5 / 0.67 ppb
Invertebrates acute/chronic = 0.36 / 0.037 ppb
Non-vascular plants acute = 140 ppb
Vascular plants acute = >100 ppb
ppb
Region
Central
Confluence
North
Sacramento
South
Suisun
30
42
17
101
123
29


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
ppb
40
30
20
10
0
179
88
361
252
159
45
Central
Confluence
North
Sacramento
South
Suisun
Region

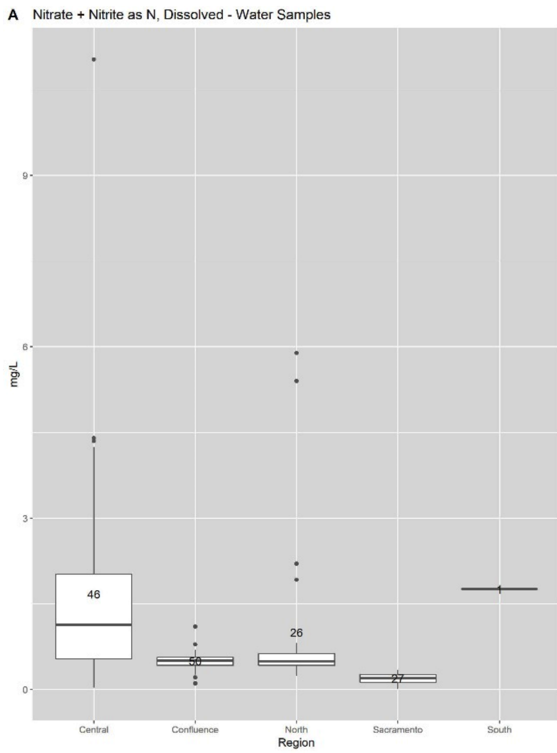

lindane (gamma-bhc) - SURF Data
Benchmarks:
Fish acute/chronic = 2.9 / 0.85 ppb
Invertebrates acute/chronic = 54 / 0.5 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data
ppb
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
9
24
7
31
29
26
Central
Confluence
North
Sacramento
South
Suisun
Region

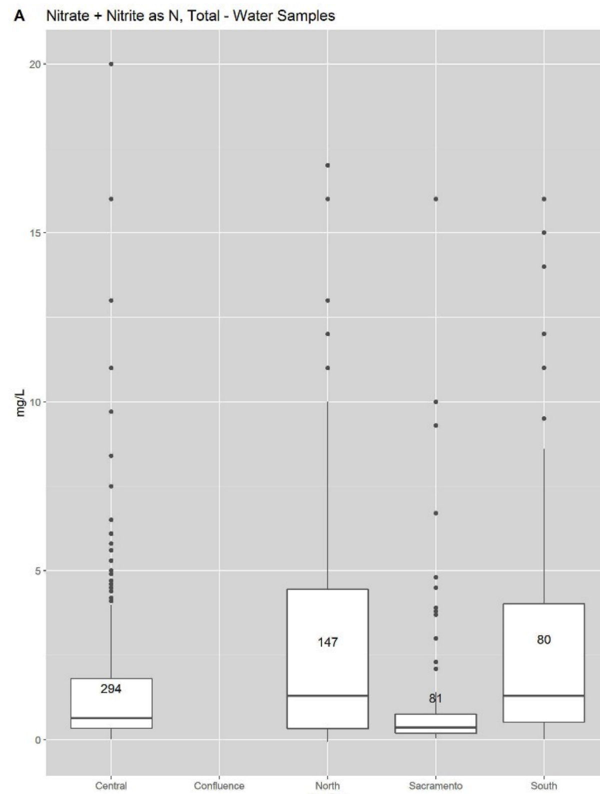

malathion - SURF Data
Benchmarks:
Fish acute/chronic = 8.6 / 2.05 ppb
Invertebrates acute/chronic = 0.06 / 0.049 ppb
Non-vascular plants acute = 2040 ppb
Vascular plants acute = 24,000 ppb
ppb
0
1
2
361
78
331
387
321
48
Central
Confluence
North
Sacramento
South
Suisun
Region

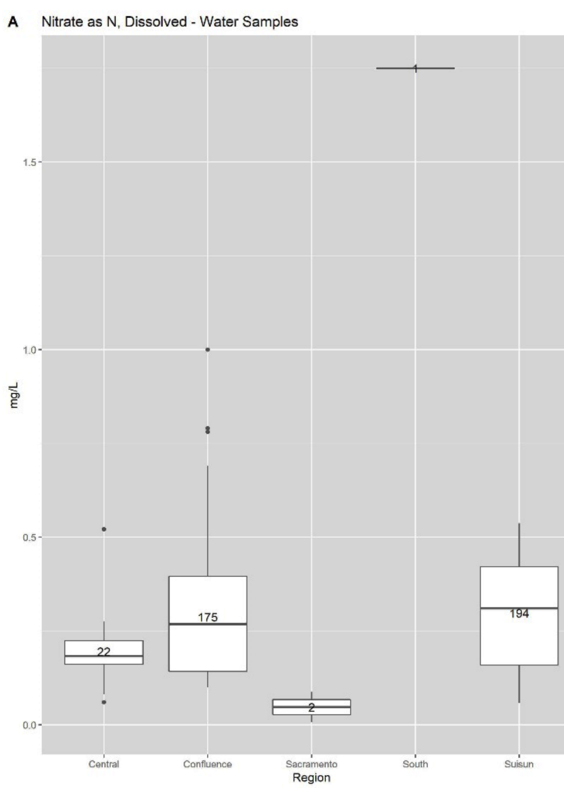

permethrin - SURF Data
Benchmarks:
Fish acute/chronic = 0.395 / 0.0515 ppb
Invertebrates acute/chronic = 0.0195 / 0.0014 ppb
Non-vascular plants acute = 68 ppb
Vascular plants acute = No data
ppb
0
5
10
15
20
210
125
402
429
326
54
Central
Confluence
North
Sacramento
South
Suisun
Region

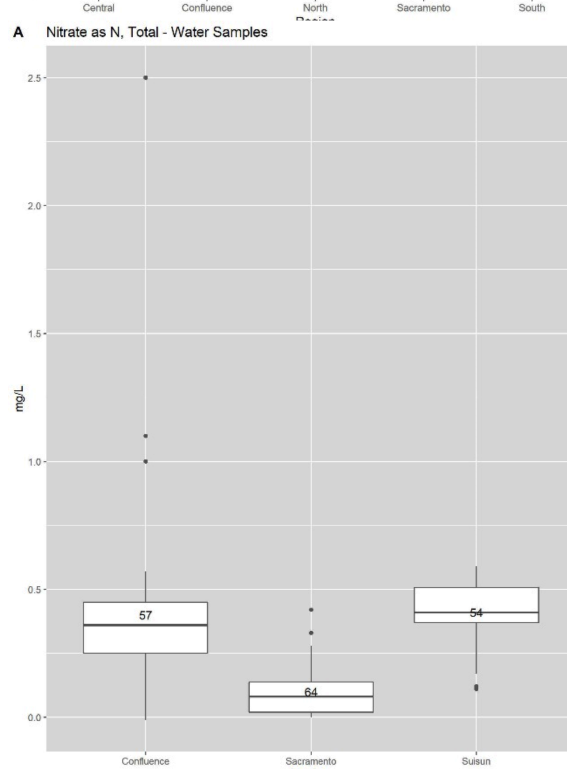

s-cypermethrin - SURF Data
Benchmarks:
Fish acute/chronic = 0.195 / 0.14 ppb
Invertebrates acute/chronic = 0.21 / 0.069 ppb
Non-vascular plants acute = No data
Vascular plants acute = No data
ppb
0
20
40
60
80
73
45
132
57
26
15
Central
Confluence
North
Sacramento
South
Suisun
Region

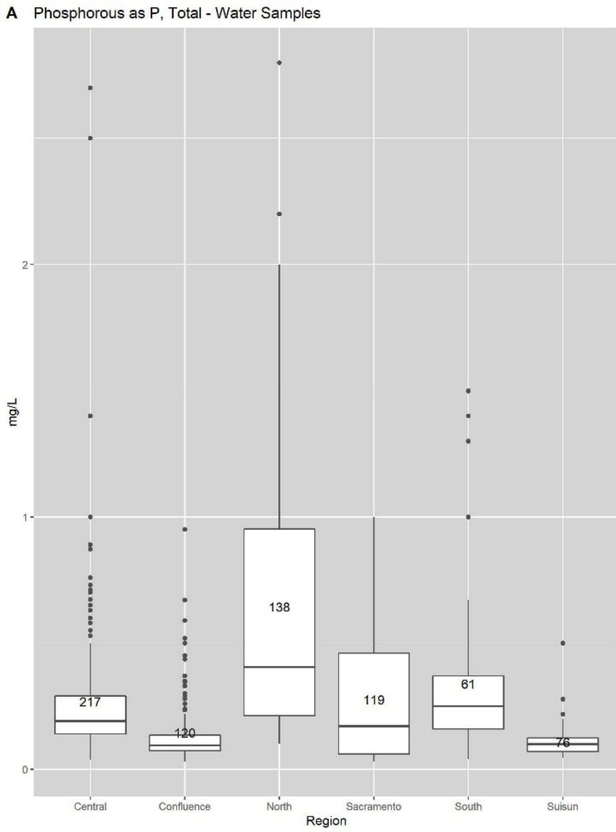
Appendix F. Boxplots of Risk Region Water Quality and Metals Data from 2009 - 2019.
(Data were obtained from CEDEN and SURF databases and plotted using R software).

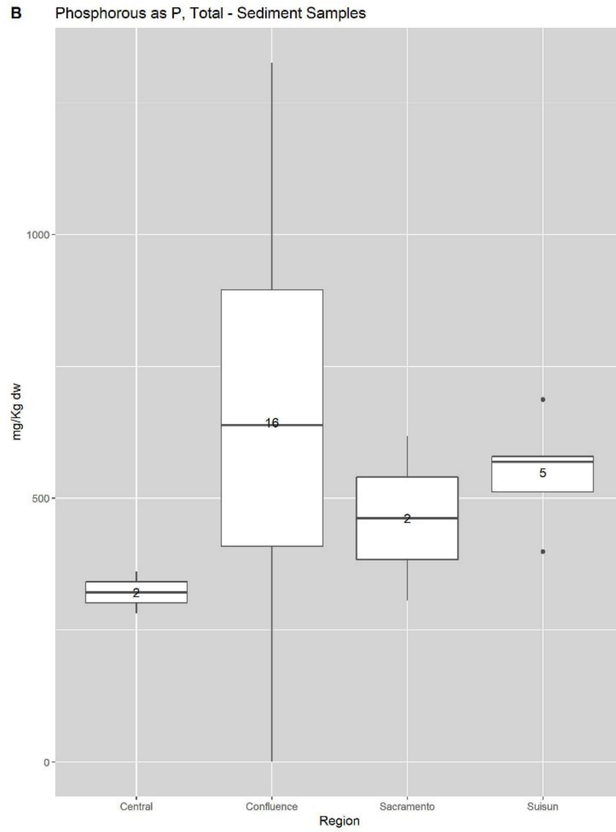


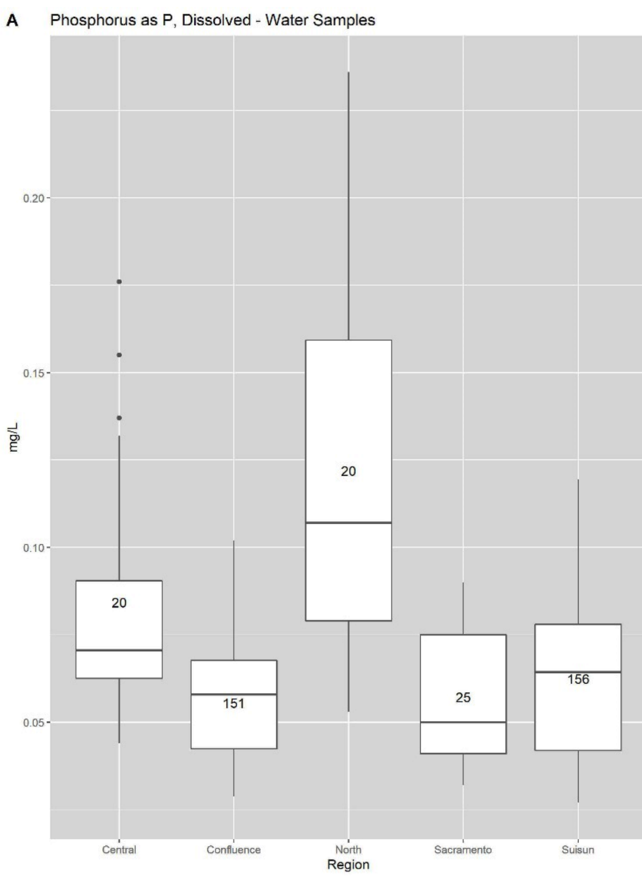


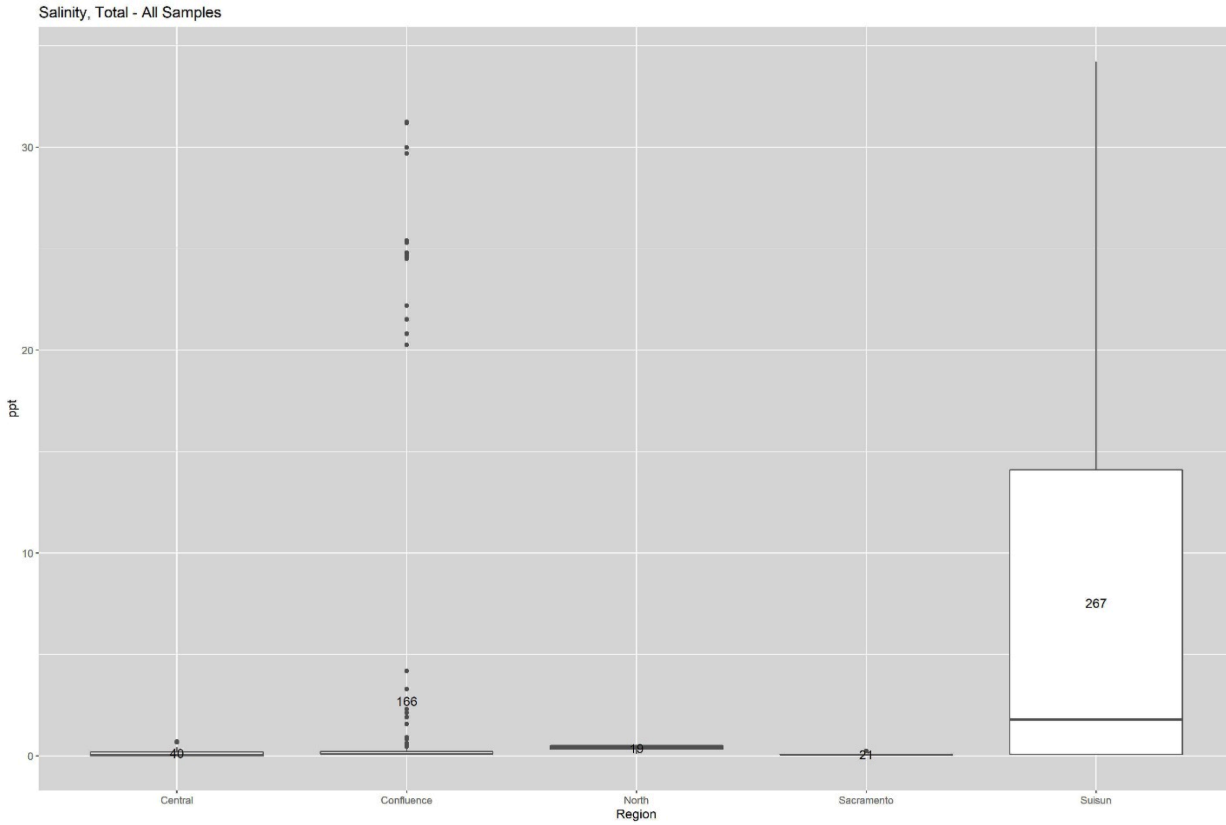


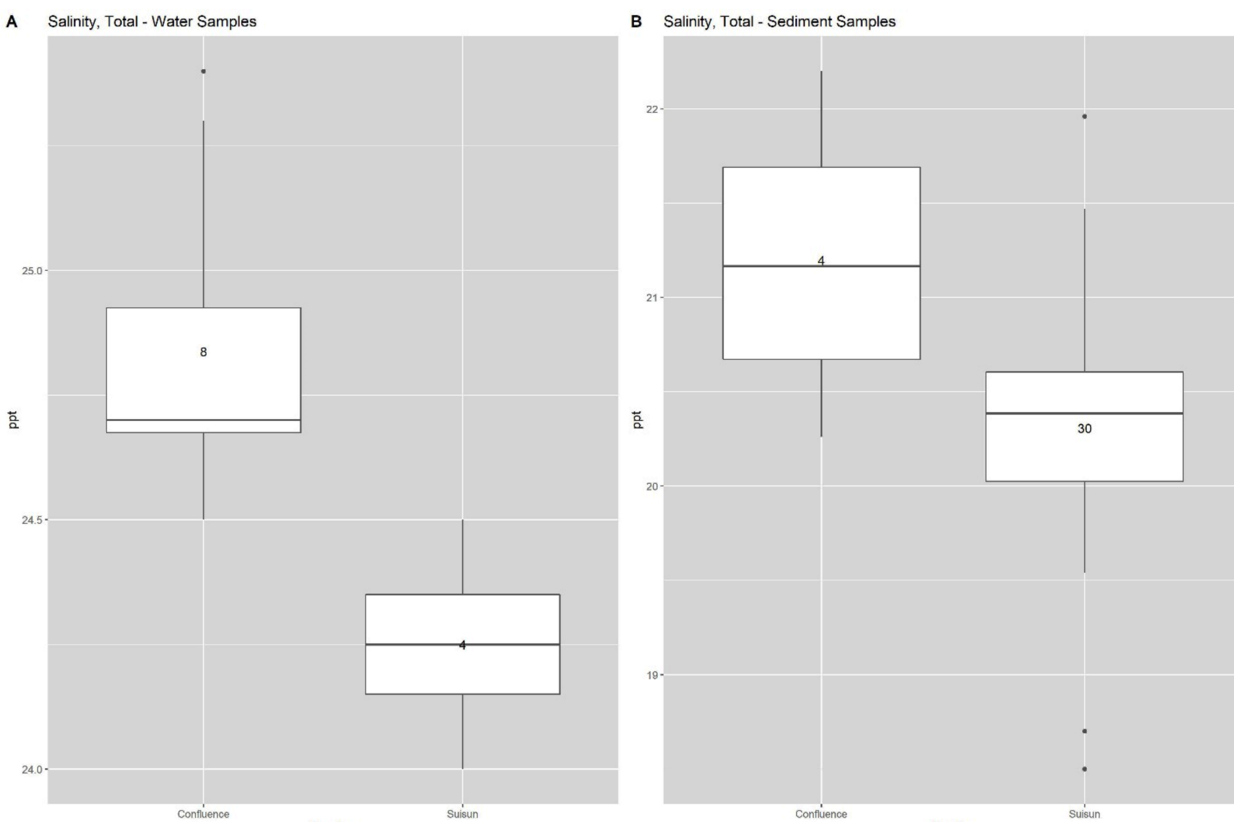


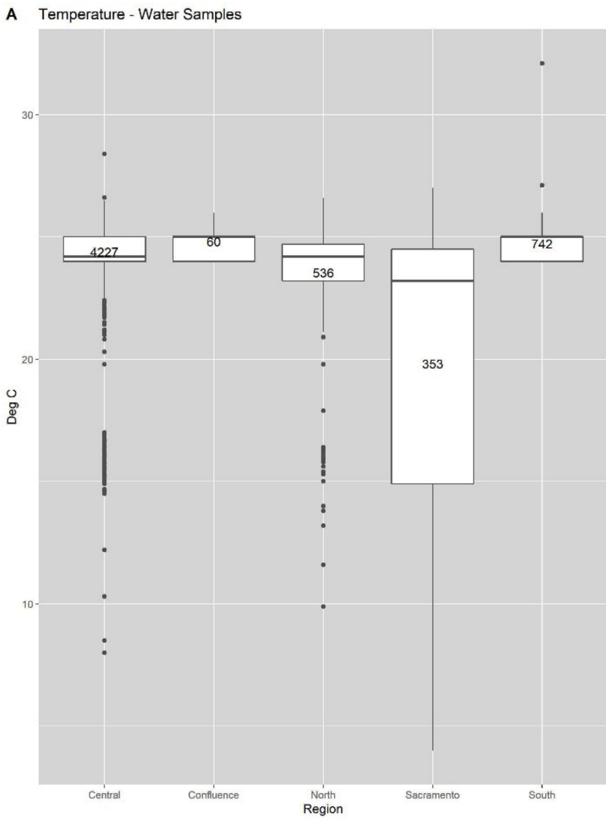

A Phosphorous as P, Total - Water Samples
mg/L
0
1
2
217
120
138
119
61
76
Central
Confluence
North
Sacramento
South
Suisun
Region

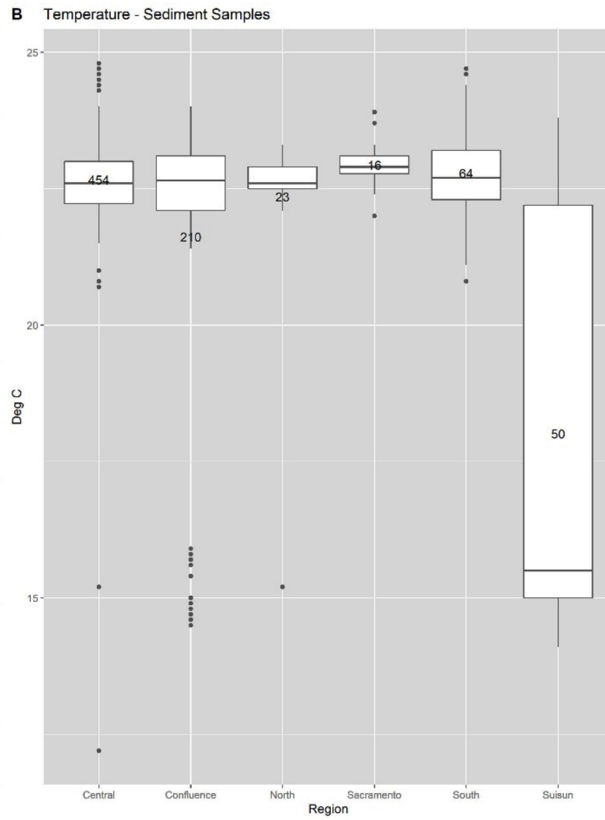

B Phosphorous as P, Total - Sediment Samples
mg/Kg dw
0
500
1000
2
16
2
5
Central
Confluence
Sacramento
Suisun
Region

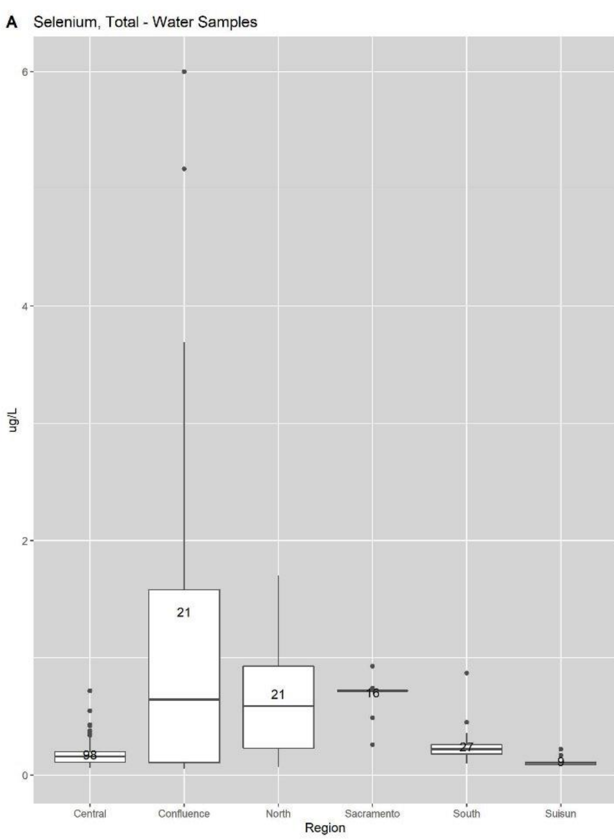

A Phosphorus as P, Dissolved - Water Samples
mg/L
0.05
0.10
0.15
0.20
20
151
20
25
156
Central
Confluence
North
Sacramento
Suisun
Region

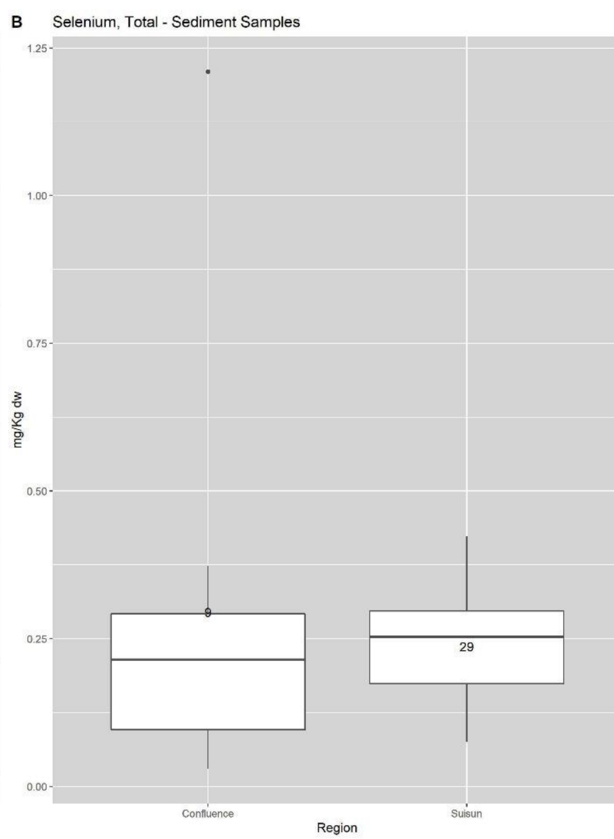

Salinity, Total - All Samples
ppt
30
20
10
0
166
267
40
19
21
Central
Confluence
North
Sacramento
Suisun
Region

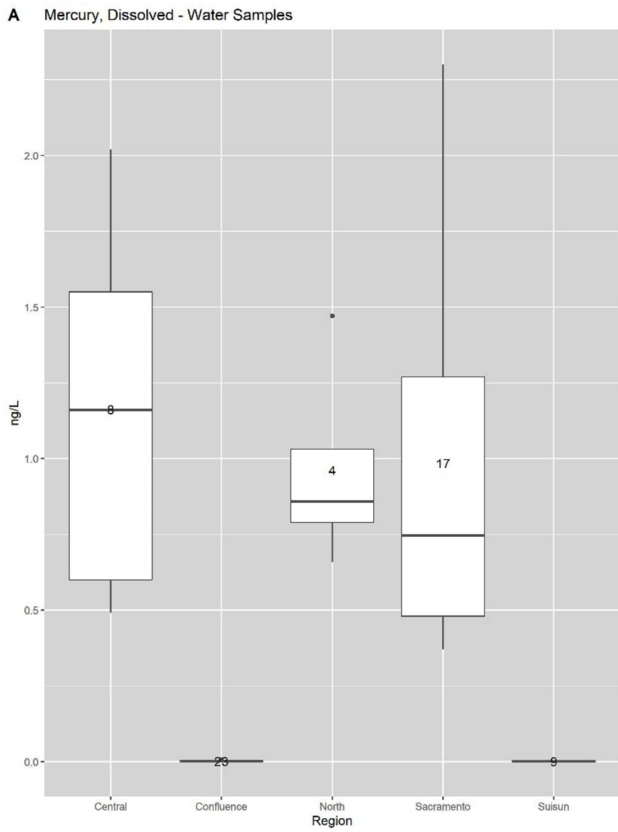

A
Salinity, Total - Water Samples
ppt
25.0
24.5
24.0
8
4
Confluence
Suisun
Region
B
Salinity, Total - Sediment Samples
ppt
22
21
20
19
4
30
Confluence
Suisun
Region

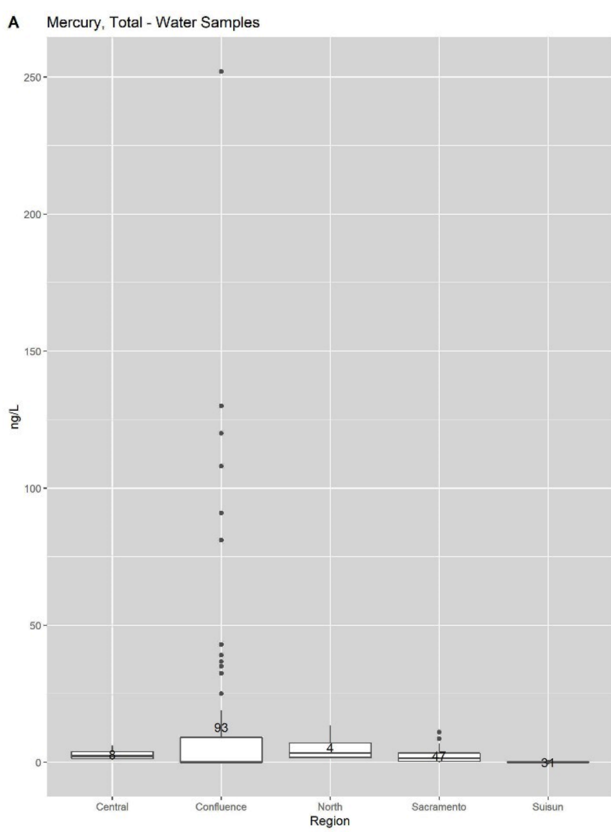

A Temperature - Water Samples
Deg C
30
20
10
4227
60
536
353
742
Central
Confluence
North
Sacramento
South
Region

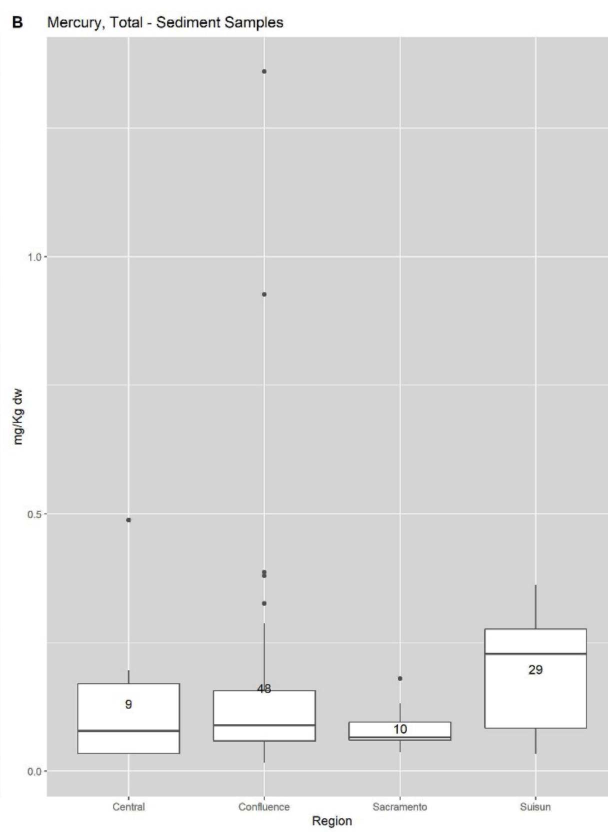

B Temperature - Sediment Samples
Deg C
25
20
15
454
210
23
16
64
50
Central
Confluence
North
Sacramento
South
Suisun
Region


A Selenium, Total - Water Samples
ug/L
6
4
2
0
98
21
21
16
27
9
Central
Confluence
North
Sacramento
South
Suisun
Region

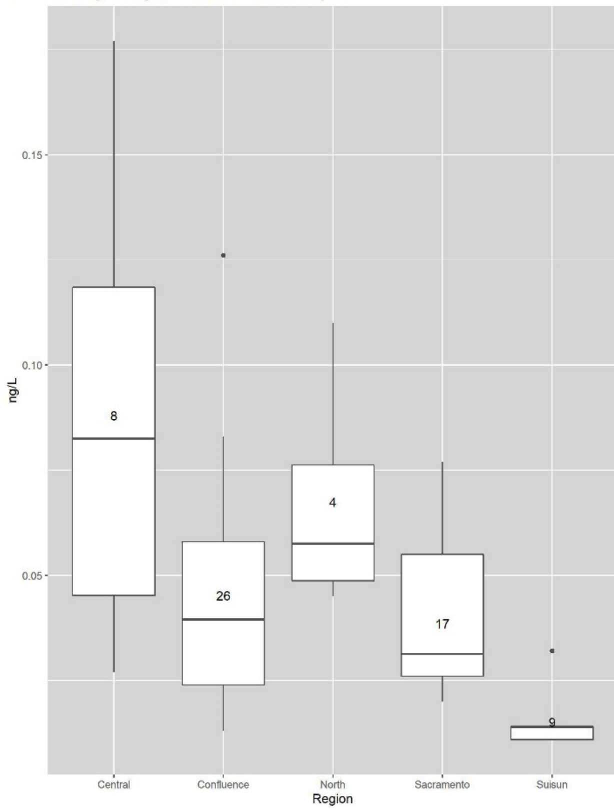

B Selenium, Total - Sediment Samples
mg/Kg dw
1.25
1.00
0.75
0.50
0.25
0.00
9
29
Confluence
Suisun
Region


A
Mercury, Dissolved - Water Samples
ng/L
2.0
1.5
1.0
0.5
0.0
8
23
4
17
9
Central
Confluence
North
Sacramento
Suisun
Region


A
Mercury, Total - Water Samples
ng/L
250
200
150
100
50
0
8
93
4
47
31
Central
Confluence
North
Sacramento
Suisun
Region


B
Mercury, Total - Sediment Samples
mg/Kg dw
1.0
0.5
0.0
9
48
10
29
Central
Confluence
Sacramento
Suisun
Region

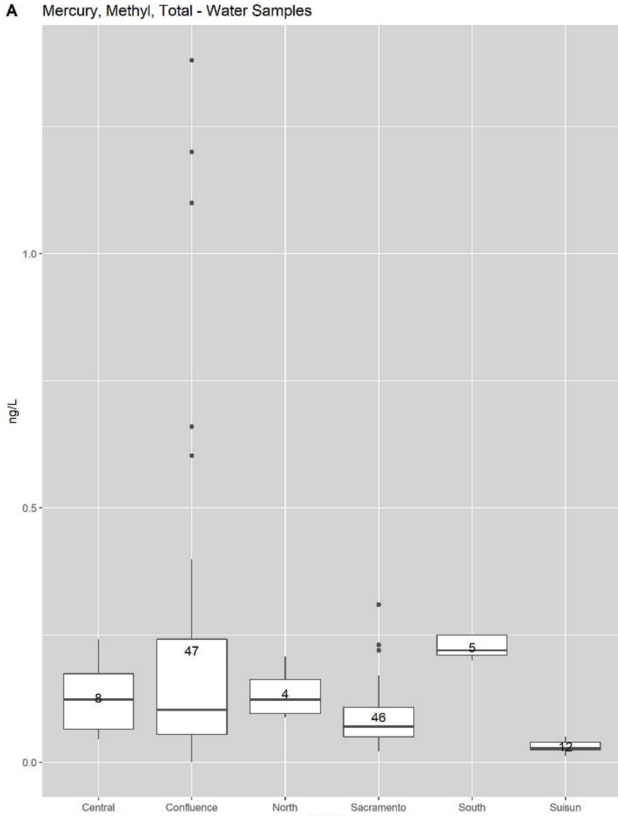
A Mercury, Methyl, Dissolved - Water Samples



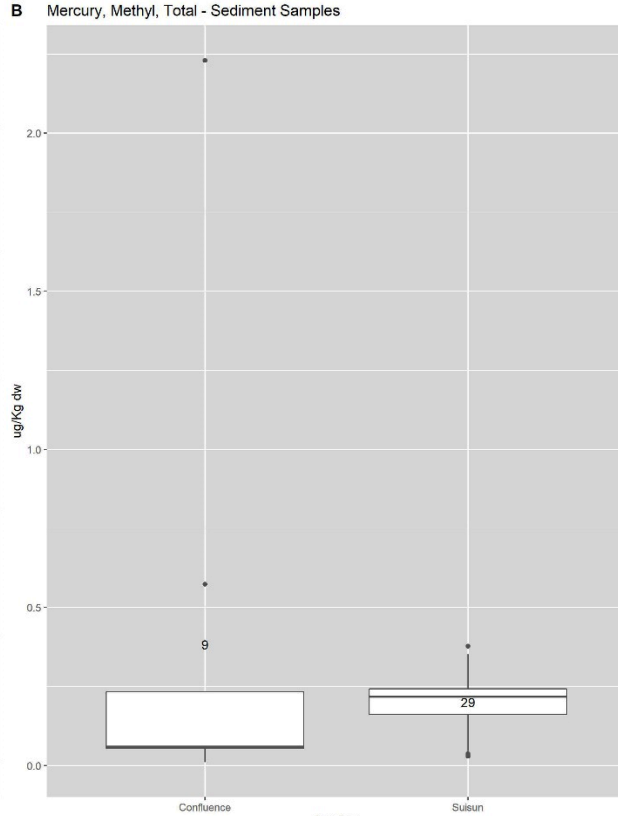
B

NA

A Mercury, Methyl, Total - Water Samples



B Mercury, Methyl, Total - Sediment Samples



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			
North	585	NA	41	3
Sacramento	55854	59	3202	433
South	10087	2	3730	99
Suisun	NA	NA	NA	NA
NA	39531	99	1629	603

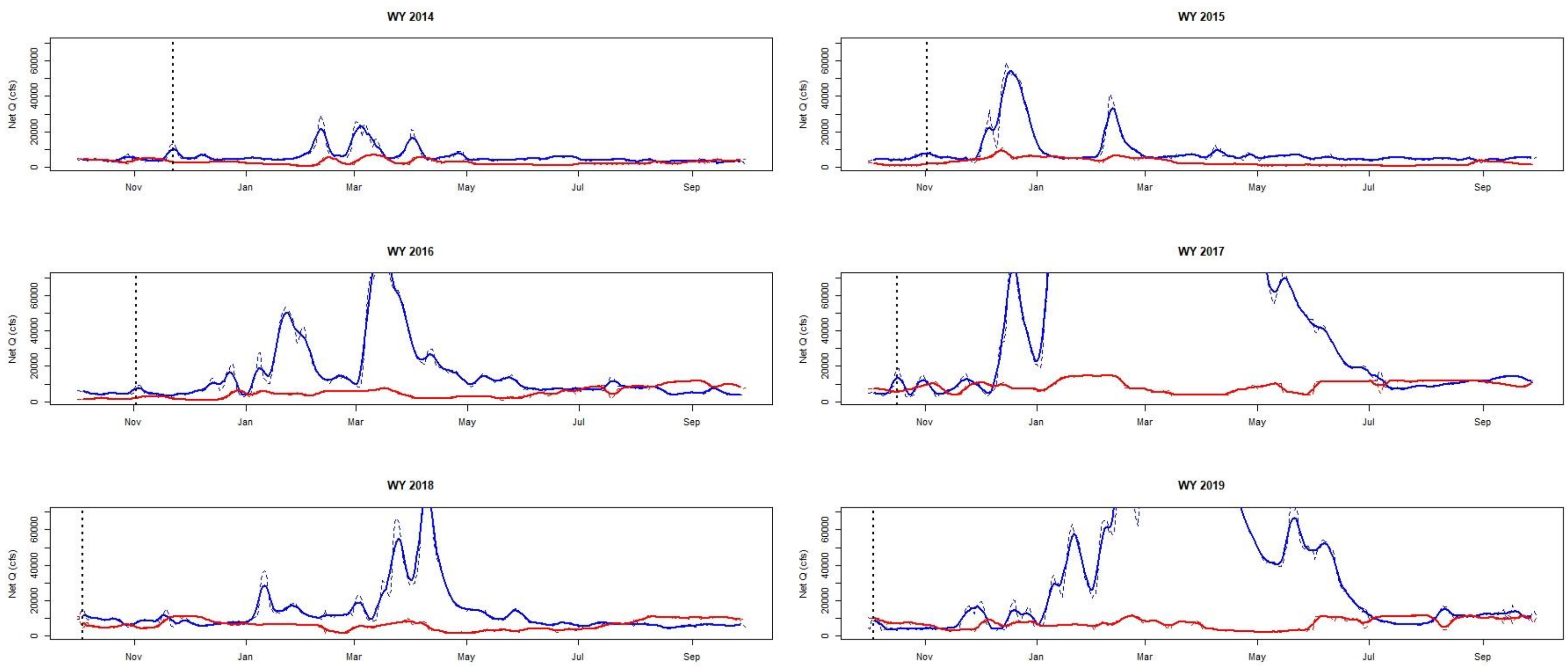
2017	Chinook Catch / Water Year			
North	673	NA	49	3
Sacramento	67646	68	5996	561
South	11682	2	4958	117
Suisun	NA	NA	NA	NA
NA	40275	117	1717	647

2018	Chinook Catch / Water Year			
Region	**Fall**	**Late Fall**	**Spring**	**Winter**
Central	1910	4	213	19
Confluence	20061	102	11176	806
North	684	NA	50	3
Sacramento	69657	77	6237	587
South	12762	2	5488	125
Suisun	NA	NA	NA	NA
NA	41077	121	1788	719

2019	Chinook Catch / Water Year			
Region	**Fall**	**Late Fall**	**Spring**	**Winter**
Central	3360	6	237	22
Confluence	23877	125	12988	904
North	705	NA	52	3
Sacramento	73742	87	6806	733
South	13359	2	5714	128
Suisun	NA	NA	NA	NA
NA	42435	131	1869	1043

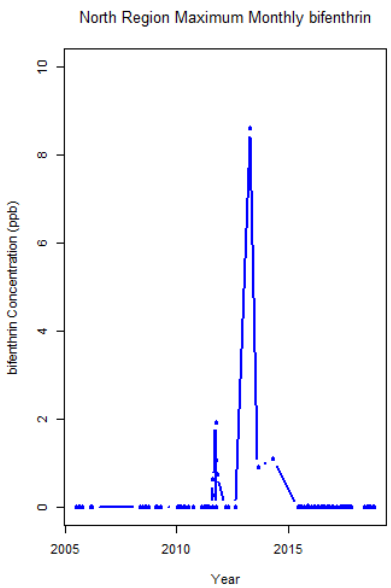
Appendix H. Delta Water Outflow Data Plots from 2014 - 2019

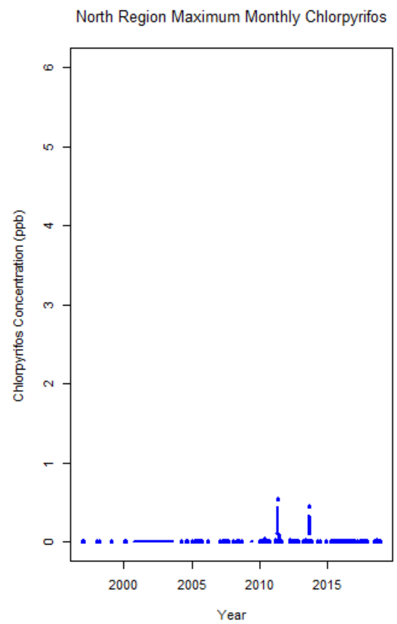
Net Delta outflow measured at Chipps Island for the last six years from 2014 through 2019. Solid blue line is 7 day rolling average of flow, dashed blue line is daily data. Solid red line is 7 day rolling average of delta water exports, dashed red line is daily export data, and the dashed black vertical line is showing the first peak flow event of the water year at or approaching 10,000cfs.

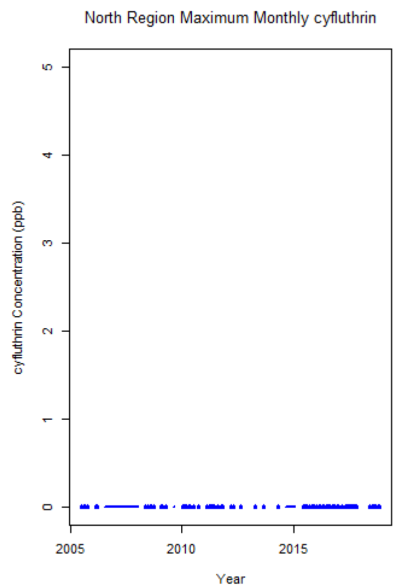


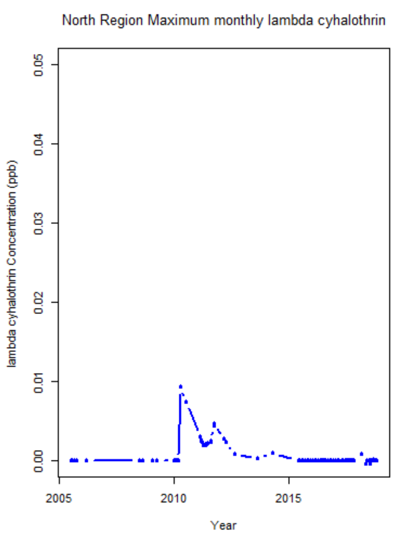
Appendix I. Pesticide, Water Quality, and Metals Data Plotted by Risk Region. R software was used to generate the plots.

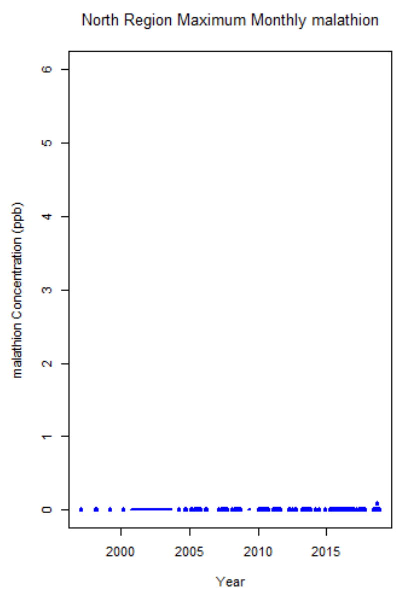
North Delta Risk Region

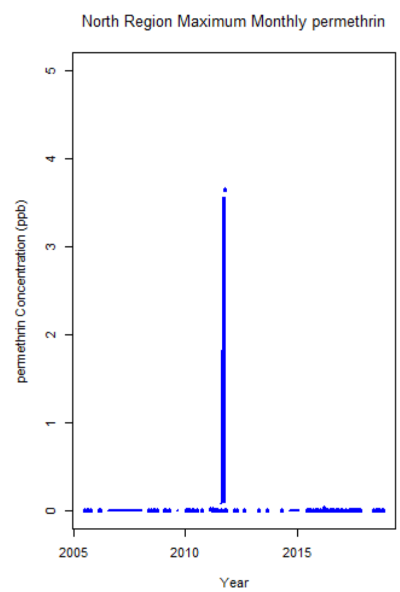


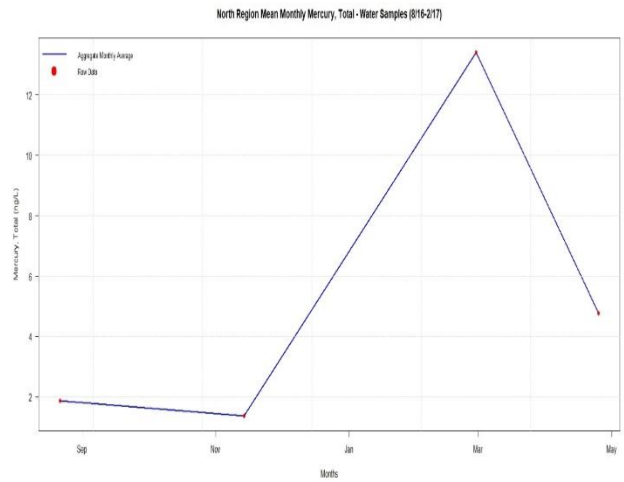


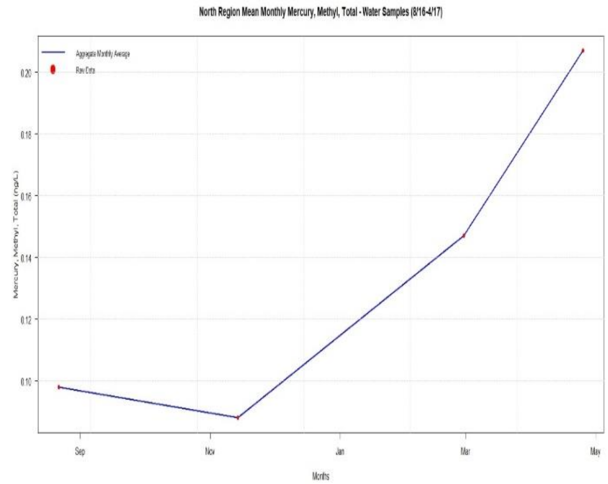


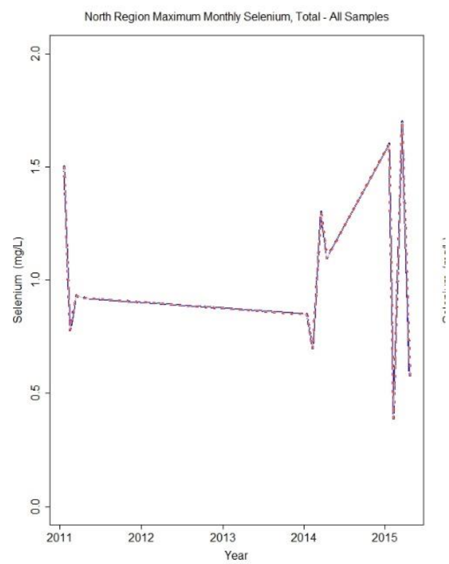


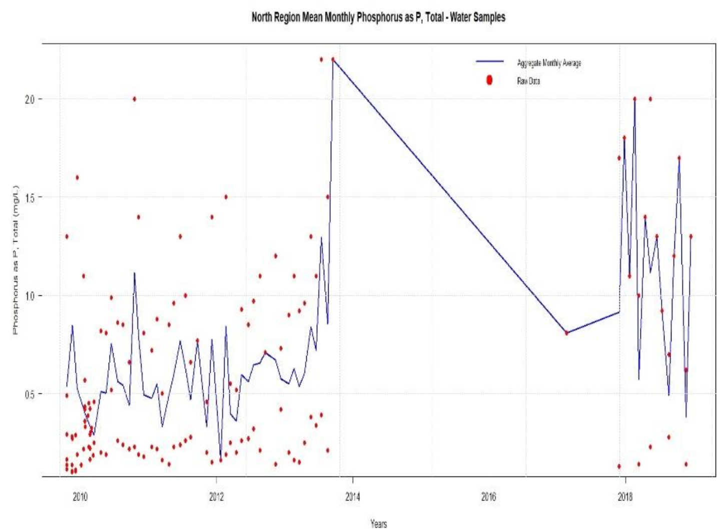


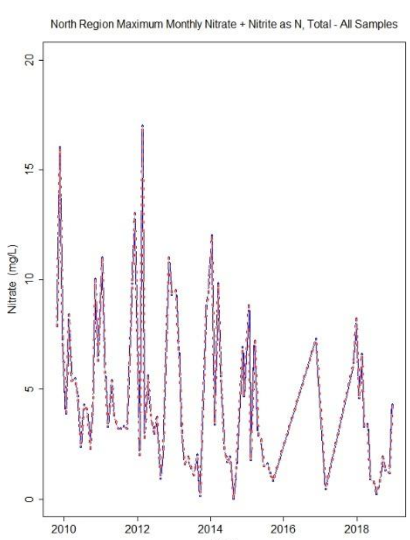


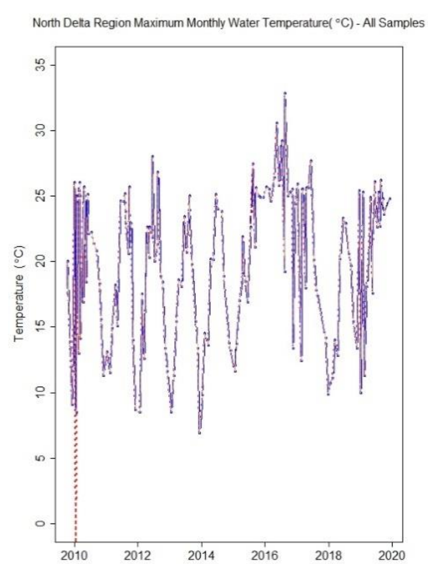

North Region Mean Monthly Mercury, Total - Water Samples (8/16-2/17)
Mercury, Total (mg/L)
Months
Sep
Nov
Jan
Mar
May

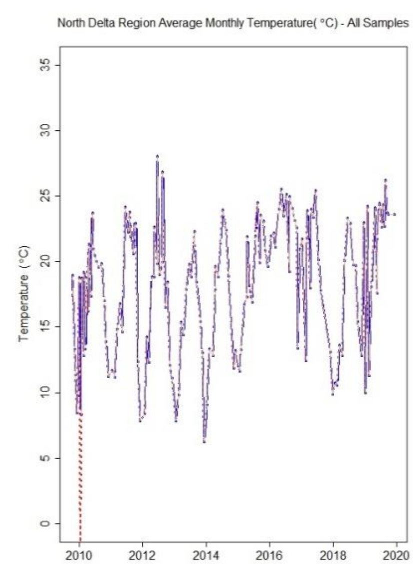

North Region Mean Monthly Mercury, Methyl, Total - Water Samples (8/16-4/17)
Months
Sep
Nov
Jan
Mar
May


North Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
Year
2011
2012
2013
2014
2015

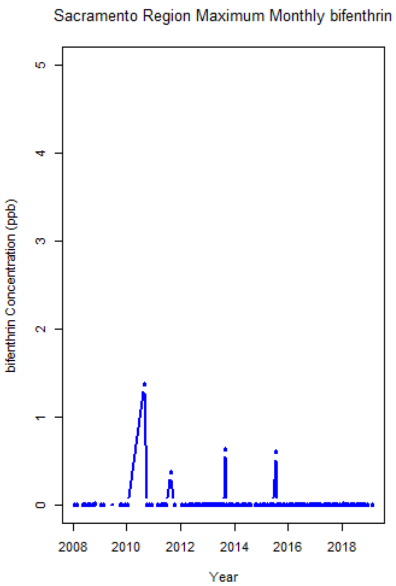

North Region Mean Monthly Phosphorus as P, Total - Water Samples
Aggregate Monthly Average
Raw Data
Phosphorus as P, Total (mg/L)
Years
2010
2012
2014
2016
2018

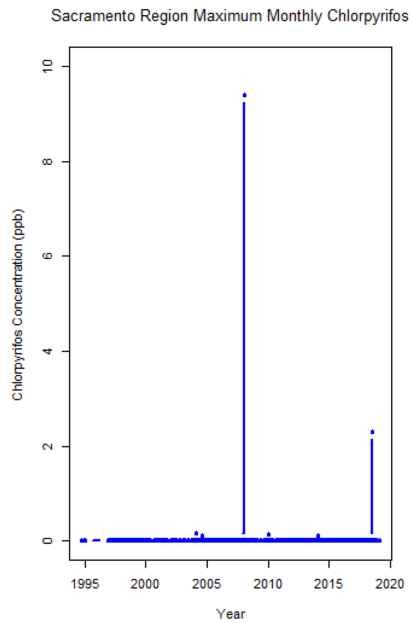

North Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
Year
2010
2012
2014
2016
2018

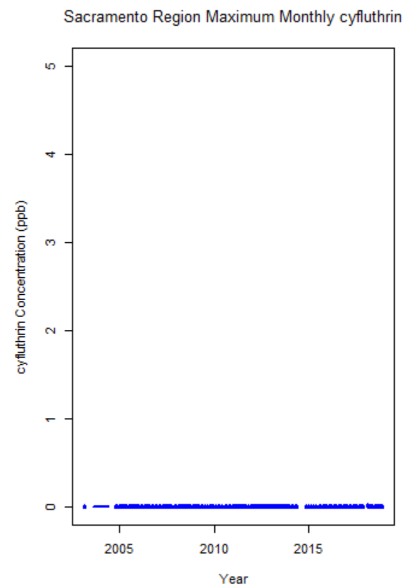

North Delta Region Maximum Monthly Water Temperature(°C) - All Samples
Temperature (°C)
2010
2012
2014
2016
2018
2020

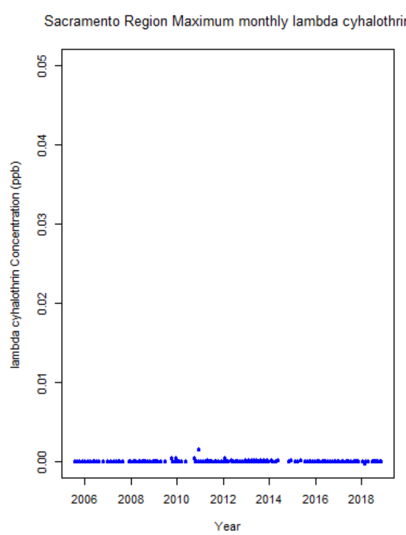

North Delta Region Average Monthly Temperature(°C) - All Samples
Temperature (°C)
2010
2012
2014
2016
2018
2020

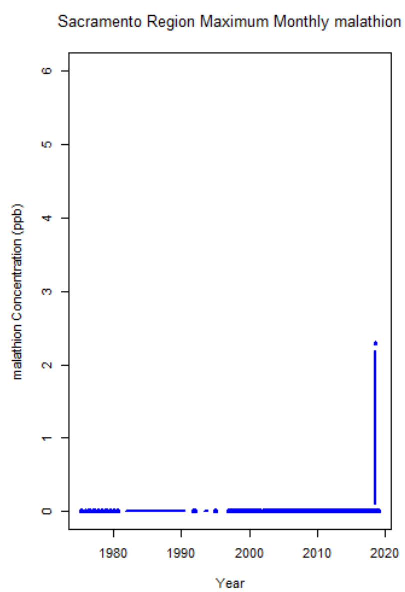
Sacramento River Risk Region

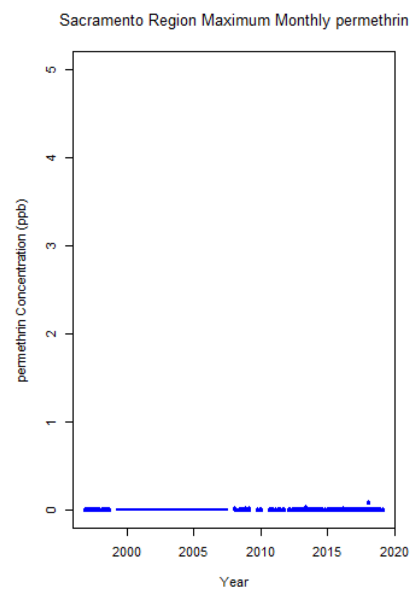


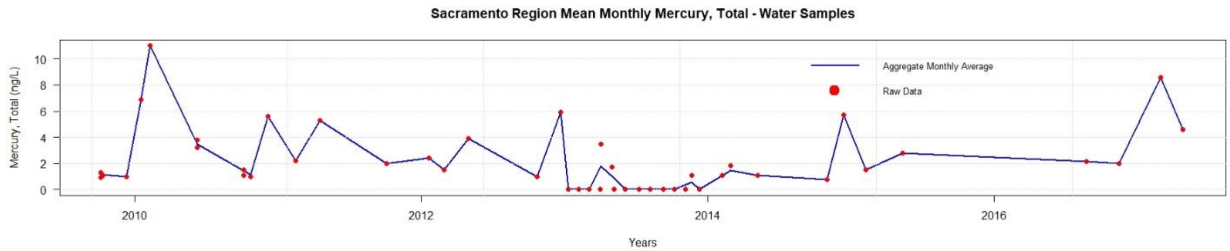


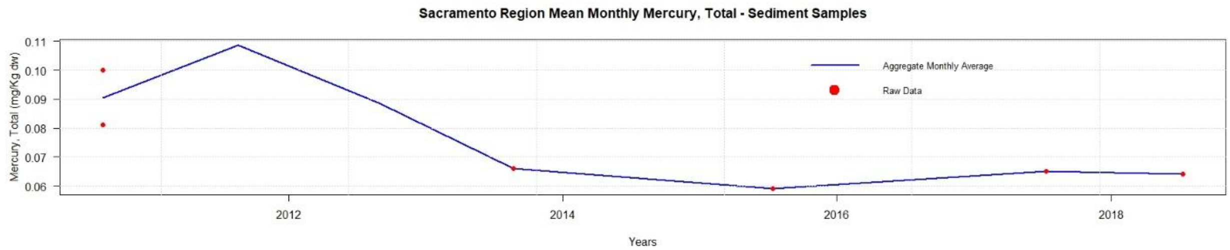


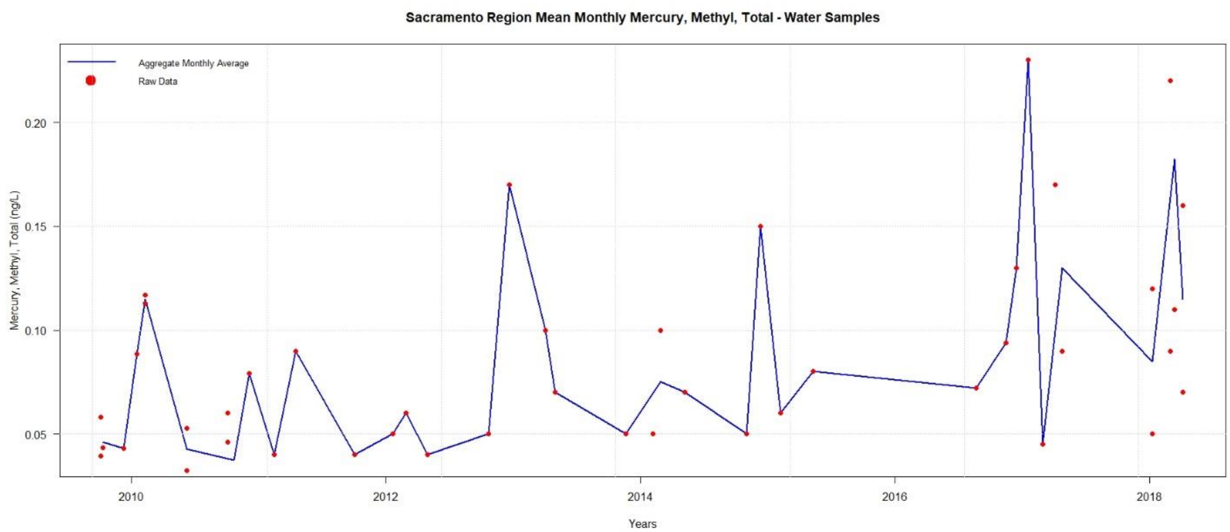


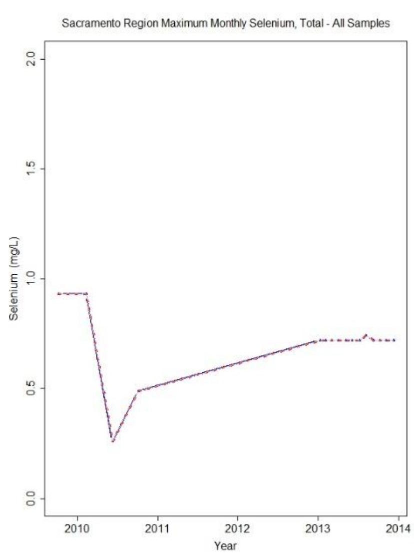


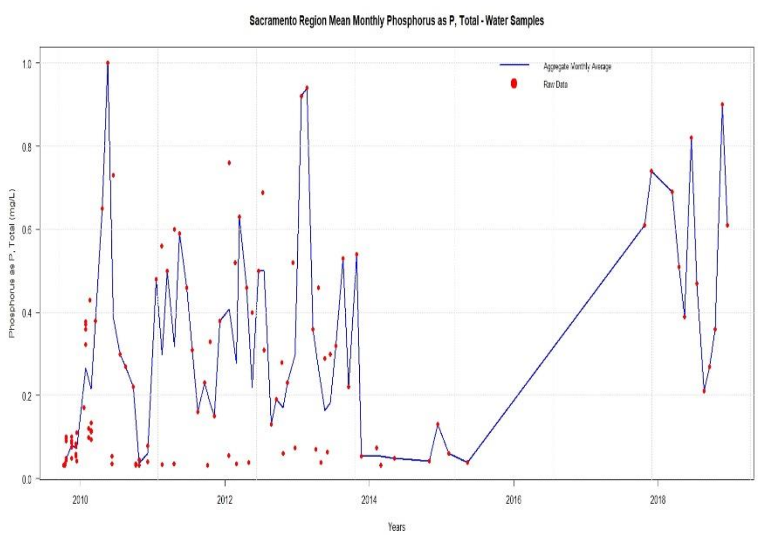


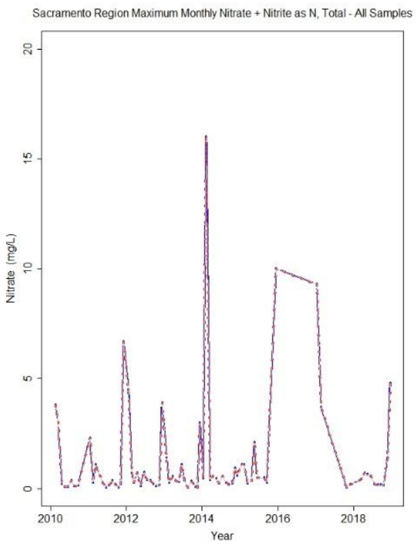

Sacramento Region Mean Monthly Mercury, Total - Water Samples
Mercury, Total (ng/L)
Years
Aggregate Monthly Average
Raw Data


Sacramento Region Mean Monthly Mercury, Total - Sediment Samples
Mercury, Total (mg/Kg dw)
Years
Aggregate Monthly Average
Raw Data

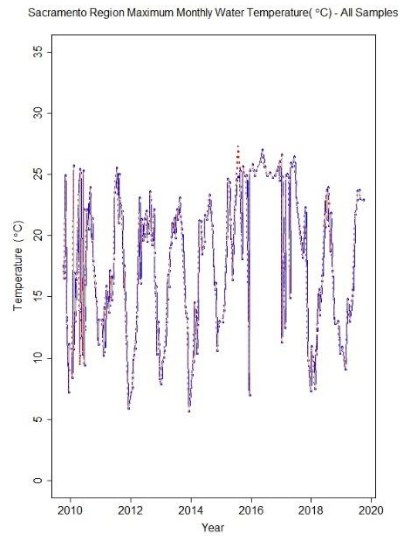

Sacramento Region Mean Monthly Mercury, Methyl, Total - Water Samples
Mercury, Methyl, Total (ng/L)
Years
Aggregate Monthly Average
Raw Data


Sacramento Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
Year

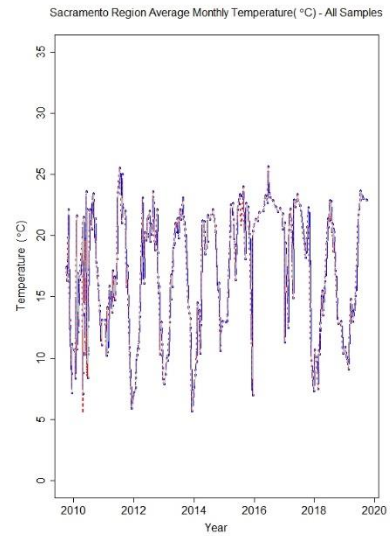

Sacramento Region Mean Monthly Phosphorus as P, Total - Water Samples
Phosphorus as P, Total (mg/L)
Years



Sacramento Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
Year

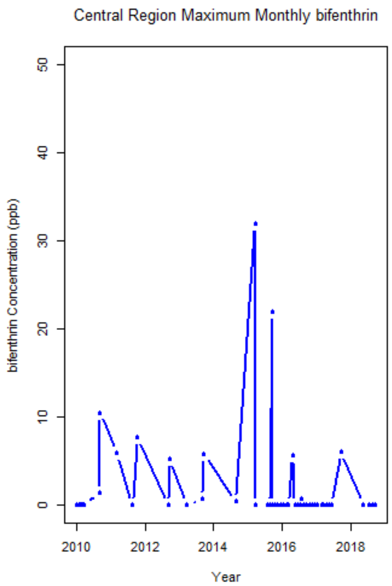


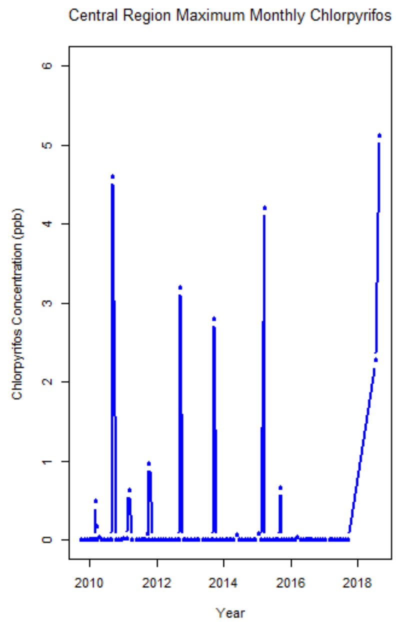
Sacramento Region Maximum Monthly Water Temperature(°C) - All Samples
Temperature (°C)
Year

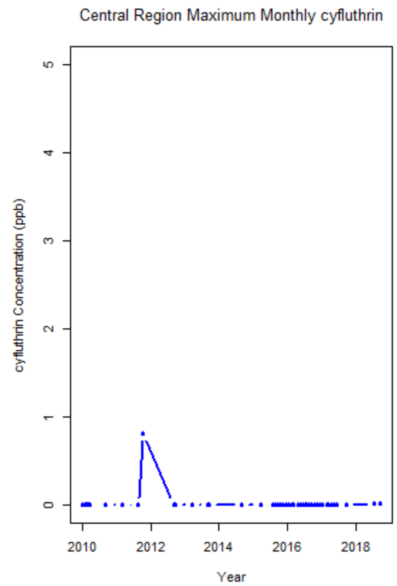


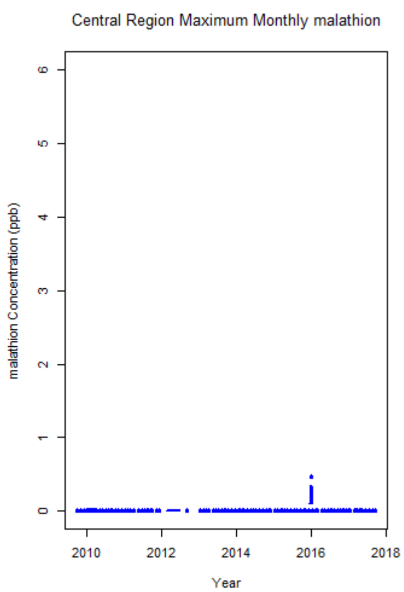
Sacramento Region Average Monthly Temperature(°C) - All Samples
Temperature (°C)
Year

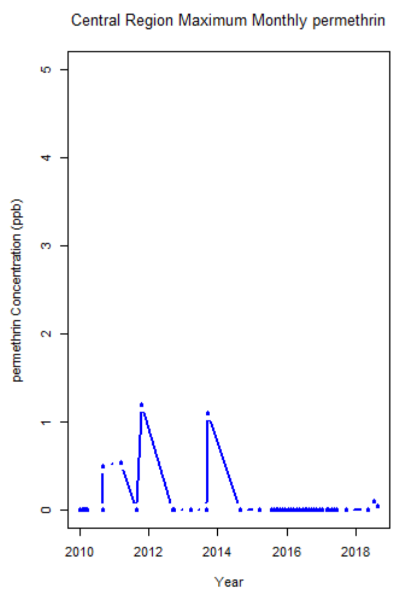
Central Delta Risk Region

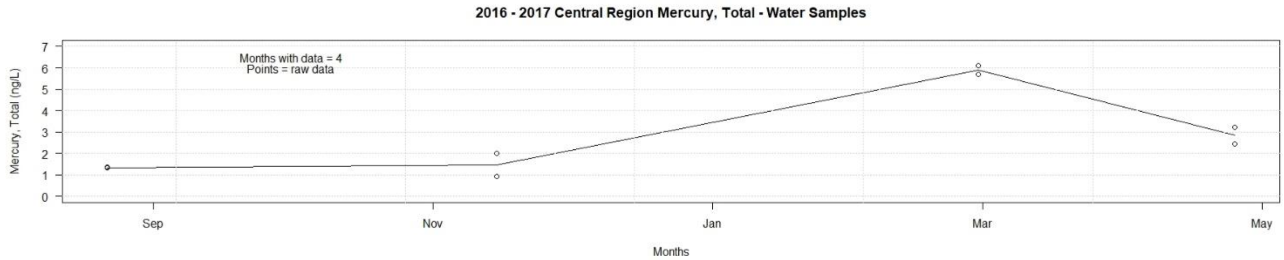


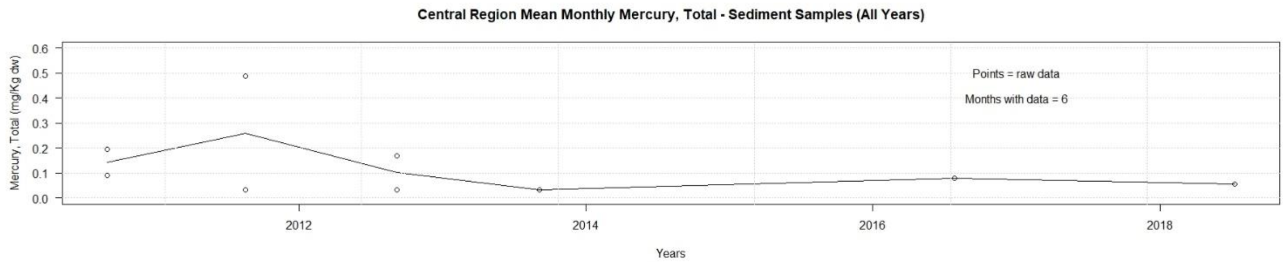


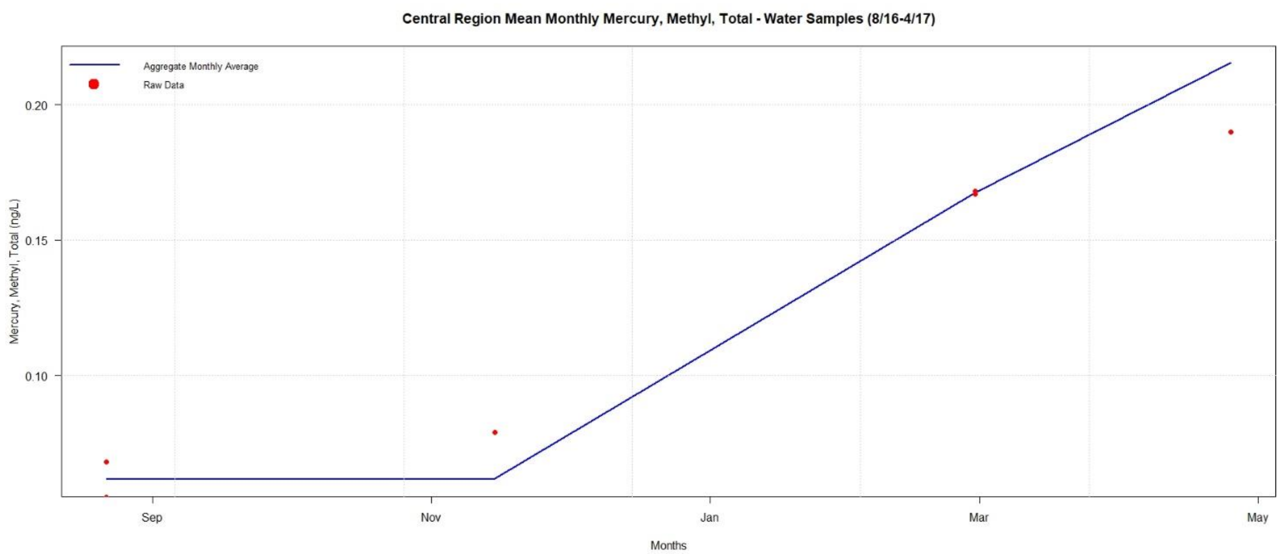


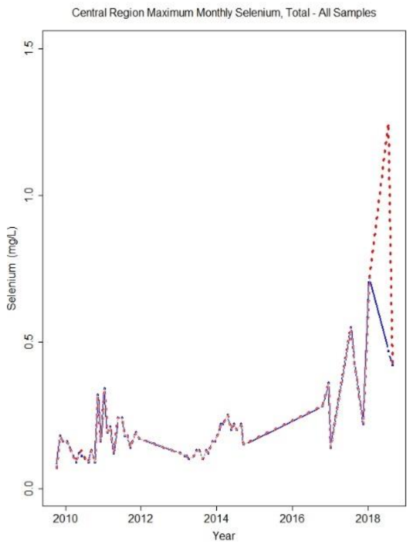


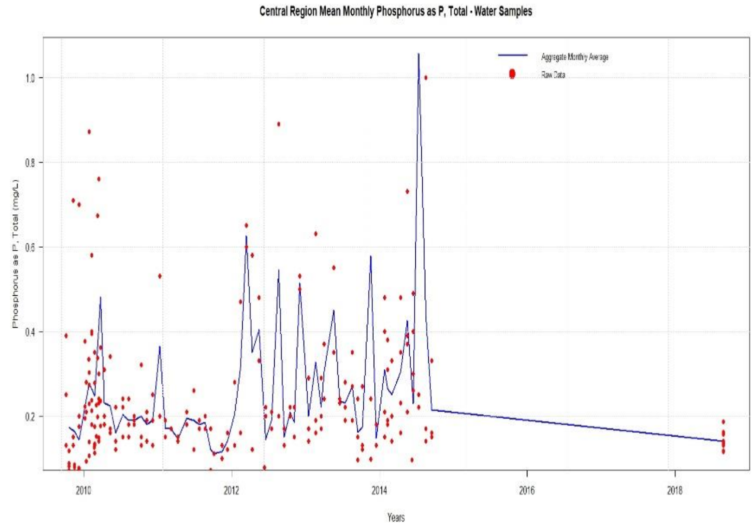


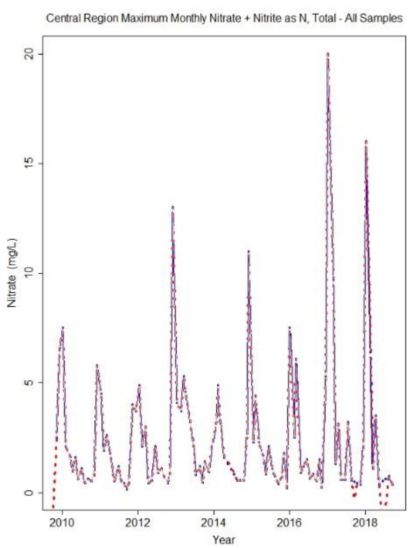

2016 - 2017 Central Region Mercury, Total - Water Samples
Months with data = 4
Points = raw data
Mercury, Total (ng/L)
Sep
Nov
Jan
Mar
May
Months

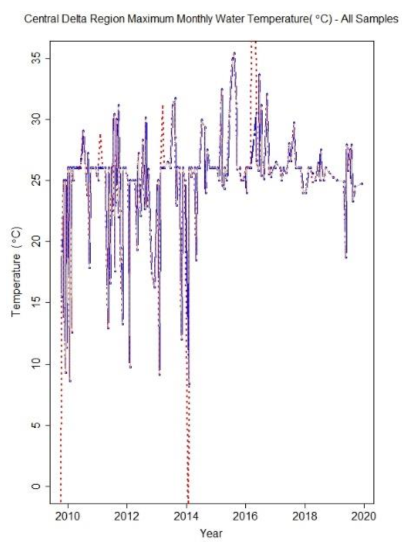

Central Region Mean Monthly Mercury, Total - Sediment Samples (All Years)
Points = raw data
Months with data = 6
Mercury, Total (mg/Kg dw)
2012
2014
2016
2018
Years

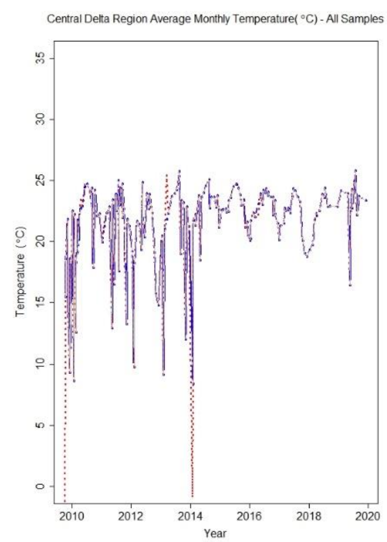

Central Region Mean Monthly Mercury, Methyl, Total - Water Samples (8/16-4/17)
Aggregate Monthly Average
Raw Data
Mercury, Methyl, Total (ng/L)
Sep
Nov
Jan
Mar
May
Months


Central Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
Year

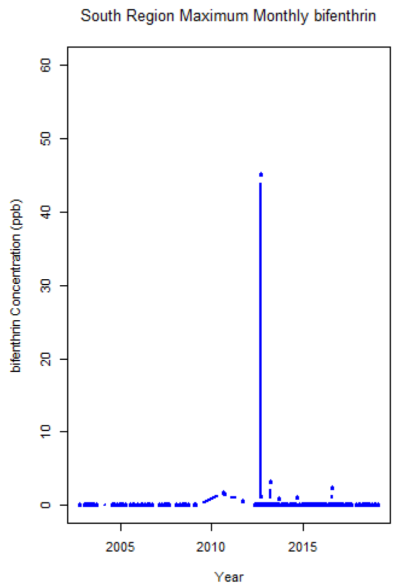

Central Region Mean Monthly Phosphorus as P, Total - Water Samples
Aggregate Monthly Average
Raw Data
Phosphorus as P, Total (mg/L)
Years

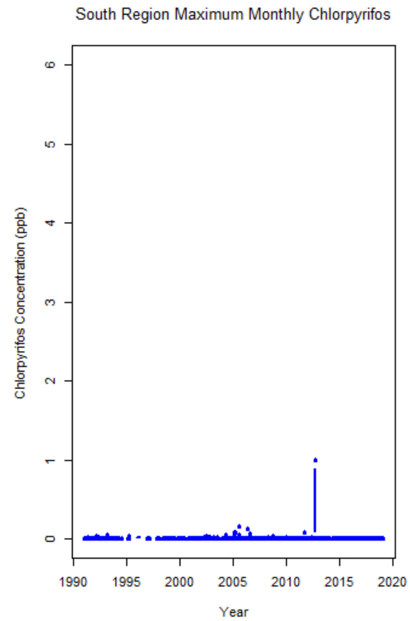

Central Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
Year

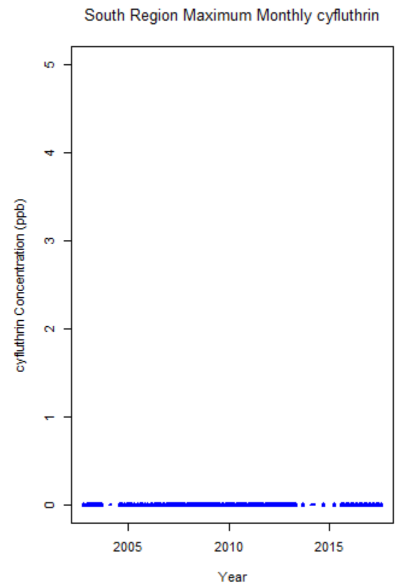

Central Delta Region Maximum Monthly Water Temperature(°C) - All Samples
Temperature (°C)
Year

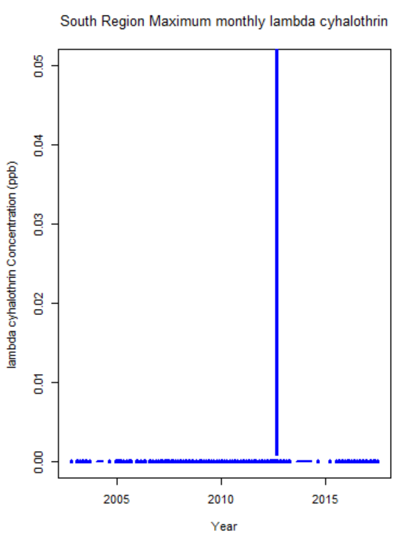

Central Delta Region Average Monthly Temperature(°C) - All Samples
Temperature (°C)
Year

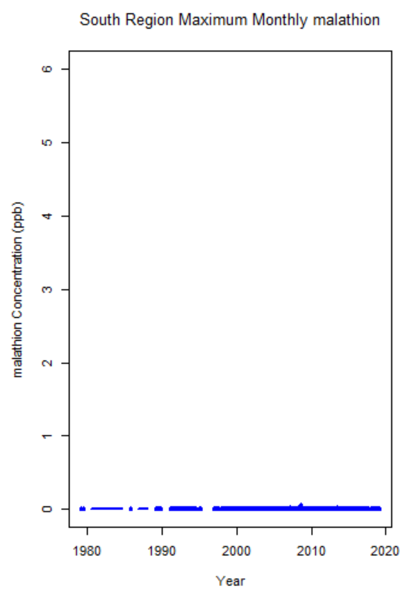
South Delta Risk Region

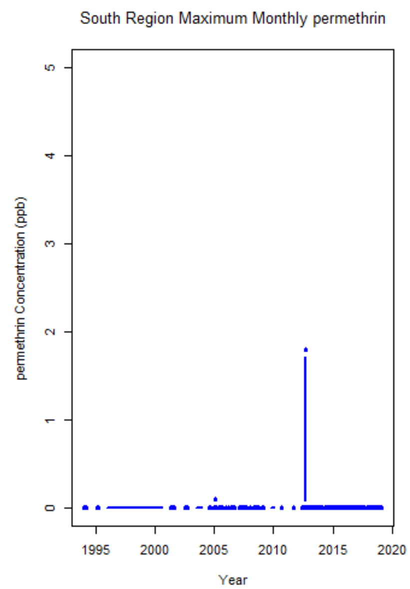


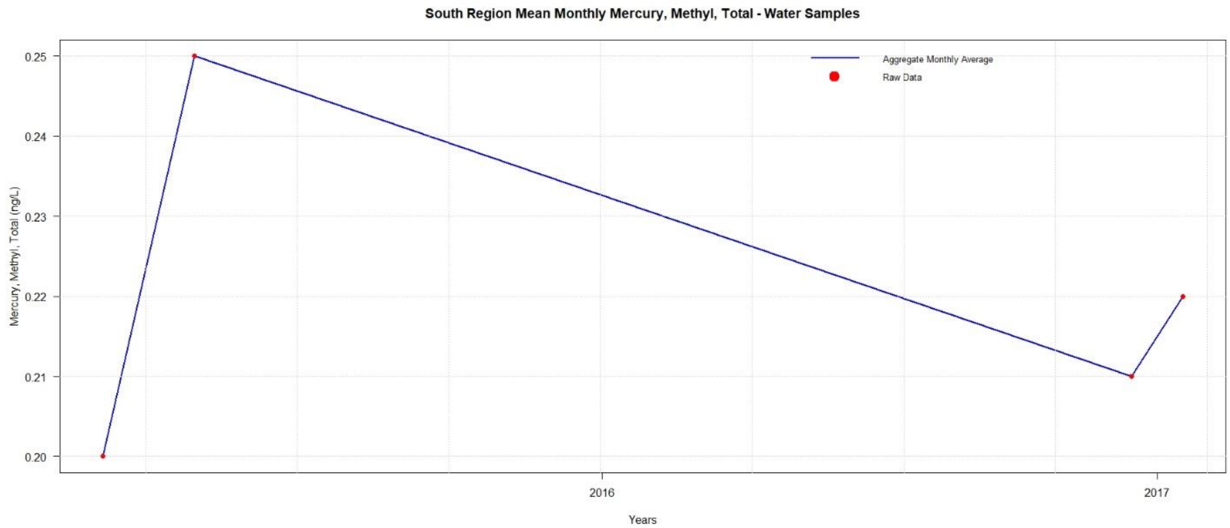


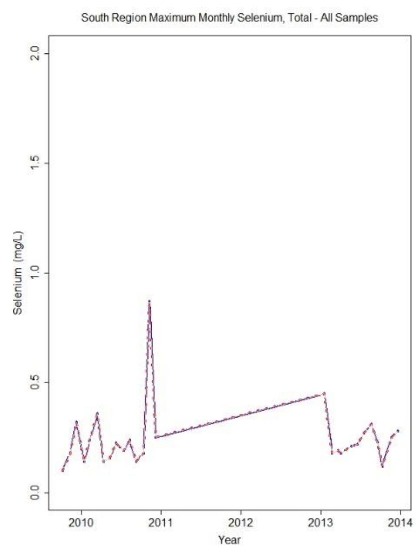


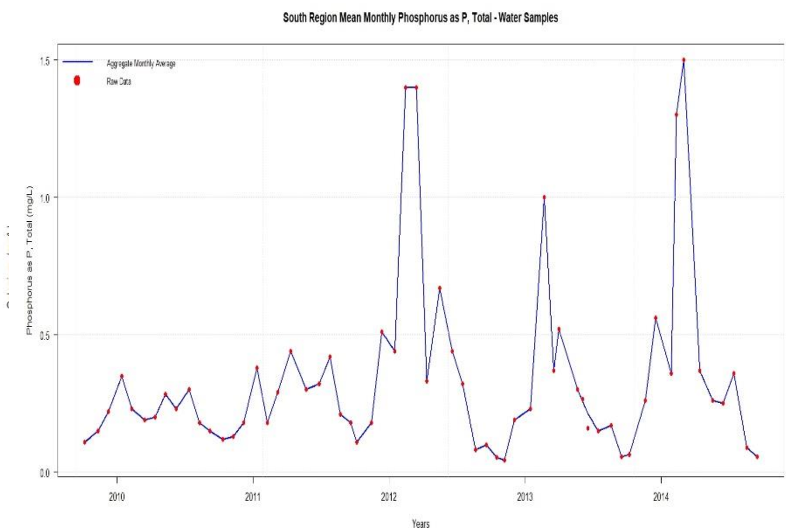


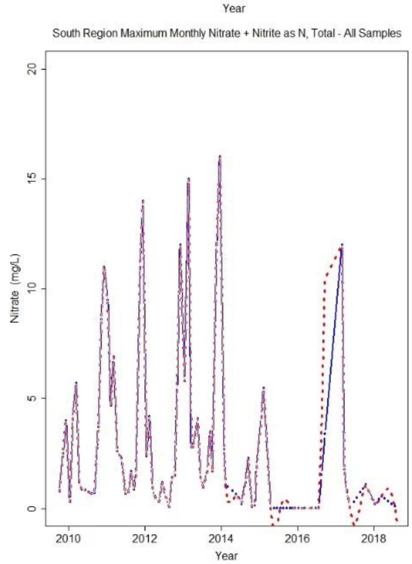


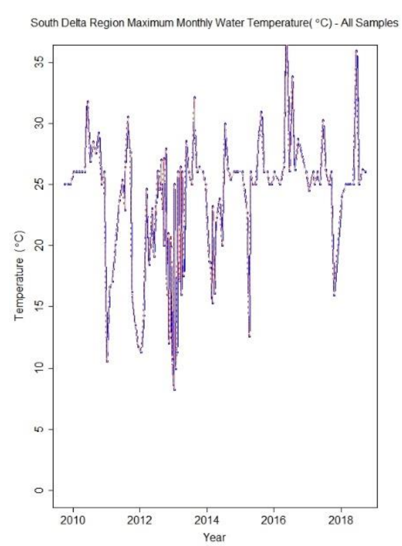


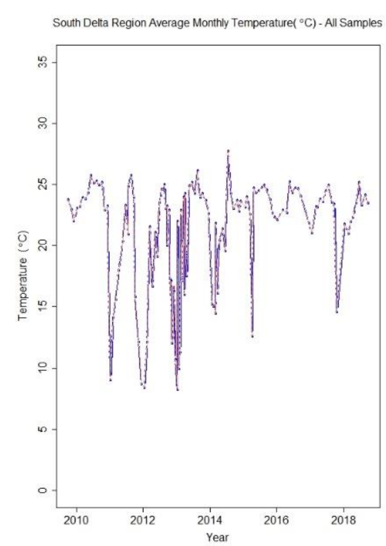

South Region Mean Monthly Mercury, Methyl, Total - Water Samples
Aggregate Monthly Average
Raw Data
Mercury, Methyl, Total (ng/L)
Years


South Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
Year

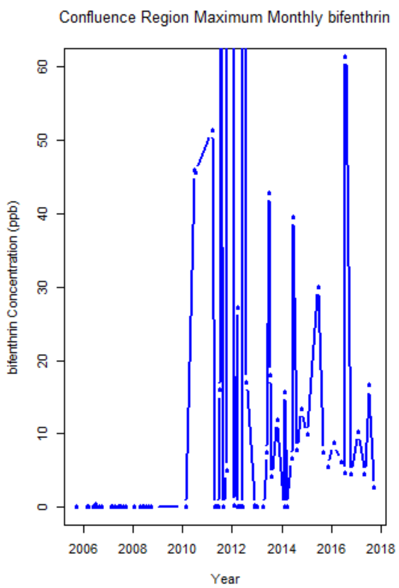

South Region Mean Monthly Phosphorus as P, Total - Water Samples
Aggregate Monthly Average
Raw Data
Phosphorus as P, Total (mg/L)
Years

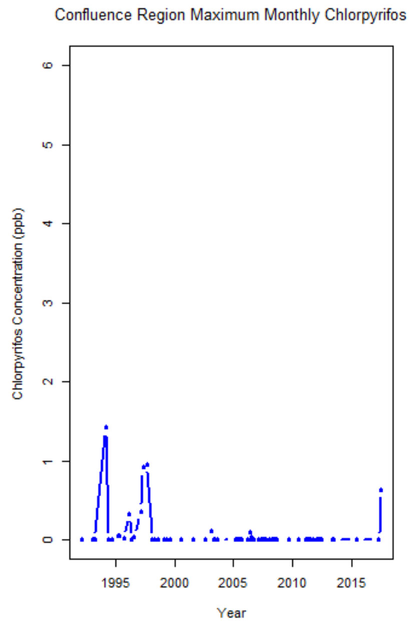

South Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
Year

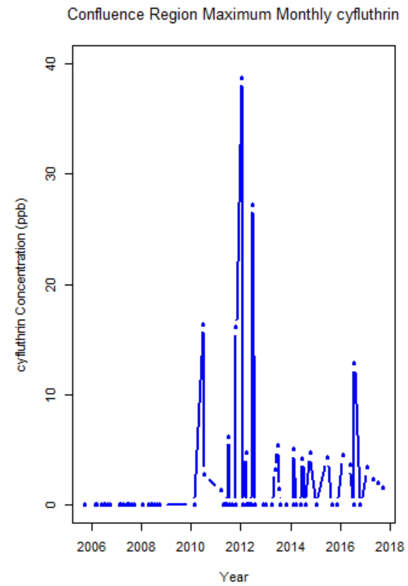

South Delta Region Maximum Monthly Water Temperature(°C) - All Samples
Temperature (°C)
Year

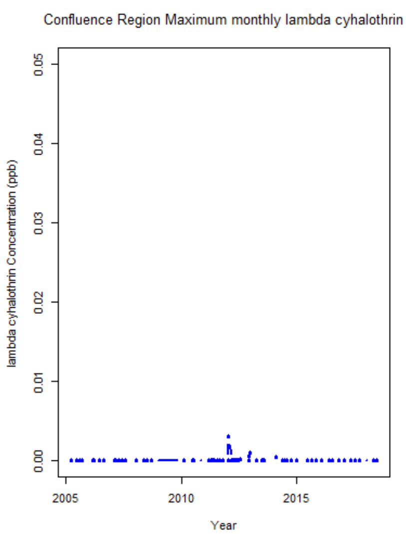

South Delta Region Average Monthly Temperature(°C) - All Samples
Temperature (°C)
Year

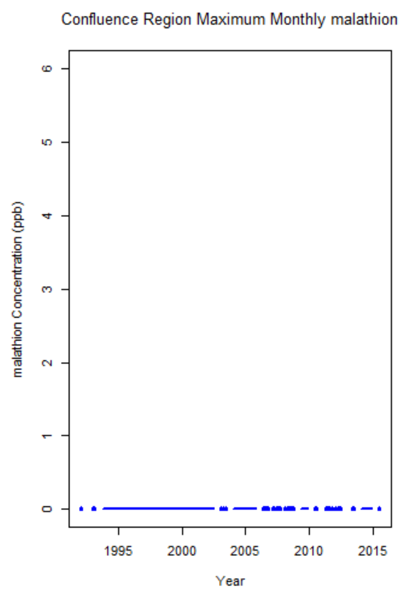
Confluence Risk Region

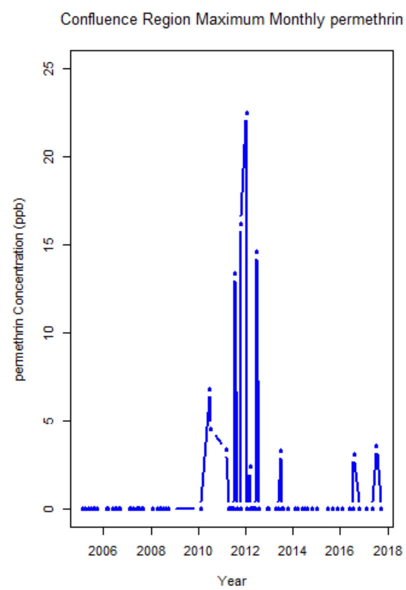




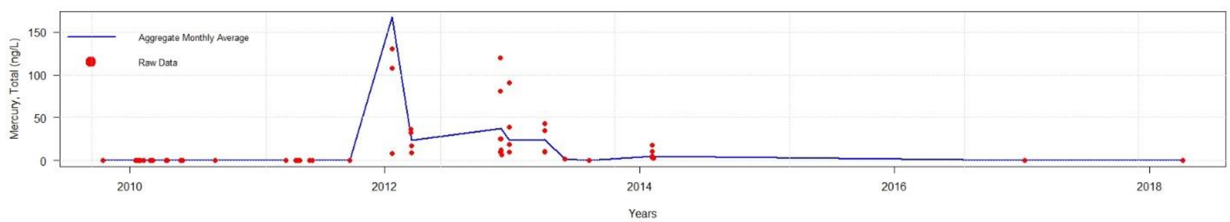




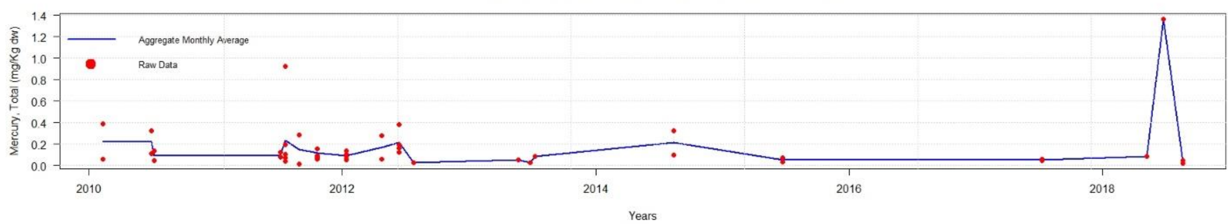




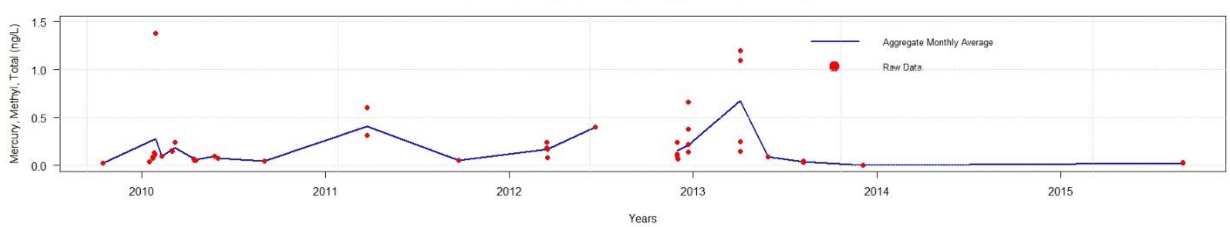
Confluence Region Mean Monthly Mercury, Total - Water Samples (8/16-2/17)



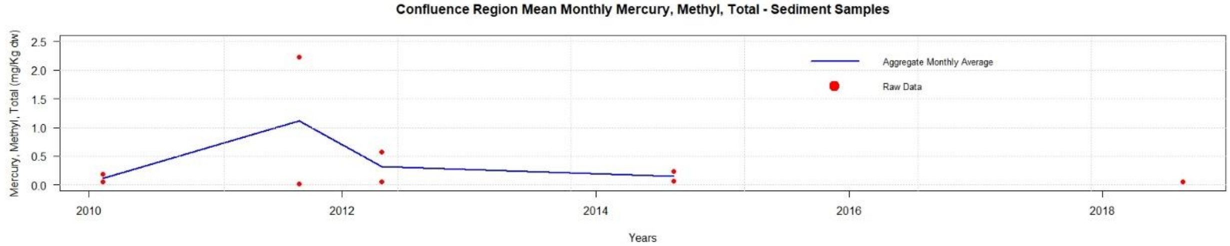
Confluence Region Mean Monthly Mercury, Total - Sediment Samples



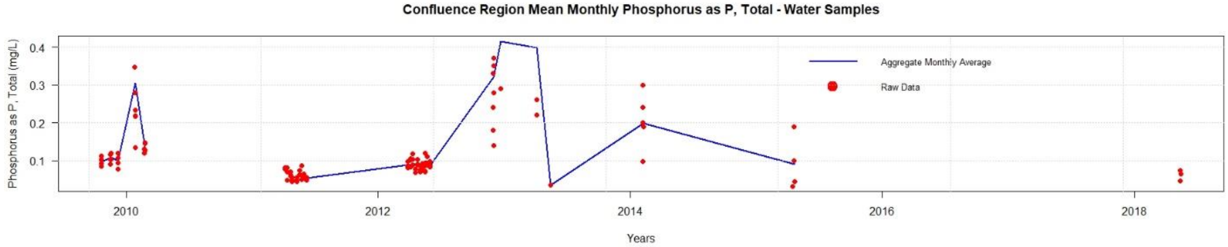
Confluence Region Mercury, Methyl, Total - Water Samples



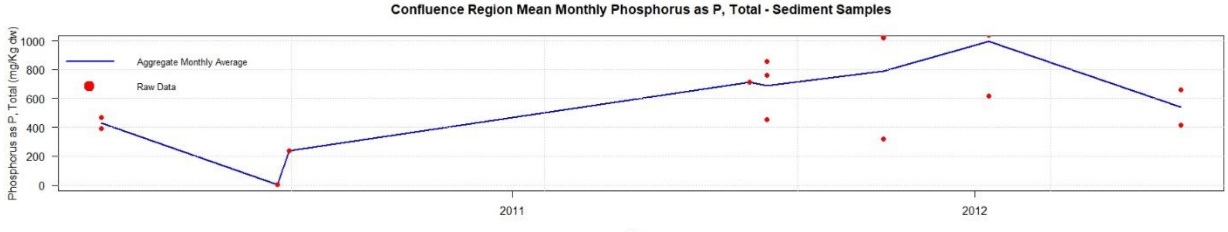
Confluence Region Mean Monthly Mercury, Methyl, Total - Sediment Samples

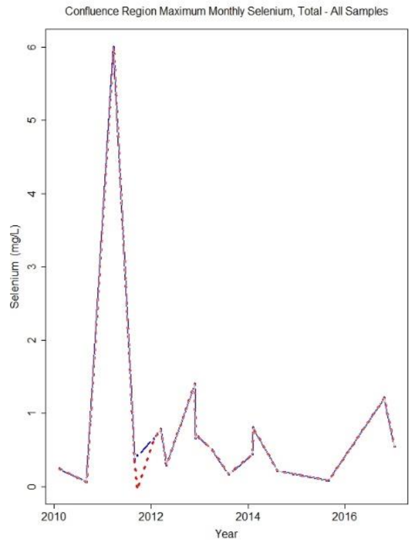


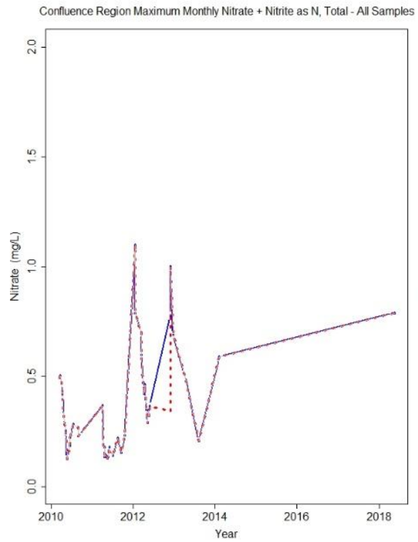
Confluence Region Mean Monthly Phosphorus as P, Total - Water Samples

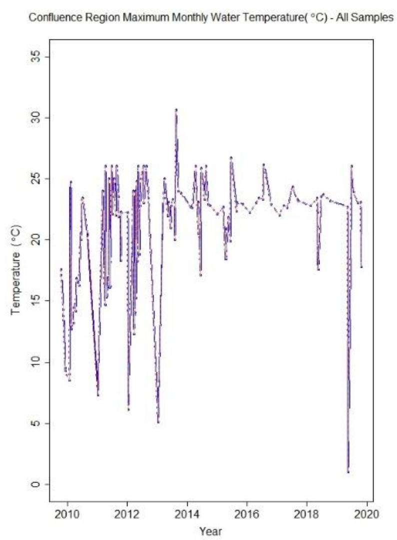


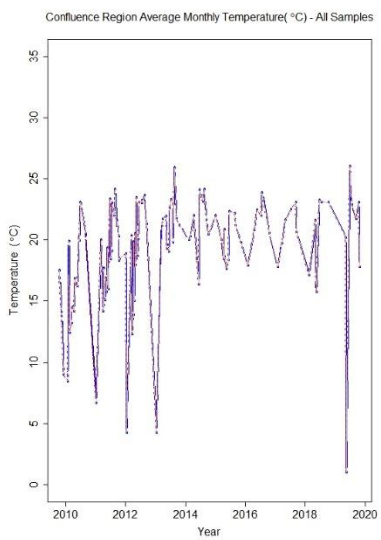
Confluence Region Mean Monthly Phosphorus as P, Total - Sediment Samples

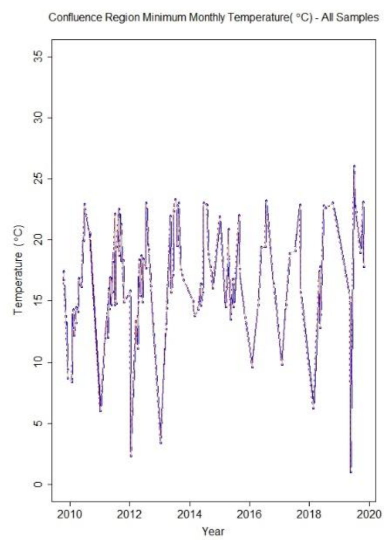



Confluence Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
Year

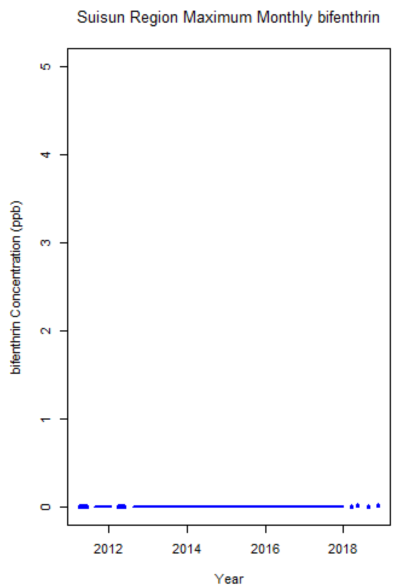

Confluence Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
Year

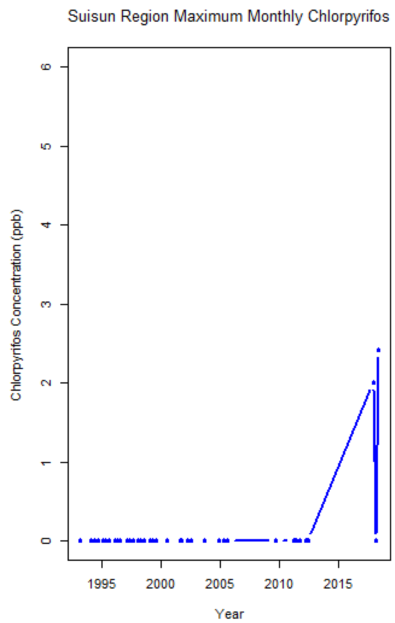

Confluence Region Maximum Monthly Water Temperature(°C) - All Samples
Temperature (°C)
Year

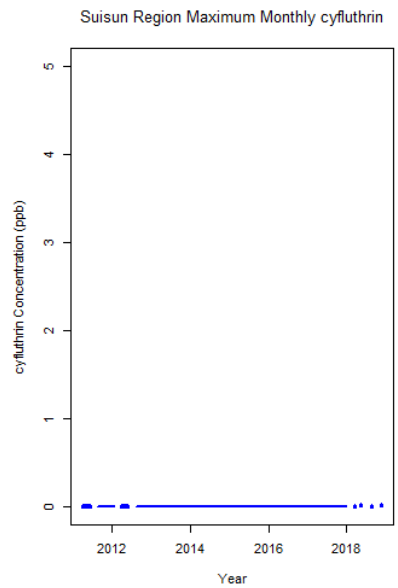

Confluence Region Average Monthly Temperature(°C) - All Samples
Temperature (°C)
Year

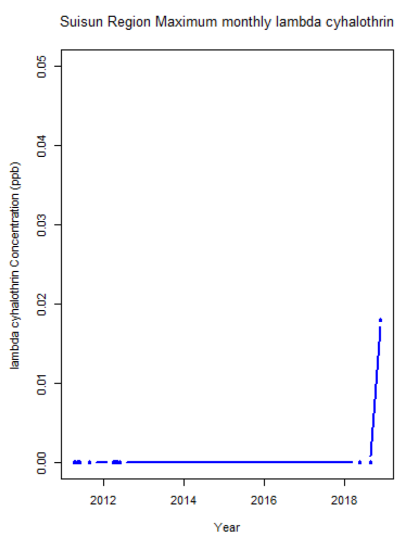

Confluence Region Minimum Monthly Temperature(°C) - All Samples
Temperature (°C)
Year

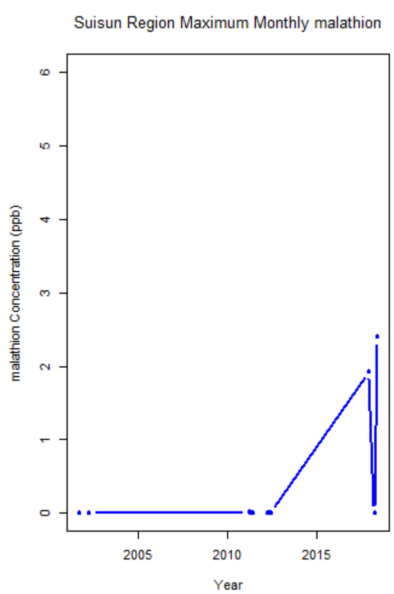
Suisun Bay Risk Region

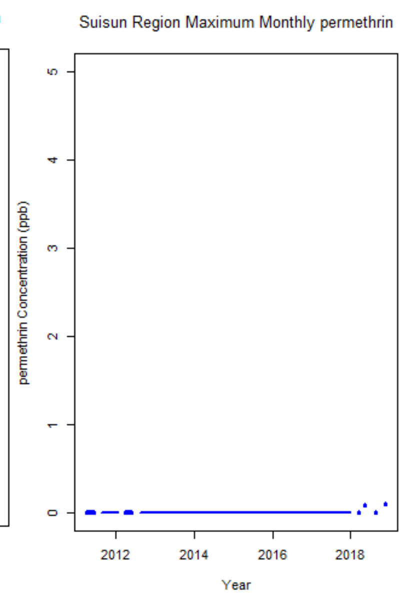


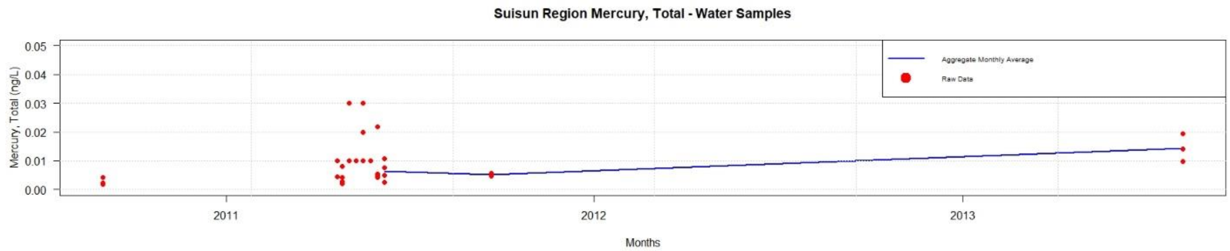


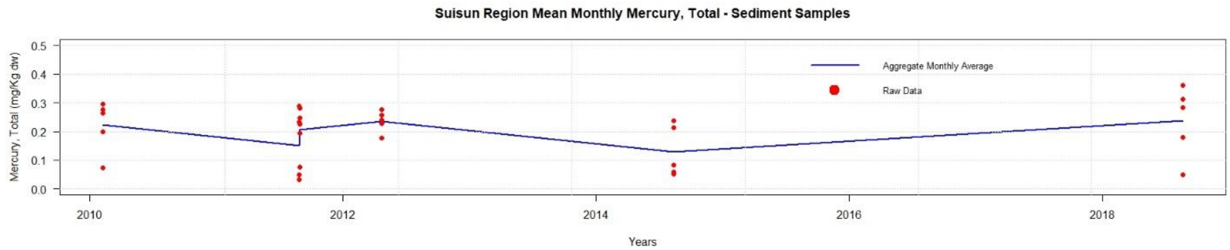


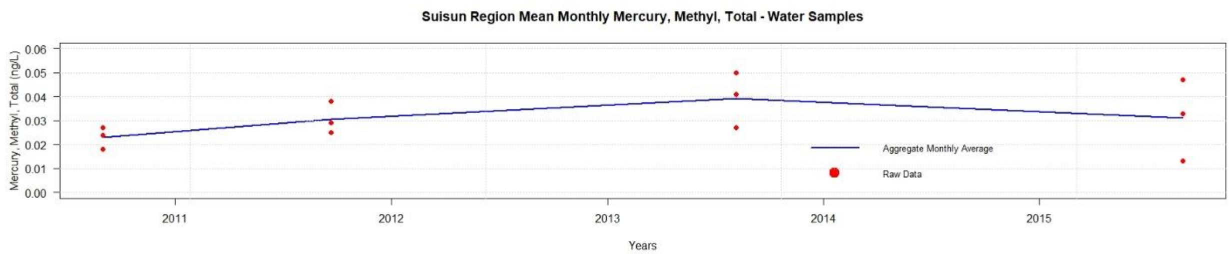


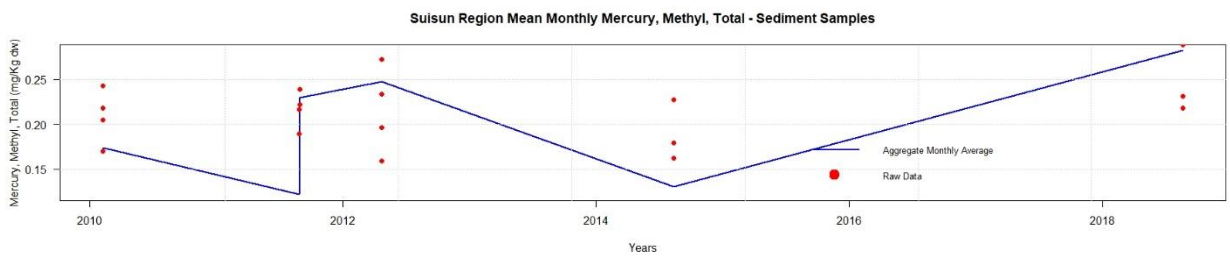


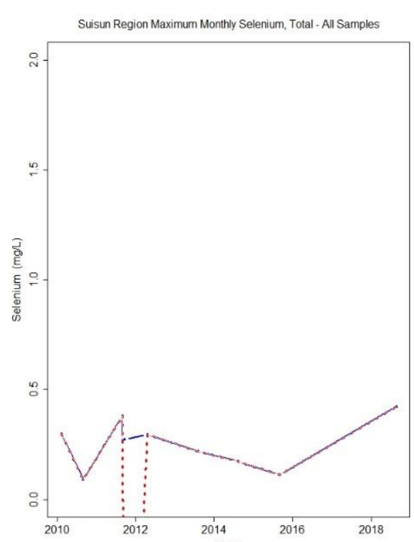


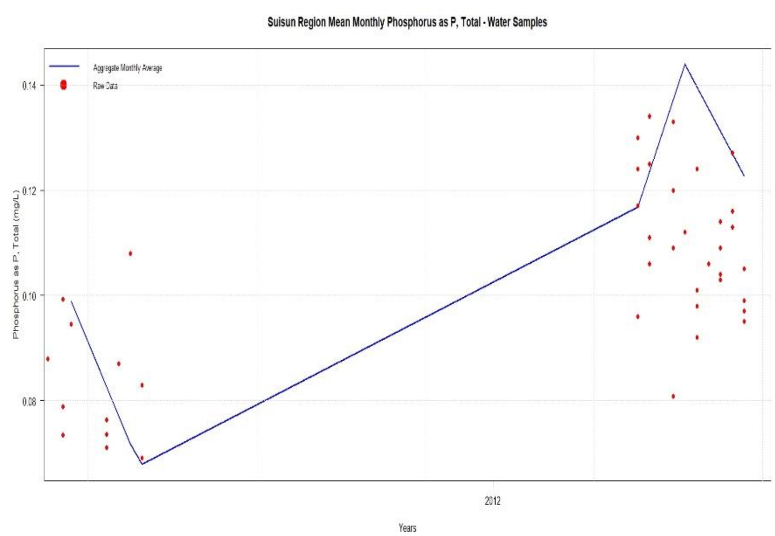

Suisun Region Mercury, Total - Water Samples
Aggregate Monthly Average
Raw Data
Mercury, Total (ng/L)
0.05
0.04
0.03
0.02
0.01
0.00
2011
2012
2013
Months

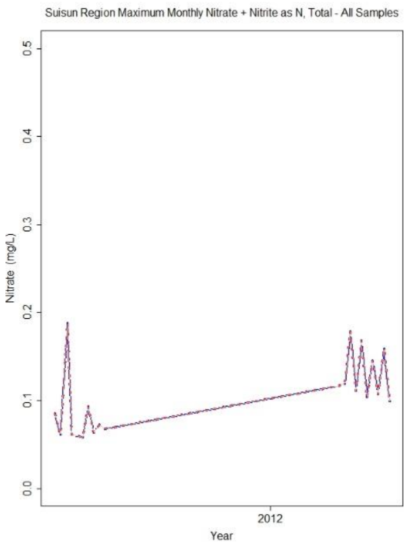

Suisun Region Mean Monthly Mercury, Total - Sediment Samples
Aggregate Monthly Average
Raw Data
Mercury, Total (mg/Kg dw)
0.5
0.4
0.3
0.2
0.1
0.0
2010
2012
2014
2016
2018
Years

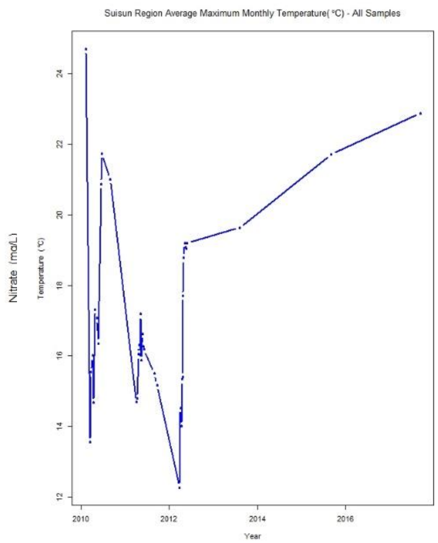

Suisun Region Mean Monthly Mercury, Methyl, Total - Water Samples
Aggregate Monthly Average
Raw Data
Mercury, Methyl, Total (ng/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2011
2012
2013
2014
2015
Years


Suisun Region Mean Monthly Mercury, Methyl, Total - Sediment Samples
Aggregate Monthly Average
Raw Data
Mercury, Methyl, Total (mg/Kg dw)
0.25
0.20
0.15
2010
2012
2014
2016
2018
Years


Suisun Region Maximum Monthly Selenium, Total - All Samples
Selenium (mg/L)
2.0
1.5
1.0
0.5
0.0
2010
2012
2014
2016
2018
Year


Suisun Region Mean Monthly Phosphorus as P, Total - Water Samples
Aggregate Monthly Average
Raw Data
Phosphorus as P, Total (mg/L)
0.14
0.12
0.10
0.08
2012
Years


Suisun Region Maximum Monthly Nitrate + Nitrite as N, Total - All Samples
Nitrate (mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
2012
Year


Suisun Region Average Maximum Monthly Temperature(°C) - All Samples
Nitrate (mg/L)
Temperature (°C)
12
14
16
18
20
22
24
2010
2012
2014
2016
Year

REFERENCES

Abell RA, Olson DM, Dinerstein E, Hurley PT, Diggs JT, Eichbaum W, Walters S, Wettengel W, Allnutt T, Loucks CJ, Hedao P, Taylor CL. 2000. Freshwater Ecoregions of North America: A Conservation Asssessment. World Wildlife Fund, Island Press, Washington, DC. 368 pp.

Bennett WA. 2005. Critical assessment of the Delta smelt population in the San Francisco Estuary, California. *San Francisco Estuary and Watershed Science* 3.

Carter JL, Resh VH. 2005. Chapter 12-Pacific Coast Rivers of the Coterminous United States. In Benke AC, Cushing CE (eds), Rivers of North America, pp. 540-589. Elsevier Academic Press, Burlington, Mass.

CDFW [California Department of Fish and Wildlife]. 2020a. Suisun Marsh Atlas. https://wildlife.ca.gov/Regions/3/Suisun-Marsh/Atlas. Accessed 22 Apr 2020.

CDFW [California Department of Fish and Wildlife]. 2020b. Suisun Marsh Habitat Management, Preservation, and Restoration. https://wildlife.ca.gov/Regions/3/Suisun-Marsh . Accessed 22 Apr 2020.

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

CDWR [California Department of Water Resources]. 2020a. The Sacramento-San Joaquin Delta Facts. 2pp. https://water.ca.gov/-/media/DWR-Website/Web-Pages/What-We-Do/Education/K-12-Education-Materials/Posters/Delta-Facts_a_y20.pdf?la=en&hash=DB023A5FB44A44CD9A75E334C4A54C2B898AEB09. Accessed 20 Apr 2020.

Connon RE, Geist J, Pfeiff J, Loguinov AV, D'Abronzo LS, Wintz H, Vulpe CD, Werner I. 2009. Linking mechanistic and behavioral responses to sublethal esfenvalerate exposure in the endangered delta smelt; *Hypomesus transpacificus* (Fam. Osmeridae). *BMC Genomics* 10:608.

Connon RE, Deanovic LA, Fritsch EB, D'Abronzo LS, Werner I. 2011. Sublethal responses to ammonia exposure in the endangered delta smelt; *Hyposmeus transpacificus* (Fam. Osmeridae). *Aquat. Toxicol.* 105:369-377.

Conomos TJ, Smith RE, Gartner JW. 1985. Environmental setting of San Francisco Bay. *Hydrobiologia* 129:1-12.

CWSC [California Water Science Center]. 2020a. San Francisco Bay Watershed. https://ca.water.usgs.gov/projects/baydelta/studyarea.html. Accessed 2 Apr 2020.

CWSC [California Water Science Center]. 2020b. San Francisco Bay Delta. Continuous Monitoring of Water Quality and Suspended-Sediment Transport in the San Francisco Bay and Delta. https://ca.water.usgs.gov/projects/baydelta/index.html. Accessed 2 Apr 2020.Delta Vision. 2020. Delta Facts. https://deltarevision.com/delta_facts.htm. Accessed 30 May 2020.

Domagalski JL, Brown LR. 1994. National Water Quality Assessment Program: The Sacramento River Basin. United States Geological Survey FS 1994-029, NAWQA Fact Sheet. https://ca.water.usgs.gov/projects/sac_nawqa/Publications/fs_1994-029.html. Accessed 15 Apr 2020.

Domagalski JL, Knifong DL, Dileanis PD, Brown LR, May JT, Connor V, Alpers CN. 2000. Water Quality in the Sacramento River Basin, California,1994–98: U.S. Geological Survey Circular 1215. 36 pp. https://pubs.water.usgs.gov/circ1215/. Accessed 17 Apr 17, 2020.

Feyrer F, Nobriga ML, Sommer TR. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. *Can J Fish Aquat Sci* 64:723–734. doi: http://dx.doi.org/10.1139/f07-048. Accessed 17 May 2020.

Grimaldo LF, Sommer T, Van Ark N, Jones G, Holland E, Moyle PB, Herbold B, Smith P. 2009. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: can fish losses be managed? *N. Am. J. Fish. Manag.* 29:1253-1270.

Herbold, B, Jassby, AD, Moyle, PB. 1992. Status and trends report on aquatic resources in the San Francisco Estuary. Report to the EPA San Francisco Estuary Project. 257 p.

Holling CS. 1978. *Adaptive Environmental Assessment and Management*. London (UK), England: John Wiley and Sons. 402pp.

Ingebritsen SE, Ikehara ME, Galloway DL, Jones DR. 2016. Delta Subsidence in California; the Sinking Heart of the State. U.S. Geological Survey Fact Sheet 005-00. 4pp. https://pubs.usgs.gov/fs/2000/fs00500/pdf/fs00500.pdf. Accessed 17 Apr 2020.

Jahagirdar S. 2006. Reviving the San Joaquin. How California's Water Boards Can Restore a Signature California Waterway to Health. Environment California Research and Policy Center. Los Angeles, CA. June 2006. 28pp. file:///E:/Sacramento%20Bay-Delta/MWD%20Reports/Reviving-the-San-Joaquin.pdf. Accessed 10 Apr 2020.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecol. Appl.* 5:272-289.

Kimmerer WJ. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? *Mar. Ecol. Prog. Ser.* 243:39-55.

Lee GF, Jones-Lee A. 2006. San Joaquin River Water Quality Issues. G. Fred Lee and Associates, El Macero, CA. 92 pp.

MARAD [U.S. Department of Transportation's Maritime Administration]. 2018. Suisun Bay Reserve Fleet. https://www.maritime.dot.gov/history/vessels-maritime-administration/suisun-bay-reserve-fleet. Updated October 29, 2018. Accessed 24 Apr 2020.

McClurg S. 1997. Sacramento-San Joaquin River Basin Study. Report to the Western Water Policy Review Advisory Commission. Water Education Foundation, Sacramento, CA. https://digitalrepository.unm.edu/law_service_westernwater_rbs/24. Accessed 14 Apr 2020.

Moyle PB, Brown LR, Durand JR, Hobbs JA. 2016. Delta smelt: life history and decline of a once-abundant species in the San Francisco Estuary. *San Franc. Estuary Watershed Sci.* 14(2) Article 7. https://ca.water.usgs.gov/pubs/2016/Brown_delta-smelt-life-decline_2016.pdf. Accessed 3 May 2020.

Porterfield G. 1980. Sediment transport of streams tributary to San Francisco, San Pablo, and Suisun Bays, California, 1909-1966. U.S. Geological Survey Water-Resources Investigations 80-64. 91 pp.

Presser TS, Ohlendorf HM. 1987. Biogeochemical cycling of selenium in the San Joaquin Valley, California. *J. Environ. Manage*. 11(6):805-821).

Rider CV, LeBlanc GA. 2005. An integrated addition and interaction model for assessing toxicity of chemical mixtures. *Toxicol. Sci.* 87(2):520-528.

Ritz C, Streibig JC. 2020. Analysis of dose-response curves. Package "drc" version 3.0-1. Available at https://github.com/DoseResponse/drc. Accessed 22 Apr 2020.

SFEP [San Francisco Estuary Partnership]. 2019. The State of the Estuary 2019 Update: Status and Trends of Indicators of Ecosystem Health. 44pp. https://www.sfestuary.org/wp-content/uploads/2019/10/State-of-the-Estuary-Report-2019.pdf. Accessed 8 Apr 2020.

SFEP [San Francisco Estuary Partnership]. 2020. About the Estuary. Accessed 8 Apr 2020.

Sommer T, Mejia FH, Nobriga ML, Feyrer F, Grimaldo L. 2011. The spawning migration of Delta smelt in the upper San Francisco Estuary. *San Franc. Estuary Watershed Sci.* 9.

Stene EA. 2015. The Central Valley Project. U.S. Bureau of Reclamation. https://www.usbr.gov/history/cvpintro.html. Accessed 9 Apr2020.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. *Trans. Am. Fish. Soc.* 101: 442-452.

USFW [United States Fish and Wildlife Service]. 2006. San Joaquin River National Wildlife Refuge Final Comprehensive Conservation Plan. US Fish and Wildlife Service California/Nevada Operations Office. 211pp.

USBR [U.S. Bureau of Reclamation]. 2019. Reinitiation of consultation on the coordinated long-term operation of the Central Valley Project and State Water Project: Final Biological Assessment. https://www.usbr.gov/mp/bdo/lto.html. Accessed 5 May 2020

USGS [United States Geological Survey]. 1964. Suisun Bay. Geographical Names Information System. United States Geological Survey http://geonames.usgs.gov/apex/feat_folder?p_file=790763. Accessed 23 Apr 2020.

USGS [United States Geological Survey]. 2020a. California Water Science Center - Science. https://www.usgs.gov/centers/ca-water/science. Accessed 8 Apr 2020.

USGS [United States Geological Survey]. 2020b. Boundary Descriptions and Names of Regions, Subregions, Accounting Units and Cataloging Units. http://water.usgs.gov/GIS/huc_name.html. Accessed 10 Apr 2020.

WEF [Water Education Foundation]. 2020a. San Joaquin Valley. https://www.watereducation.org/aquapedia/san-joaquin-valley. Accessed 20 Apr 2020.

WEF [Water Education Foundation]. 2020b. Kesterson Reservoir. Sacramento, California. https://www.watereducation.org/aquapedia/kesterson-reservoir. Accessed 20 Apr 2020.

WEF [Water Education Foundation]. 2020c. Suisun Marsh. https://www.watereducation.org/aquapedia/suisun-marsh. Accessed 23 Apr 2020.

Wolfe MF, Schwarzbach S, Sulaiman RA. 1998. Effects of mercury on wildlife: a comprehensive review. *Environ Toxicol Chem* 17(2):146-160.

Xing H, Liu T, Zhang Z, Wang X, Xu S. 2015. Acute and subchronic toxic effects of atrazine and chlorpyrifos on common carp (*Cyprinus carpio* L.): Immunotoxicity assessments. *Fish Shellfish Immun.* 45:327-333.