DRAFT SCIENTIFIC BASIS REPORT SUPPLEMENT IN SUPPORT OF PROPOSED VOLUNTARY AGREEMENTS FOR THE SACRAMENTO RIVER, DELTA, AND TRIBUTARIES UPDATE TO THE SAN FRANCISCO BAY/SACRAMENTO-SAN JOAQUIN DELTA WATER QUALITY CONTROL PLAN

Prepared By:

State Water Resources Control Board
California Department of Water Resources
California Department of Fish and Wildlife

January 2023

State Water Resources Control Board, California Department of Water Resources, and California Department of Fish and Wildlife. 2023. Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan. January. (ICF 103625.0.002.01.004.01.) Sacramento, CA.

Contents

Page

Tables

Page

Figures

Acronyms and Abbreviations

Acronym or Abbreviation	Definition
2017 Scientific Basis Report	*Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows*
AFRP	Anadromous Fish Restoration Program
Bay-Delta	San Francisco Bay/Sacramento-San Joaquin River Delta Estuary
Bay-Delta Plan	Water Quality Control Plan for the Bay-Delta
BiOp	Biological Opinion
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CPU	central processing unit
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
cyanoHABs	cyanobacterial blooms
D-1641	State Water Board Revised Water Right Decision 1641
DG	doubling goal
Draft Supplement Report	*Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan*
DSM2	DWR's Delta Simulation Model 2
DSP	Delta Science Program
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
EC	electrical conductivity
ESHE	Emigrating Salmonoid Habitat Estimation
ISB	Independent Science Board
ITP	Incidental Take Permit
m^2	square meters
MFE	Meaningful Floodplain Event
MOU	Memorandum of Understanding
NMFS	National Marine Fisheries Service
RMA	Resource Management Associates
PWA	public water agencies
Reclamation	U.S. Bureau of Reclamation

Acronym or Abbreviation	Definition
Sacramento/Delta Update to the Bay-Delta Plan	process to update the Sacramento River and Delta tributary inflow and cold-water habitat, Delta outflow, and interior Delta flow components of the Bay-Delta Plan
State Water Board	State Water Resources Control Board
SWP	State Water Project
TAF	thousand acre-feet
USFWS	United States Fish and Wildlife Service
VA	Voluntary Agreement
VAs	Voluntary Agreements
VA Term Sheet	*Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions*
YWA	Yuba Water Agency

Executive Summary

The State Water Resources Control Board (State Water Board) is currently in the process of updating and implementing the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). In 2022, the State Water Board received a Memorandum of Understanding (MOU; hereafter referred to as the VA Term Sheet) signed by state and federal agencies and water users proposing Voluntary Agreements (VAs) for updating and implementing the Bay-Delta Plan. The State Water Board is in the process of evaluating and considering the VAs, including preparing necessary environmental documentation and other technical analyses. This *Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan* (Draft Supplement Report) is part of that process and has been prepared to document the science supporting the proposed provisions included in the VAs.

This Draft Supplement Report was developed by State Water Board staff in collaboration with staff from the California Department of Fish and Wildlife (CDFW) (lead for limiting factors analysis and description of VA assets on the Sacramento River and tributaries) and the California Department of Water Resources (DWR) (lead for limiting factors in the Bay-Delta Estuary, hydrology and modeling, analytical approach, and anticipated VA outcomes). This Draft Supplement Report will be made available for public comment. Following receipt of public comments, the draft will be revised as appropriate and a final Draft Supplement Report will be developed for peer review pursuant to the requirements of California Public Health and Safety Code (section 57004), which requires that the scientific basis of any statewide plan, basin plan, plan amendment, guideline, policy, or regulation undergo external scientific peer review before adoption.

The State Water Board initiated a process to update the Sacramento River and Delta tributary inflow and cold water habitat, Delta outflow, and interior Delta flow components of the Bay-Delta Plan (referred to as the Sacramento/Delta Update to the Bay-Delta Plan) in 2012. In 2017, the State Water Board finalized the *Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows* (2017 Scientific Basis Report), documenting the science supporting possible Sacramento/Delta Update to the Bay-Delta Plan. The lower San Joaquin River flow and southern Delta salinity components of Bay-Delta Plan were updated separately in 2018. The VAs are proposed as an alternative pathway to update and implement the Bay-Delta Plan. This Draft Supplement Report serves as an addendum to the 2017 Scientific Basis Report that documents the science supporting the anticipated benefits of the proposed VAs in support of their consideration as part of the Sacramento/Delta Update to the Bay-Delta Plan (see Chapter 1, *Introduction*, for details on the report background). This report builds on the 2017 Scientific Basis Report, particularly with additional scientific information supporting specific flow and non-flow habitat restoration actions in the tributaries, flood bypasses, and Delta outlined in the VAs.

This report evaluates the effects of potential VA flow contributions from the lower San Joaquin River on Delta outflows, but it does not evaluate benefits on the lower San Joaquin River and its tributaries. This report is not intended to support possible updates to the portions of the Bay-Delta Plan covering the lower San Joaquin River, which could incorporate lower San Joaquin River VAs, and would be subject to a separate process and subsequent analysis.

As described further in this report and the 2017 Scientific Basis Report, native aquatic species have been declining in tributaries and the Bay-Delta due to anthropogenic stressors (see Chapter 2, *Limiting Factors for Native Fish Species*, for details on limiting factors for native species), including degradation of habitat and changes in flows. The VAs include a combination of assets (Table ES-1) to address these stressors over 8 years (with the possibility of extension), including varying amounts of increased flows, depending on water year type, and non-flow habitat restoration actions targeted at improving spawning and rearing capacity for juvenile salmonids and other native fishes (see Chapter 3, *Description of Flow and Non-Flow Assets*, for details on VA assets).

Table ES-1. Proposed VA Assets

	Flows (thousand acre-feet) by Water Year Type					Restoration (acres)		
Location	C	D	BN	AN	W	Spawning	Instream Rearing	Floodplain
Sacramento	2	102	100	100		113.5	137.5	20,000
American	30	40	10	10		25	75	
Yuba		60	60	60			50	100
Feather		60	60	60		15	5.25	1,655
Putah	7	6	6	6		1.4		
Friant		50	50	50				
Mokelumne		5	5	7			1	25
Delta		125*	125*	175*				5,227.5**
PWA Fixed Price Purchases	3	63.5	84.5	99.5	27			
PWA Market Price Purchases		50	60	83				
Permanent State Water purchases	65	108	9	52	123			
San Joaquin by San Joaquin Water Year Type (placeholder volumes from VA Term Sheet[1])	48	156	181	122				
Total including San Joaquin placeholder volumes	**155**	**825.5**	**750.5**	**824.5**	**150**	**154.9**	**268.75**	**21,780 + 5,227.5****

Flow assets are proposed to be additive to the Delta outflows resulting from State Water Board Revised Water Right Decision 1641 (D-1641) and the implementation of the 2019 Biological Opinions for operations of the State Water Project and Central Valley Project. C = Critical, D = Dry, BN = Below Normal, AN = Above Normal, W = Wet, * = foregone exports, ** = includes tidal wetland habitat. Blank cells indicate no proposed assets in that category.
[1]The placeholder volumes are not currently fully committed to by VA Term Sheet MOU signatories. These contributions are assumed to be provided according to the San Joaquin 60-20-20 water year type index.

The VA habitat and flow actions are proposed as implementation measures for an existing and new water quality objective in the Bay-Delta Plan. Specifically, the VAs propose: 1) a new narrative objective to achieve the viability of native fish populations (Box ES-1); and 2) to provide the participating parties' share, during implementation of the VAs, to contribute to achieving the existing Narrative Salmon Protection Objective (Box ES-1) by 2050.

Box ES-1. Objectives for the VAs Proposed in the VA Term Sheet (Voluntary Agreements Parties 2022)

The proposed new narrative viability objective states:

> Maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations. Conditions and measures that reasonably contribute toward maintaining viable native fish populations include, but may not be limited to, (1) flows that support native fish species, including the relative magnitude, duration, timing, temperature, and spatial extent of flows, and (2) conditions within water bodies that enhance spawning, rearing, growth, and migration in order to contribute to improved viability. Indicators of viability include population abundance, spatial extent, distribution, structure, genetic and life history diversity, and productivity. Flows provided to meet this objective shall be managed in a manner to avoid causing significant adverse impacts to fish and wildlife beneficial uses at other times of the year.

The existing salmon protection objective (also referred to as the salmon doubling goal) states:

> Water quality conditions shall be maintained, together with other measures in the watershed, sufficient to achieve a doubling of natural production of chinook salmon from the average production of 1967-1991, consistent with provisions of State and federal law.

This Draft Supplement Report includes quantitative evaluations of the projected changes in habitat provided for native species from VA proposed flows and non-flow habitat restoration actions compared to baseline conditions. This report also includes quantitative evaluations of projected changes in native species abundance indices with VA proposed flows compared to baseline conditions. In addition, a qualitative literature review was conducted to evaluate possible benefits of the VAs where no quantitative models exist (see Chapter 4, *Hydrology and Operations Modeling Methods and Results*, for details on quantitative analyses and Chapter 5, *Analytical Approach to Evaluating Assets*, for details on the analytical approach to evaluating the benefits of the VAs). The quantitative analyses indicate expected increases in suitable spawning and rearing habitat for salmonids and increases in suitable habitat and population abundance indices for estuarine species. Salmonid spawning (Figure ES-1), instream rearing (Figure ES-2), and floodplain (Table ES-2) habitats are expected to contribute toward the narrative objectives described above. However, the magnitude of increase varies with water year type and tributary such that not all habitat categories will have increases in all water year types.

The VAs are projected to surpass the spawning habitat needed to support 25% of the doubling goal (the target for the VAs) in all tributaries (Figure ES-1). The combination of instream rearing and floodplain habitat needed to support 25% of the doubling goal population is projected to be met in the Mokelumne (which currently meets the target) and Yuba Rivers, but not in the American, Feather, and Sacramento Rivers (Figure ES-2). Sacramento River rearing habitat would surpass the habitat needed to support 25% of the doubling goal population with the addition of 20,000 acres of floodplain restoration on the Sutter Bypass, provided that juvenile fish passage considerations can be addressed. Floodplain habitat is expected to be provided to support 25% of the doubling goal population in 80–98% of years in the Feather (84%), Mokelumne (80%), and Yuba (98%) Rivers (Table ES-2). Habitat areas for estuarine species are also expected to increase in the Bay-Delta (Table ES-3), contributing toward the narrative objective for viable native fish populations proposed in the VAs. However, increases would be small relative to total region size. Abundance indices based on flows under the VAs of four species (California Bay shrimp [*Crangon franciscorum*], Sacramento splittail [*Pogonichthys macrolepidotus*], longfin smelt [*Spirinchus Thaleichthys*], and starry flounder [*Platichthys stellatus*]) are expected to increase in all water year types except wet years (in which they are expected to decrease) (Figure ES-3). Qualitatively, the synergy of flow and non-flow habitat restoration assets proposed in the VAs is expected to improve conditions for salmonids and estuarine species toward achieving the proposed new narrative viable native fish population objective and existing salmon protection objective (see Chapter 6, *Anticipated Biological and Environmental Outcomes*, for details on the anticipated biological and environmental outcomes).

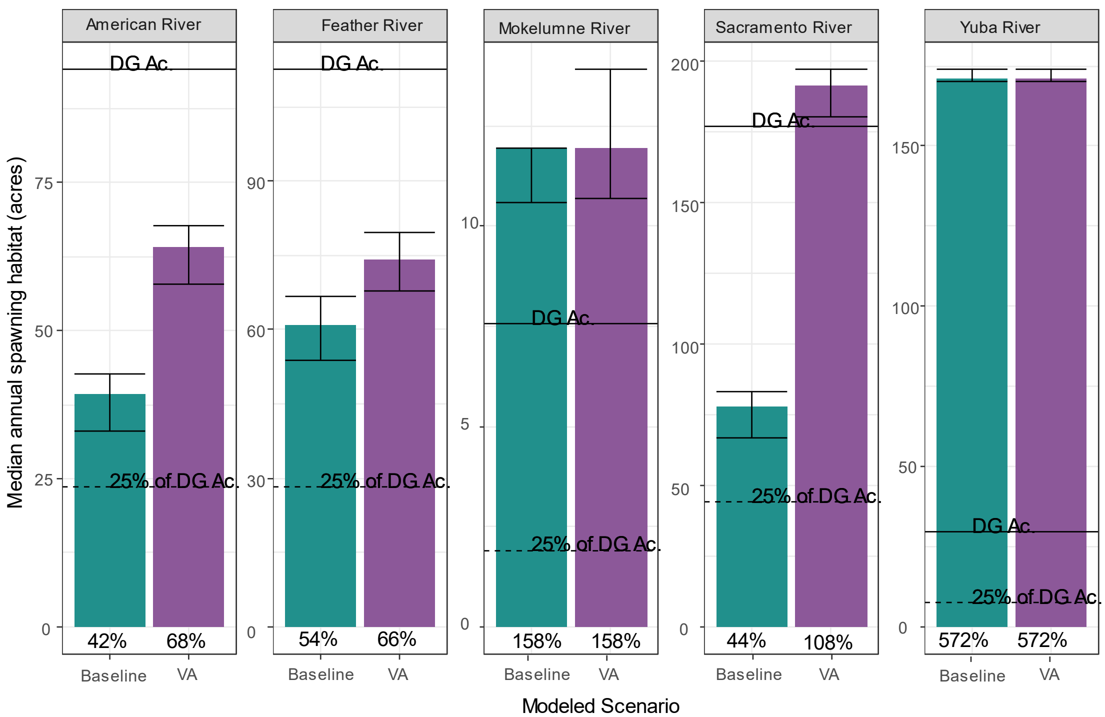

Figure ES-1. Median (across All Years) Spawning Habitat (Acres) under Baseline (Green) and VA (Purple) Scenarios for Each Watershed
Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25% of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is printed below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

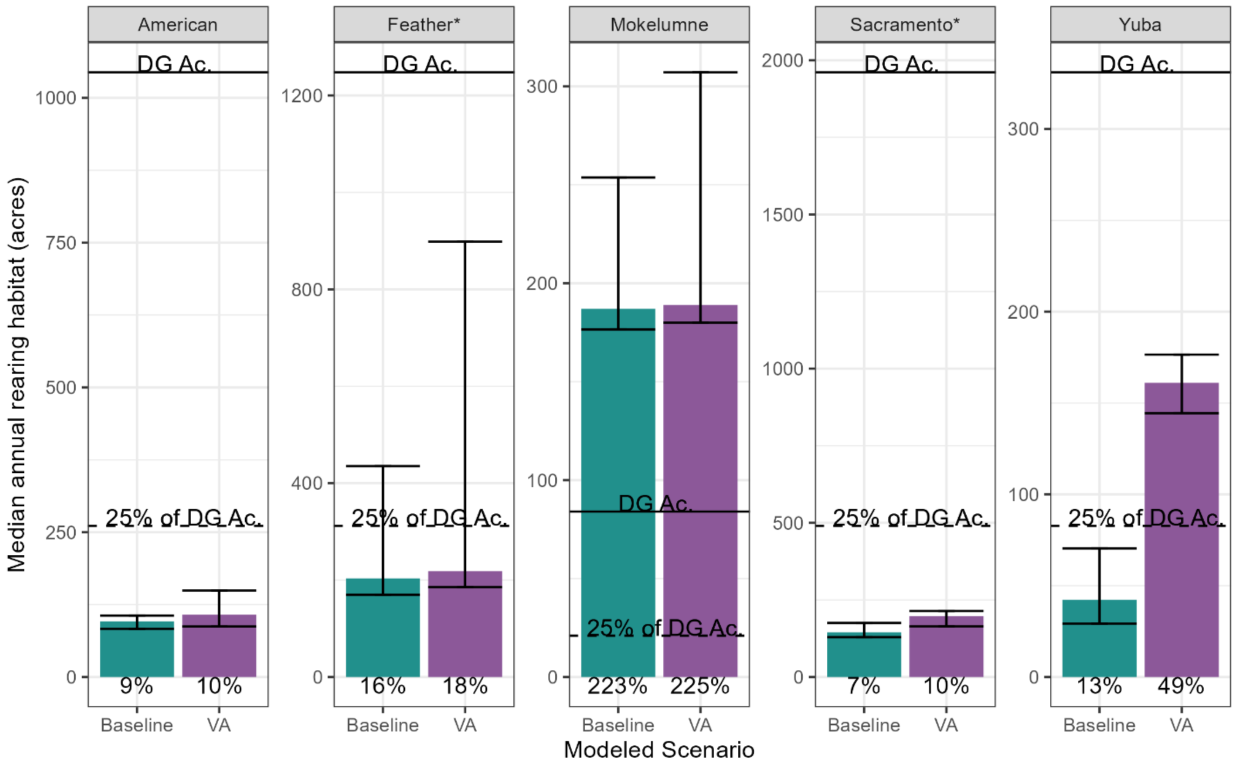

Figure ES-2. Median (across All Years) Rearing Habitat (Acres) under Baseline (Green) and VA (Purple) Scenarios for Each Watershed, including Both Floodplain and In-Channel Rearing Habitat
The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25% of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is noted below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. *Note that this does not include the 20,000 acres of floodplain restoration on the Sutter Bypass which may be available as rearing habitat for fish from the Feather and Sacramento Rivers.

Table ES-2. Percent of Years with Meaningful Floodplain Events at a Habitat Level Estimated to Support 25 Percent of the Offspring of a Doubled Salmon Population (the Target of the VAs)

Watershed	Baseline	VAs
Feather River	42%	84%
Mokelumne River	62%	80%
Yuba River	0%	98%

Table ES-3. Projected Increases in Habitat Area for Delta Smelt, Longfin Smelt, and Salmonids within Relevant Seasons for Each Species

Species	Season	Region	VA increase from baseline
Delta Smelt	Spring	Delta	5.8%
		Suisun	3.6%
		Bay	2.1%
	Summer–Fall	Delta	0.1%
		Suisun	8.8%
		Bay	1.1%
Longfin Smelt	Spring–Summer	Delta	5.0%
		Suisun	3.3%
		Bay	3.4%
Salmonid	Winter–Spring	Delta	5.7%
		Suisun	14.2%
		Bay	0.0%

Spring is defined as March–May; summer is defined as June–August; fall is defined as September–November; and winter is defined as December–February.

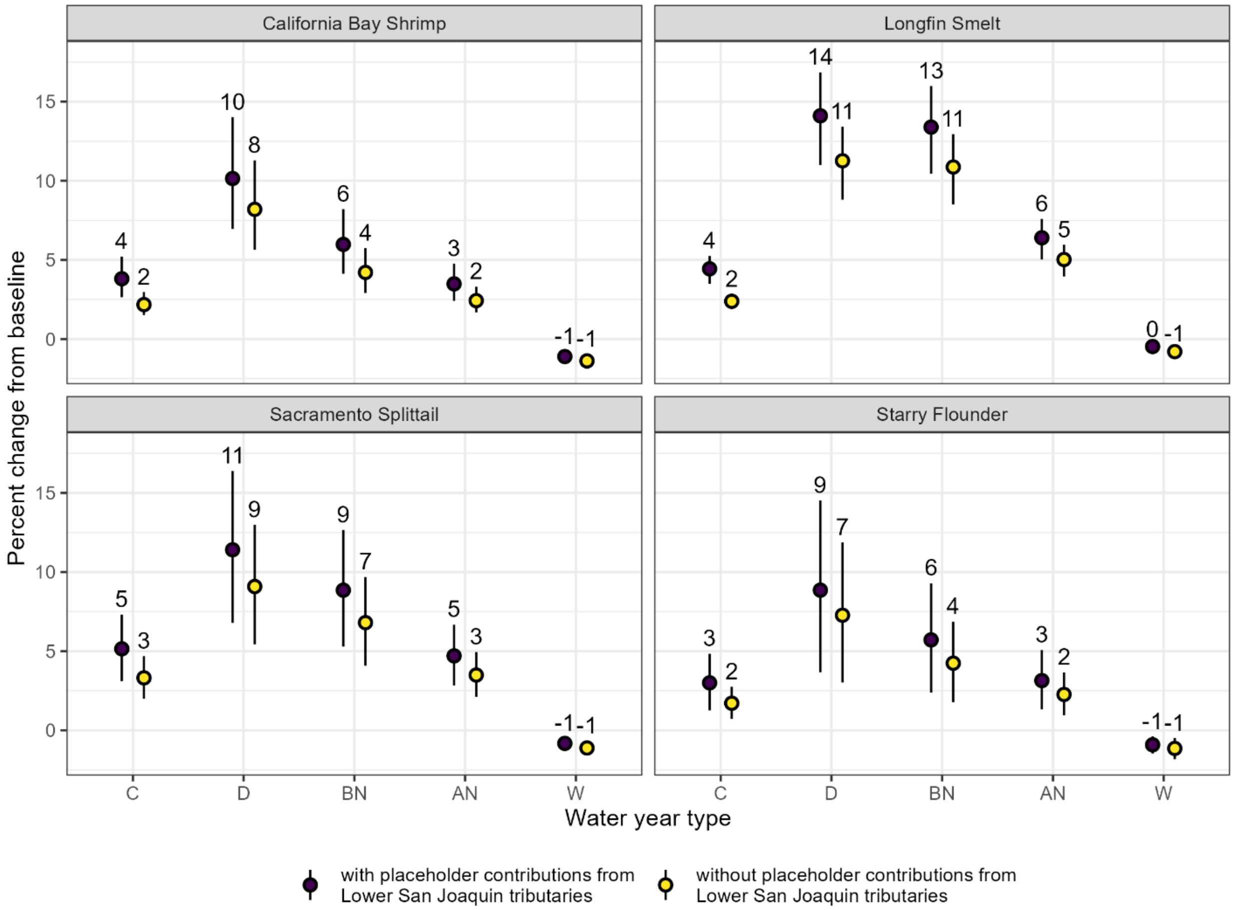

Figure ES-3. Potential Percent Increase (Median Prediction ± 95% Confidence Intervals) in Abundance Indices Relative to Baseline Conditions
The median predictions (rounded to a whole number) are also printed above each point. The current August 2022 VA Term Sheet identifies placeholder San Joaquin River flow contributions. However, to date, only Tuolumne River water users (as well as contributions from Friant water users) have signed on to the VA Term Sheet. To account for the range of possible VA flows from the lower San Joaquin River, this report includes an analysis of percent change from baseline with and without placeholder lower San Joaquin River flow contributions to Delta outflow using the volumes identified in Appendix 1 of the VA Term Sheet.

While the quantitative and qualitative analyses described in this report indicate expected benefits from the VAs, the actual outcomes of the VAs are not certain at this time. As with all modeling analyses, the quantitative results have uncertainty arising from assumptions and simplifications. Additional uncertainties in VA outcomes arise from flexibility in the timing of VA assets, both in terms of timing of flows and when habitat restoration actions will be completed; assumptions of the suitability of VA habitat assets; limitations in the habitat modeling approaches; the lack of a quantitative connection between certain aspects of habitat and species abundance; the focus on a few at-risk species; and other uncertainties (see Chapter 7, *Conclusions and Uncertainties*, for details on the uncertainty and a summary of the findings). The VAs, if adopted, would include a set of implementation criteria and habitat suitability and utilization criteria, along with a monitoring program, to ascertain the actual benefits realized and overall program success.

Chapter 1
Introduction

1.1 Overview of the Bay-Delta Water Quality Control Plan Update Process

The State Water Resource Control Board's (State Water Board's) mission is to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations. The State Water Board protects water quality that affects beneficial uses of water in the San Francisco Bay/Sacramento-San Joaquin River Delta Estuary (Bay-Delta) in part through its Water Quality Control Plan for the Bay-Delta (Bay-Delta Plan). The State Water Board is responsible for adopting and updating the Bay-Delta Plan, which establishes water quality control measures and flow requirements needed to provide reasonable protection of beneficial uses of water in the watershed.

The State Water Board has been engaged in a process since 2008 to update the 2006 Bay-Delta Plan to ensure that beneficial uses of water in the Bay-Delta watershed are reasonably protected. In 2018, the State Water Board updated the Bay-Delta Plan water quality objectives and the program of implementation to address San Joaquin River flows for the protection of fish and wildlife beneficial uses and southern Delta salinity for the protection of agricultural beneficial uses. The State Water Board is currently in the process of updating other components of the Bay-Delta Plan to protect native fish and wildlife in the Sacramento River, Delta, and associated tributaries (Sacramento/Delta Update to the Bay-Delta Plan). In support of that work, in 2017 the State Water Board prepared a final *Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows* (2017 Scientific Basis Report) (State Water Board 2017). The 2017 Scientific Basis Report described the science supporting possible changes to the Bay-Delta Plan being considered at the time. Based on the 2017 Scientific Basis Report, in July 2018, the State Water Board released a framework (State Water Board 2018) for a possible Sacramento/Delta Update to the Bay-Delta Plan for the reasonable protection of fish and wildlife, including Sacramento River and tributary and Delta eastside tributary (including Calaveras, Cosumnes, and Mokelumne rivers) inflows and cold water habitat measures, Delta outflows, and interior Delta flows (State Water Board 2018).

Since completion of the 2017 Scientific Basis Report and the 2018 updates to the Bay-Delta Plan, the State Water Board received proposed Voluntary Agreements (VAs) proposing updates to the Bay-Delta Plan and its implementation on March 29, 2022 (and amended on August 11, 2022 and November 10, 2022) titled, *Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions* (Voluntary Agreements Parties 2022; MOU; hereafter referred to as the VA Term Sheet). The VAs included signatories from state and federal agencies, local water agencies, private companies, and a nonprofit mutual benefit corporation (collectively referred to in the VA documents as "Parties," "public water agencies," or "PWAs"). The Parties submitted the VAs as a Bay-Delta Plan alternative that is proposed as a voluntary pathway to achieve reasonable protection of fish and wildlife beneficial uses.

This draft report, the *Draft Scientific Basis Report Supplement in Support of Proposed Voluntary Agreements for the Sacramento River, Delta, and Tributaries Update to the San Francisco Bay/Sacramento-San Joaquin Delta Water Quality Control Plan* (Draft Supplement Report), was developed as a supplement to the 2017 Scientific Basis Report. The Draft Supplement Report was developed by State Water Board staff in collaboration with staff from the California Department of Fish and Wildlife (CDFW) (lead for limiting factors analysis and description of VA assets on the Sacramento and tributaries) and the California Department of Water Resources (DWR) (lead for limiting factors in the Bay-Delta Estuary, hydrology and modeling, analytical approach, and anticipated VA outcomes) to document the science supporting the proposed flow and non-flow habitat provisions included in the VAs (Voluntary Agreements Parties 2022). This Draft Supplement Report builds on the 2017 Scientific Basis Report, particularly with additional scientific information supporting specific flow and non-flow habitat restoration actions in the tributaries, flood bypasses, and Delta outlined in the VAs. This Draft Supplement Report will be made available for public comment. Following receipt of public comments, the Draft Supplement Report will be revised as appropriate and a final Draft Supplement Report will be developed for peer review pursuant to the requirements of California Public Health and Safety Code section 57004, which requires that the scientific basis of any statewide plan, basin plan, plan amendment, guideline, policy, or regulation undergo external scientific peer review before adoption.

1.2 Background on the 2017 Scientific Basis Report

In October 2017, the State Water Board released its final Scientific Basis Report in support of the possible Sacramento/Delta Update to the Bay-Delta Plan (State Water Board 2017). The 2017 Scientific Basis Report documents the science upon which possible changes to the Bay-Delta Plan are based, including documentation of the prolonged and severe decline in numerous native species, such as spring-run and winter-run Chinook salmon (*Oncorhynchus tshawytscha*), longfin smelt (*Spirinchus thaleichthys*), Delta smelt (*Hypomesus transpacificus*), Sacramento splittail (*Pogonichthys macrolepidotus*), and other species. The 2017 Scientific Basis Report discusses the impacts that non-flow stressors like habitat loss are having on the ecosystem and the importance of addressing these stressors to protect the Bay-Delta ecosystem. Additionally, the 2017 Scientific Basis Report acknowledges that habitat restoration and other non-flow actions can potentially reduce the needs for flows. The 2017 Scientific Basis Report also presents evidence indicating that native fish and other aquatic species require more flow of a more natural pattern than is currently required under the Bay-Delta Plan to provide appropriate quantities of quality habitat and to support specific functions needed to protect these species. The information summarized in the 2017 Scientific Basis Report specifically establishes the need for new and modified inflow and cold water habitat, Delta outflow, and interior Delta flow requirements that work together in a comprehensive framework with other complementary actions to protect the Bay-Delta ecosystem.

A working draft version of the 2017 Scientific Basis Report was released on October 19, 2016, to receive public input prior to the submittal of the 2017 Scientific Basis Report for external peer review. The 2017 Scientific Basis Report builds upon the priorities and science in the State Water Board's 2008 Bay-Delta Strategic Workplan, 2009 Periodic Review Staff Report, and 2010 Report on the Development of Flow Criteria for the Bay-Delta Ecosystem required by the Sacramento-San

Joaquin Delta Reform Act of 2009 (Wat. Code, §§ 85000–85350); three informational workshops held in September, October, and November 2012; an additional three independent science workshops held in collaboration with the Delta Science Program (DSP), National Marine Fisheries Service (NMFS), and CDFW; and the public comments submitted on those processes.

A public workshop on the draft 2017 Scientific Basis Report was held on December 7, 2016. Part of the input on the draft 2017 Scientific Basis Report included consultation and input from the Delta Independent Science Board (ISB). The Delta ISB's Final Review Document was provided to the State Water Board in February 2017 (Delta ISB 2017).

Based on public and agency input—including input received at the December 2016 workshop, associated public comment letters, and the Delta ISB's Final Review Document—the 2017 Scientific Basis Report was refined, and a final draft 2017 Scientific Basis Report was prepared for independent peer review, as required by Health and Safety Code section 57004. Through the external peer review process, the final version of the 2017 Scientific Basis Report was reviewed by five independent external scientific peer reviewers with a broad range of expertise; these reviewers determined that the report is based on sound science.

1.3 Description of the Proposed Voluntary Agreements

The VAs propose that the State Water Board update the Bay-Delta Plan to include a new narrative viability objective as well as a combination of voluntary flow and non-flow habitat restoration actions that would achieve the new narrative viability objective and, by 2050, the existing Bay-Delta Plan salmon protection objective (Voluntary Agreements Parties 2022).

The proposed narrative viability objective states:

> Maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations. Conditions and measures that reasonably contribute toward maintaining viable native fish populations include, but may not be limited to, (1) flows that support native fish species, including the relative magnitude, duration, timing, temperature, and spatial extent of flows, and (2) conditions within water bodies that enhance spawning, rearing, growth, and migration in order to contribute to improved viability. Indicators of viability include population abundance, spatial extent, distribution, structure, genetic and life history diversity, and productivity. Flows provided to meet this objective shall be managed in a manner to avoid causing significant adverse impacts to fish and wildlife beneficial uses at other times of the year.

The existing salmon protection objective (also referred to as the salmon doubling objective) states:

> Water quality conditions shall be maintained, together with other measures in the watershed, sufficient to achieve a doubling of natural production of chinook salmon from the average production of 1967-1991, consistent with provisions of State and federal law.

The VAs propose an 8-year term and a set of flow and non-flow habitat restoration actions, or assets, in selected tributaries, flood bypasses, and the Delta, which are described in more detail in Chapter 3, *Description of Flow and Non-Flow Assets*. Flow assets are expected to be concentrated in January through June, with some flexibility outside of this period (under consideration in the VA governance process), with more limited flow assets also planned for fall months (Mokelumne and Putah systems). Priority months include April through May, and priority water year types include

Dry, Below Normal, and Above Normal water years. Flows during these time periods and water year types are intended to benefit spawning and rearing habitats for salmonids in the tributaries and provide benefits for more Delta-centric native species such as longfin smelt. Proposed restoration actions target spawning and rearing capacity for juvenile salmonids, as well as other native fishes. Tributary restoration actions are intended to restore spawning and rearing habitats sufficient to support approximately 25% of the offspring of the salmon doubling goal populations for each tributary. Restoration actions are also intended to improve regional aquatic food supply and improve connectivity between the in-channel and the new and existing floodplains. Where appropriate, restoration actions are intended to be integrated with and complementary to VA flow assets.

The process for updating the Bay-Delta Plan has been ongoing since 2009, with a revised Notice of Preparation issued for the Sacramento/Delta Update to the Bay-Delta Plan in 2012. When the 2017 Scientific Basis Report was developed, it used—for comparison when evaluating expected Delta outflow from changes to the Bay-Delta Plan—a regulatory baseline that included State Water Board Revised Water Right Decision 1641 (D-1641) and flows the Central Valley Project (CVP) and State Water Project (SWP) were required to provide pursuant to federal Endangered Species Act Biological Opinions (BiOps) issued in 2008/2009 for long-term CVP/SWP operations. In contrast, the VA proposal, as submitted, accounts for environmental flows relative to flows modeled with D-1641 and BiOps for CVP/SWP long-term operations issued in 2019. Because this report is a supplement to the 2017 Scientific Basis Report, the expected benefits of the VAs' contributions to Delta outflow are analyzed relative to the same baseline as the 2017 Scientific Basis Report to provide a consistent basis of environmental analysis (Section 4.12, *Postprocessing of Data Outflow*). This approach analyzes VA flows and habitat above flows and habitat required by D-1641 and the 2008/2009 BiOps (including assuming completion of the 8,000 acres of tidal wetland restoration required by the BiOps).

The VAs include a proposed Governance Program that would "direct flows and habitat restoration, conduct assessments, develop strategic plans and annual reports, implement a science program, and hire staff and contractors" (Voluntary Agreements Parties 2022). This Governance Program would include a Systemwide Governance Committee to oversee overall coordination of the VA Program, and Tributary/Delta Governance Entities that would oversee implementing the agreements for which that entity is responsible. The VA Science Program is proposed to "(A) inform decision-making by the Systemwide Governance Committee, Tributary/Delta Governance Entities, and VA Parties; (B) track and report progress relative to the metrics and outcomes stated in Appendix 4; (C) reduce management-relevant uncertainty; and (D) provide recommendations on adjusting management actions to the Systemwide Governance Committee, Tributary/Delta Governance Entities and VA Parties" (Voluntary Agreements Parties 2022). The framework for the VA Science Program is proposed to be collaboratively developed by the VA Parties in coordination with the State Water Board.

On the eighth year of the VAs, the State Water Board would consider the reports, analyses, information, and data from the VA Science Program, as well as recommendations from the VA Governance Committee and the Delta ISB to decide the future of the VA program. If the VAs are substantially achieving the stated objectives, the VA Parties would continue implementation of the VAs without any substantial modification in terms. If the VAs are expected to achieve the stated objectives with some modifications, the VA Parties would continue implementation with substantive modifications in terms. However, if the VAs are not expected to achieve the stated objectives, then either 1) new agreements may be negotiated or 2) the State Water Board would impose regulations to implement the Bay-Delta Plan (Voluntary Agreements Parties 2022).

1.4 Overview of Chapters

The following is a summary of the components of this Draft Supplement Report:

- **Chapter 1, *Introduction*,** provides an overview of the Bay-Delta Plan Update process, background on the 2017 Scientific Basis Report, the purpose of the Draft Supplement Report, and the stated objectives of the VAs.
- **Chapter 2, *Limiting Factors for Native Fish Species*,** summarizes the best available science related to flow and non-flow limiting factors in both the tributaries and Delta.
- **Chapter 3, *Description of Flow and Non-Flow Assets*,** presents assets outlined in Appendices 1 and 2 of the VA Term Sheet, including assets for the Sacramento River, American River, Yuba River, Feather River, Putah Creek, Friant system, Mokelumne River, and Delta and estuary.
- **Chapter 4, *Hydrology and Operations Modeling Methods and Results*,** presents modeling assumptions and an evaluation of changes in Bay-Delta hydrology that would result from implementation of the VAs.
- **Chapter 5, *Analytical Approach to Evaluating Assets*,** describes the analytical approach to evaluating assets, including the use of flow:area relationships to quantify tributary and off-stream habitats, two-dimensional hydrodynamic analysis for the Delta and estuary, and flow-abundance relationships for certain native species occupying the estuary.
- **Chapter 6, *Anticipated Biological and Environmental Outcomes*,** presents the anticipated outcomes that implementation of the VAs' assets is expected to provide.
- **Chapter 7, *Conclusions and Uncertainties,*** presents the findings of this Draft Supplement Report and includes a characterization of uncertainties associated with anticipated outcomes.
- **Chapter 8, *References*,** includes bibliographical information for sources cited in this Draft Supplement Report.

Chapter 2
Limiting Factors for Native Fish Species

The 2017 Scientific Basis Report (State Water Board 2017) describes a variety of known limiting factors for native fish species in the Sacramento-San Joaquin Delta ("Delta" hereafter) and its tributaries. The Sacramento/Delta Update to the Bay-Delta Plan is primarily focused on providing reasonable protection for native fish and other aquatic species rearing or residing in or migrating through the Delta. The main focal species are Chinook salmon, Central Valley steelhead (*Oncorhynchus mykiss*), longfin smelt, green sturgeon (*Acipenser medirostris*), white sturgeon (*Acipenser transmontanus*), Sacramento splittail (*Pogonichthys macrolepidotus*), Delta smelt, starry flounder (*Platichthys stellatus*), and California Bay shrimp (*Crangon franciscorum*). The life histories and other information regarding each of these species, as well as native and nonnative zooplankton upon which many of them feed, are described in Chapter 3 of the 2017 Scientific Basis Report. This chapter briefly summarizes an updated review of the best available science on limiting factors related to flow and non-flow habitat in both the tributaries and Delta. Table 2-1 provides an overview of the most important of these limiting factors and how the VA package is expected to ameliorate these limiting factors.

Table 2-1. Limiting Factors for Fishes in the Tributaries and Delta, along with Qualitative Predictions of How the VA Package Is Expected to Address These Factors

Limiting Factor	Subfactor	How VA Flow Actions Are Expected to Help	How VA Habitat Actions Are Expected to Help
Food supply/ecosystem productivity		May move food from high-density to low-density areas.	Wetlands and floodplains provide greater primary productivity and increased foraging opportunities.
Physical habitat loss/alteration	Riparian habitat and open channels	Flood flows support healthy riparian vegetation, allow river meanders.	Restoration increases habitat quantity and quality.
	Spawning habitat	Higher flows and correct flow timing increase spawning habitat area and reduce redd dewatering.	Restoration increases habitat quantity and quality.
	Rearing habitat	Higher flows transport fish between rearing habitat patches and increase access to off-channel habitat.	Restoration increases habitat quantity and quality.
	Tidal marsh	Higher flows transport fish to marsh habitat and superimpose the low salinity zone over regions with high amounts of tidal marsh habitat.	Restoration increases habitat quantity and quality.
	Floodplain and wetland habitat	Higher flows increase frequency of floodplain inundation.	Restoration increases habitat area, allows inundation at lower flow rates.

Limiting Factor	Subfactor	How VA Flow Actions Are Expected to Help	How VA Habitat Actions Are Expected to Help
Water quality	Contaminants	High flows increase loading of contaminants, but also increase dilution of contaminants. For cyanotoxins, higher flow reduces potential for cyanobacterial growth.	Wetland plants can remove contaminants. Transitioning from managed wetland to tidal wetlands may reduce mercury methylation.
	Dissolved oxygen	Higher flows keep water circulating, raising dissolved oxygen, but flow pulses can also increase biological oxygen demand from agricultural drainage or managed wetlands. This may become worse with climate change.	Riparian vegetation decreases temperature, increasing dissolved oxygen. Shallow water has higher mixing. Replacing managed wetlands with tidal wetlands may increase dissolved oxygen.
	Sediment and turbidity	Higher flows increase turbidity in the Delta – if there is sufficient upstream sediment supply.	Shallow shoals usually have higher turbidity, but wetlands often have lower turbidity due to plants.
	Temperature	Higher flows decrease temperatures below dams. Higher flows in the Delta are correlated with lower temperature, but cause-effect relationship is unclear.	Plants shading water may lower temperature. Wetlands allow for nighttime cooling.
Movement/migration/ passage/connectivity	Juvenile outmigration and rearing habitat connectivity	Higher flows transport anadromous fish to ocean or different habitats faster. More sustained flows during the full outmigration window support diverse timings and sizes of fish, which in turn support life history diversity.	Provide access to more habitat and resting points along migration route; allow fish to reach destination in better condition and across a broader distribution of body sizes, which is related to life history diversity.
	Floodplain connectivity	Higher winter/spring flows increase floodplain inundation and habitat availability. Higher summer/fall flows increase export of primary production from managed floodplains.	Provide increased access to highly productive off-channel habitat for growth and rearing.
	Adult upstream migration and passage	Increased flow restores migration cues and reduces straying.	Some actions may reduce or resolve adult fish passage impediments, providing improved access to spawning areas
Invasive species	Fish – as predators and competitors	Flow moves fish through high-predation areas more quickly. More natural flow regimes may favor native species.	Habitat restoration may provide refugia from predation.

Limiting Factor	Subfactor	How VA Flow Actions Are Expected to Help	How VA Habitat Actions Are Expected to Help
	Aquatic vegetation	Flood flows may discourage establishment of submerged aquatic vegetation and flush out invasive floating vegetation, but more research is needed.	Careful and proactive management at restoration sites, including revegetation with native species, may help keep out invasives.
	Invertebrates	Higher flows will restrict clams and jellies from moving into freshwater regions of the Delta.	Small sloughs and wetlands have fewer invasive clams than main channels.
Direct take	Diversions and exports	Entrainment risk can decrease with increased flow. Increased flow also reduces travel time, routing fish into corridors with increased survival rates, etc.	Provide other habitat away from diversion impacts.
	Stranding	Increased flow can reduce the incidence of juvenile Chinook stranding when habitat becomes disconnected from the main channel during low flows.	
Fishery management	Hatcheries	Higher flows make trucking from hatcheries unnecessary, which reduces straying.	Hatchery production is designed to offset loss of habitat for natural spawning. With greater spawning/rearing habitat, reliance on hatcheries may be reduced.
Disease		Increased flow may reduce temperatures and reduce susceptibility to disease.	
Climate change	Temperature	Flow in tributaries will be key to managing cold water pools.	Vegetation may shade water, reduce temperature. Wetlands may sequester carbon.
	Sea level rise		Restoration of upland transition zone will be important to future marsh sustainability.
	Salinity intrusion	More flow will be necessarily to offset salinity intrusion.	Placement of restoration sites will influence how salinity changes.

2.1 Bay-Delta Tributaries

2.1.1 Sacramento River

2.1.1.1 Physical Habitat Loss or Alteration

Loss and alteration of physical habitat on the Sacramento River is covered in detail in the 2017 Scientific Basis Report (State Water Board 2017). The majority of Chinook salmon spawning in the Sacramento River occurs between Keswick Dam and Red Bluff Diversion Dam. Water temperature and flow in this reach must be carefully managed to support egg and embryo development and not dewater completed redds before fry emergence. Redd dewatering is both a flow and non-flow habitat issue. The earliest life history stages of salmonids (egg incubation to emergence from the gravel) are particularly sensitive. These life stages require suitable water temperature regimes and stable and continuous river flows to prevent redds from being dewatered or exposed to warm, deoxygenated water so incubating eggs and larval fish may survive. Dewatering can occur anytime a streamflow reduction occurs and is of concern on a managed river system such as the Sacramento River. Redds constructed in shallow areas (less than or equal to a depth of 2 feet) are susceptible to dewatering by flow reduction actions undertaken by the U.S. Bureau of Reclamation (Reclamation) as operations transition from high summer export regimes to low winter storage flow regimes (Revnak et al. 2017). Late spawning winter-run Chinook (mid-July to mid-August) are of concern because of the time required for embryos to fully develop and fry to escape the redd, and the need for cool water temperatures during this summer period. Reclamation is required to limit the number of dewatered winter-run Chinook redds to 1% or less (NMFS 2019). Other Chinook salmon runs (such as spring-run Chinook salmon and fall-run Chinook salmon) can be affected as well since they tend to be actively spawning prior to and during the flow reduction period from fall to winter base flows in October.

2.1.1.2 Ecosystem Productivity and Food Supply

As discussed in the Habitat Connectivity sections below as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat is considered a limiting factor for salmonids on the Sacramento River. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes since the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022a). However, it is uncertain whether food supply is currently limiting salmonid populations on the Sacramento River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.1.3 Water Quality

Limiting factors related to water quality are discussed in the 2017 Scientific Basis Report (State Water Board 2017).

2.1.1.4 Habitat Connectivity

The importance of a natural flow regime to the native flora and fauna, function, and resilience of lotic ecosystems is covered in the 2017 Scientific Basis Report (State Water Board 2017), and newer studies (Rolls & Bond 2017; Yarnell et al. 2020; Grantham et al. 2022) have added to existing knowledge.

One significance of the water management infrastructure and altered flow regimes in the Sacramento River is the reduction in spring outmigration (i.e., seaward) survival of juvenile salmon (Kjelson and Brandes 1989; Notch et al. 2020). Survival bottlenecks at this critical life stage have significant repercussions throughout the Chinook salmon lifecycle (Michel 2018). Most juvenile Chinook salmon in the Sacramento River rear and out-migrate during the winter or spring months, with winter-run Chinook rearing and leaving the system the earliest (Fisher 1994). Except for drought years, historically these seasons provided adequate flows and cool water temperatures for juveniles to rear in and successfully transit through downstream regions. At present, except for very wet years, flows are only occasionally adequate for outmigration or off-channel rearing due to reduced reservoir releases to store water for use in the summer months (Sturrock et al. 2019a). In California's Central Valley, studies have found that increased streamflow can improve survival of imperiled juvenile salmon populations during their oceanward migration (Michel et al. 2021).

All natural-origin Chinook salmon spring-run in the Sacramento River basin can be affected by low flows during smolt outmigration. Natural-origin spring-run have been particularly affected by low reservoir releases and spring agricultural diversions due to their slow embryonic development in high-elevation tributaries (e.g., Deer and Mill Creeks), which results in late emergence, rearing, and outmigration timing in downstream reaches (Johnson and Merrick 2012). The hydrograph of the Sacramento River is highly regulated and can result in a mismatch between the ideal outmigration conditions the smolts experience as they leave their natal creeks and the altered outmigration conditions they encounter as the enter the mainstem Sacramento River.

Hatchery managers recognize the relationship between survival and flow in the mainstem Sacramento River and to the best of their ability release hatchery-origin smolts immediately prior to or during storm events. When in-river conditions (flow and water temperature) in the mainstem Sacramento River in April and May are exceptionally poor, hatchery managers historically truck all or a percentage of this economically important species to the Delta or Bay systems in order to improve survival and maximize ocean recruitment (Sturrock et al. 2019b).

Extensive acoustic tagging studies on the mainstem Sacramento River over the last decade show that flow was the most important environmental covariate in predicting outmigration success, with increased levels of flow correlating with increasing smolt survival (Michel et al. 2015; Notch et al. 2020). A synthesis of the survival estimates of several thousand acoustically tagged Chinook smolts released into the Sacramento River March through May identified key flow-survival thresholds based on river stage at Wilkins Slough (Michel et al. 2021). Greater than 50% survival of Chinook smolts was achieved when flows at Wilkins were 10,700 cubic feet per second (cfs) or greater, and survival was near zero when flows were less than 4,000 cfs at Wilkins.

2.1.1.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report for a description of nonnative species (State Water Board 2017).

2.1.2 Feather River

2.1.2.1 Physical Habitat Loss or Alteration

Impacts from dams, water operations, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Feather system below Oroville Dam, affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain connectivity, and water quality (NMFS 2016).

Although pathogens occur naturally in the Feather River, the operations of Oroville Dam facilities may have produced environmental conditions where fish are more susceptible to disease (NMFS 2016), and outbreaks of the salmonid parasite *Ceratonova shasta* have been documented in recent years (Lehman et al. 2020). Susceptibility of fishes to disease is related to several factors that occur in the environment, including fish species and their densities, water quality conditions, decreased flows, and amount of pathogens in the environment (Foott 2016a). Impediments to upstream migration and lack of sufficient flow can alter the exposure of fish by delaying downstream migration and decreasing survival by increasing residence time to certain pathogens.

Downstream water diversions along the lower Feather River have the potential to entrain fish, change water flow and hydrology in the vicinity of the facility, or create an environment that is hospitable to fish species that prey on anadromous fishes (Moyle and White 2002; Mussen et al. 2013). Unscreened diversions can entrain juveniles, which can be either killed or injured by the pump or transported to a canal where their survival is greatly diminished (Poletto et al. 2015).

2.1.2.2 Ecosystem Productivity and Food Supply

As discussed in the Habitat Connectivity sections as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat is considered a limiting factor for salmonids on the Feather River. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes since the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022a). However, it is uncertain whether food supply in and of itself is currently limiting salmonid populations on the Feather River as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.2.3 Water Quality

Water quality issues are discussed in Section 5.4.2.3 of the 2017 Scientific Basis Report (State Water Board 2017) and references herein.

2.1.2.4 Habitat Connectivity

As described in 2017 Scientific Basis Report (State Water Board 2017), 3,600 square miles of the 4,400-square-mile Feather River watershed is located above Oroville Dam. Oroville Dam is a barrier to fish passage, blocking anadromous fishes from accessing historical spawning and rearing habitat, likely making it the single largest stressor to native fishes in the Feather River.

Downstream of Oroville Dam, the Fish Barrier Dam acts as a guidance weir for adult Chinook salmon and steelhead to reach the Feather River Fish Hatchery and, as such, is the true terminus of anadromous fish upstream accessibility. Further downstream near the town of Live Oak, California, the Sutter Extension Water District operates a pumping facility that includes a boulder weir that stretches across the river to raise the water surface elevation. The boulder weir does not have an engineered fish ladder designed for anadromous fish passage; at low to moderate flows in the Feather River, the weir imposes a passage impediment to those fish species. The Sunset Weir is a 10-foot-tall boulder weir originally constructed in the 1920s on the Feather River approximately 2 miles southeast of the town of Live Oak. The weir represents a significant barrier for adult fish passage, particularly for Chinook salmon and sturgeon.

2.1.2.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.3 Yuba River

2.1.3.1 Physical Habitat Loss or Alteration

Impacts from reduced flows, dams, barriers, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Yuba River (NMFS 2019), affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain, and water quality (NMFS 2016). Three sediment barriers (Daguerre Point, New Bullards Bar, and Englebright Dams) and the 15 miles of 20- to 75-foot-high training walls 4.5 miles upstream of Daguerre Point Dam to 2.5 miles downstream are key pieces of infrastructure diminishing natural river processes in the Yuba River. Though Daguerre Point Dam has two fish ladders for upstream fish passage, Englebright Dam is a complete barrier to salmonid fish passage with no fish ladder, while the ladder designs at Daguerre Point Dam are an impediment to sturgeon upstream passage.

All three sediment barriers prevent the physical transport and recruitment of large woody materials to the lower Yuba River. Large woody material is important for maintaining habitat complexity and creating refuge that is hospitable for adult and juvenile fish. The creation of training walls along the river prevents natural river processes from occurring and has reduced lateral movement of the river, resulting in a more channelized river. This has confined the corridor, particularly in the Dry Creek and Daguerre Dam Reaches (Wyrick and Pasternack 2012). It has also diminished habitats necessary for salmonid productivity, including inundation of the natural floodplain, formation of fine sediment and organic matter deposition, and sediment benches that encourage riparian vegetation recruitment necessary for overhanging cover for fish, stream shading, and as a source of terrestrial and aquatic invertebrate food sources for fish.

There are several unscreened diversions on the Yuba River; they likely will result in loss of juvenile salmonids and should be considered a limiting factor (Moyle and White 2002; NMFS 2019).

2.1.3.2 Ecosystem Productivity and Food Supply

As discussed in the previous section as well as in the 2017 Scientific Basis Report (State Water Board 2017), the disconnection and destruction of rearing habitat is considered a limiting factor for salmonids on the Yuba River. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes, and the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al.

2022a). However, it is uncertain whether food supply is currently limiting salmonid populations on the Yuba River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.3.3 Water Quality

There is an abundance of mercury in the sediment-laden tailings piles that currently make up the lower Yuba floodplain and are stored behind the Englebright and New Bullards Bar Dams. In the northwestern Sierra Nevada, the highest average levels of bioaccumulation occur in the Bear River and South Yuba River watersheds (Slotton et al. 1997). Further water quality issues are discussed in Section 5.4.2.4 of the 2017 Scientific Basis Report (State Water Board 2017) and references herein.

2.1.3.4 Habitat Connectivity

High winter and spring storm flows from rain and snowmelt inundate the riparian and floodplain habitat, vital for prolonged juvenile salmonid rearing. These flows also provide outmigration cues in which juvenile salmonids have evolved and mobilize and clean spawning gravels (State Water Board 2017). The current flow regime on the Yuba River does not allow for floodplain inundation during the winter and spring juvenile growth period. This limits habitat diversity and complexity necessary for juvenile refugia. The habitat that does become inundated dewaters rapidly, disconnecting habitat availability and diminishing the amount of time available for a meaningful growth period. In addition, some regulated flow fluctuations under current conditions have dewatered redds and created isolated pools, thereby stranding juveniles (Stokes 2009; Larrieu and Pasternack 2021).

The dams on the Yuba River directly affect longitudinal fish passage by either delaying (Daguerre Point Dam) or completely blocking (Englebright and New Bullards Bar Dams) the movement of anadromous fishes. The 15 miles of 20- to 75-foot-high training walls in the lower Yuba River limit lateral connectivity by confining the river channel to a narrow corridor and separating the Yuba River from its original floodplain. These floodplains and other off-channel habitats provide refuge from increased high flows and sediment loads, extend rearing habitat to reduce competition between individuals, increase prey availability for growth, and potentially reduce encounters with piscivorous predators, all of which can improve rearing conditions and increase growth and survival rates (Sommer et al. 2001b; Limm and Marchetti 2003; Moyle et al. 2007; Jeffres et al. 2008; Limm and Marchetti 2009). Available information indicates that fry and juvenile rearing physical habitat structure (complexity, sinuosity, diversity, instream objects, and overhanging cover) is an ongoing stressor and limiting factor for anadromous salmonids in the lower Yuba River (Wyrick and Pasternack 2012).

2.1.3.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.4 American River

2.1.4.1 Physical Habitat Loss or Alteration

Along with flow alterations stemming from Folsom Dam operations, physical transport of gravel and large woody materials has also been inhibited by the construction of both Folsom and Nimbus Dams. Gravel and woody material transport are important for the creation of favorable spawning and rearing habitat, and for maintaining habitat complexity and refuge that are hospitable for juvenile anadromous fish species in the lower American River. Without the dams, gravel and large woody material typically can be transported downstream during high flow events. However, with the dams in place, recruitment of spawning gravel and woody material habitat features are diminished in the lower American River.

Stable and continuous river flows are important to the early life history (egg incubation to emergence from the gravel) of salmonids. Reductions in flow during the early life stages can completely dewater incubating eggs and/or larval fish or expose them to warm, deoxygenated water, affecting their survival (NMFS 2019). Dewatering redds has the potential to occur anytime a flow reduction occurs.

With respect to flow and water temperatures along the lower American River, the current operating regime is often not reliable for the protection of aquatic resources during various life stage periodicities. Low flows and elevated water temperatures in the fall can lead to stressful conditions and increased susceptibility to disease for holding adult Chinook salmon, which may affect survival of early-run prespawning adults. Early spawning adult Chinook during periods of increased water temperatures can expose eggs and larvae to unfavorable warmer, deoxygenated water and decrease the likelihood of surviving these conditions. Flow decreases following the peak of Chinook salmon spawning in December and January also can lead to dewatered redds, exposing eggs and larvae to lower dissolved oxygen levels and increasing mortality from stranding (Reclamation 2021). Low flow conditions or flow fluctuations from January through April provide suboptimal conditions for adult steelhead spawning, increasing the risk of redd dewatering and of stranding and isolating rearing juvenile salmonids. Lower flows may also affect downstream juvenile migration and survival through increased travel time.

The lower section of the American River is highly leveed and shallow, with fewer deep pools and limited off-channel habitats and riparian vegetation necessary for rearing juveniles and promoting salmonid production. Floodplains and other off-channel habitats provide refuge from increased high flows and sediment loads, extend rearing habitat to reduce competition between individuals, increase prey availability for growth, and potentially reduce encounters with piscivorous predators, all of which can improve rearing conditions and increase growth and survival rates (Sommer et al. 2001a; Limm and Marchetti 2003; Moyle et al. 2007; Jeffres et al. 2008; Limm and Marchetti 2009).

2.1.4.2 Ecosystem Productivity and Food Supply

As described above, the physical changes on the American River prevent natural movement of flows through the river channel and inhibit interactions with the surrounding landscape, which in turn limit the biophysical processes that create rearing habitat and enhance foodweb dynamics (NMFS 2016; State Water Board 2017). The dynamic shallow water habitats that historically provided rearing habitat for salmonids have been diminished through levee construction in all but the wettest years (NMFS 2019). Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes, since the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022a). However, it is uncertain whether food supply is currently limiting salmonid populations on the American River, as it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.4.3 Water Quality

Specific effects attributed to elevated water temperatures during juvenile rearing, over summering, and outmigration include increased mortality, increased susceptibility and exposure to diseases, impaired ability to avoid predators, altered migration timing, and changes in fish community structure that favor competitors of salmonids. Water temperatures during the summer months can become unsuitable for juvenile steelhead rearing, and increased water temperature is believed to be one of the limiting factors for steelhead production in the lower American River (NMFS 2019). On March 23, 2022, the State Water Board adopted Resolution No. 2022-0006, which identified the lower American River as an impaired waterbody for temperature. Warm water temperatures observed in the lower American River during summer were identified as impairing cold freshwater habitat, a beneficial use identified for the lower American River. See Section 5.4.2.2 of the State Water Board (2017) for more detail on water quality issues on the American River.

2.1.4.4 Habitat Connectivity

Impacts on connectivity caused by dams, water operations, and levees are described more generally in State Water Board (2017) and in the previous three sections. The current flow in the lower American River regime does not allow for floodplain inundation during the winter and spring juvenile growth period, limiting lateral connectivity. The habitat that does become inundated dewaters rapidly, disconnecting habitat availability and diminishing the amount of time available for a meaningful growth period. In addition, regulated flow fluctuations under current conditions dewater redds and create isolated pools that strand juvenile fish (CDFG 2001; Snider et al. 2001; NMFS 2019). Stranding can lead to direct mortality when these areas drain or dry up. Indirect mortality can result through increased susceptibility to predation or water quality deterioration in shallow or stagnant stranding locations (Revnak et al. 2017). A delay in migration to the Delta has the potential to reduce any benefits from water operation protection measures, which are intended to minimize entrainment from south of Delta operations.

2.1.4.5 Invasive Species

See Section 4.4 of the 2017 Scientific Basis Report (State Water Board 2017) for a description of nonnative species.

2.1.5 Mokelumne River

2.1.5.1 Physical Habitat Loss or Alteration

Impacts from dams, water operations, levees, and channelization as described in the 2017 Scientific Basis Report (State Water Board 2017) similarly apply to the Mokelumne River below Camanche Dam, affecting and reducing spawning and rearing habitat, natural flow regimes, floodplain connectivity, and water quality. Descriptions of stressors and physical changes to the Mokelumne River can be found in Sections 2.2.7.1 and 5.4.2.5 of the 2017 Scientific Basis Report (State Water Board 2017).

Limited spawning substrate because of available suitable spawning substrates that have been dewatered or diminished through lower flows can result in competition for space and can lead to redd superimposition. While the returning adult escapement population for in-river and hatchery returns has recently been at or above that of the 1992–2016 Anadromous Fish Restoration Program (AFRP) doubling goal, Johnson et al. (2012) found that approximately 90% of the returning adults in 2004–2005 were hatchery stock. Most of the available spawning habitat in the lower Mokelumne River is limited to a 9.8-mile section of river directly downstream of Camanche Dam (Setka and Bishop 2003). However, most of the spawning occurs upstream of Mackville Road up to Camanche Dam, a stretch of roughly 4 miles.

Along with flow alterations stemming from Camanche Dam operations, physical transport of gravel and large woody materials has also been inhibited by the construction of Camanche Dam. Gravel and woody material transport are important for creation of favorable spawning habitat and maintaining habitat complexity and refuge that are hospitable for juvenile anadromous fish species in the lower Mokelumne River. Without the dam, gravel and large woody material typically can be transported downstream during high flow events. However, with the dam in place, recruitment of spawning gravel and woody material habitat features are diminished in the lower Mokelumne River.

2.1.5.2 Ecosystem Productivity and Food Supply

Lateral movement of the Mokelumne River has been reduced, along with the frequency of floodplain inundation, which severely limits the biophysical processes that creates rearing habitat. Losses of riparian habitat, floodplains, and side channels have affected the food supply available to native fishes, since the productivity of these habitats has been well documented (Feyrer et al. 2006b; Grosholz and Gallo 2006; State Water Board 2017; Sturrock et al. 2022a). However, it is uncertain whether food supply is currently limiting salmonid populations on the Mokelumne River because it is difficult to disentangle effects of primary and secondary productivity from other components of rearing habitat (water temperature, cover, water velocity, and predator refuge).

2.1.5.3 Water Quality

Early season water temperatures can approach the upper limits for adult Chinook salmon spawning. Specific effects attributed to increased temperatures include delay in spawning and increased susceptibility and exposure of eggs to diseases. Specific effects attributed to elevated water temperatures during juvenile rearing and outmigration include increased mortality, increased susceptibility and exposure to diseases, impaired ability to avoid predators, altered migration timing, and changes in fish community structure that favor competitors of salmonids (State Water Board 2017). Low flow rates can cause the water temperature to rise above the preferred range for outmigrant fry and juvenile salmonids downstream of Woodbridge Diversion Dam and can persist into the summer months during dry and critically dry water year types. The abundance of salmonids could increase if water temperatures and flows for juvenile rearing and migration were improved, particularly in dry years (NMFS 2014).

2.1.5.4 Habitat Connectivity

Springtime flows below Woodbridge Diversion Dam are often a small proportion of the inflow, particularly in the drier years, and are inadequate to effectively convey juvenile salmonids downstream and through the Delta. There is the potential for stranding of juvenile salmonids due to elevated flow fluctuations in several reaches downstream of Camanche Dam, based on predicted changes in wet surface area over a range of flows. The stranding potential increased at flows below 400 cfs (USFWS 1995).

Current stressors to salmonids from low flows on the Mokelumne River can delay attraction and migratory cues to adults and inhibit juvenile emigration. Often, adult Chinook salmon returning to the Mokelumne River stray to other rivers systems or experience increased travel time. This is believed to be caused by insufficient attraction flows, elevated water temperature during the summer–early fall period, and operations of the Delta Cross Channel gates in the summer and early fall when adult Chinook salmon are migrating upstream (McKibbin 2022). Minimum flows below the Woodbridge Diversion Dam range from 15 to 300 cfs (EBMUD 1988), and they can range from 15 to 25 cfs in the late summer and from 45 to 100 cfs in October, depending on water year type. Elevated water temperatures due to low flows during the summer and early fall may block or delay migrating adults moving upstream or cause them to stray to other river systems in the Central Valley.

Reservoir operations and diversions on the Mokelumne River have reduced the current flows to below 24% of the unimpaired January–June average flows, and lower in drier years. Adequate flows during outmigration are necessary for juveniles to reach parts of the Delta with tidal influence. Reduced flow duration or magnitude, along with tidal cycles, can cause the lower Mokelumne River forks to be difficult to navigate for juveniles during outmigration and delay their migration through increased travel times. Juveniles are therefore subject to lethal or sublethal water quality effects, thus reducing successful outmigration. Additionally, they may be subject to predation.

Among the many restoration actions reviewed by the Mokelumne River Technical Advisory Committee, screening of diversions was rated the second highest priority behind gravel augmentation. Water diversions can entrain juvenile fish, change water flow and hydrology in the vicinity of the facility, or create an environment that is hospitable to fish species that prey on anadromous fishes (Moyle 2002; Mussen et al. 2013).

2.1.6 Putah Creek

2.1.6.1 Physical Habitat Loss or Alteration

Gravel quantity and quality in lower Putah Creek is considered a limiting factor for salmonid spawning and incubation (Wildlife Survey and Photo Service 2015). Completion of Monticello Dam and the Putah Creek Diversion Dam have blocked sediment supply, causing lower Putah Creek to be "sediment starved" (EDAW 2005)**.** Erosion and down-cutting have occurred as a result of the sediment-starved river and increased streamflow due to channelization and levees (EDAW 2005). In lower Putah Creek, gravel generally occurs in small patches, often only in a thin layer over the underlying clay (Small et al. 2004). Sections of lower Putah Creek have 60–90% of the spawning gravels embedded with or covered by sediment (Wildlife Survey and Photo Service 2015), which has made it difficult for trout and salmon to dig into the gravel to create a redd. When spawning does occur in this embedded gravel, eggs can be washed away (Wildlife Survey and Photo Service 2015), likely as a result of scouring shallow redds. Scouring of redds due to high flows released from Lake

Berryessa has also occurred (Small et al 2004). Regardless of the cause of redd scour, whether poor gravel quality or high flows, redd scour reduces the number of offspring produced in Putah Creek. The limited quantity and poor quality of gravel in Putah Creek likely cause detrimental impacts on spawning Pacific lamprey because they dig nests in gravel for spawning (Moyle 2002). Recently, a project has been implemented to rehabilitate some of the embedded gravel through scarification, a process of loosening gravel with large equipment (Wildlife Survey and Photo Service 2015). Redds in scarified sections have been found to be deeper and of better quality than in control sections (Wildlife Survey and Photo Service 2015). Salmon have also begun building redds in areas along the margins of the scarified sections, such as the gravel areas between Putah Diversion Dam and Scarification Site 6 that were used by salmon for redds in 2014, 1 year after the scarification (Wildlife Survey and Photo Service 2015). Salmon redd construction in these areas expands the area of loosened and potentially suitable gravel. Rainbow trout have been found building redds in the scarified sections (Wildlife Survey and Photo Service 2015). Sculpins have also been found to use the larger cobbles for cover that were made available through scarification (Wildlife Survey and Photo Service 2015).

2.1.6.2 Water Quality

Temperature in Putah Creek below the Putah Diversion Dam is consistently cool, in the range of 53–59°F throughout the year (Jones & Stokes Associates 1996; EDAW 2005). Temperature begins to increase downstream as ambient heat is gained by the relatively small flow released from the Putah Diversion Dam, resulting in approximately 19°F (from 53°F to 72°F) of warming between the Putah Diversion Dam and Stevenson Bridge (EDAW 2005). In addition to this natural warming, additional warming may be occurring in several wide areas of the channel degraded by a history of gravel mining (EDAW 2005). Although there is limited temperature data available, water temperature in April generally reaches or exceeds the upper range of suitable spawning conditions for Pacific lamprey, hitch, and Sacramento sucker (EDAW 2005). Temperatures in the lower parts of Putah Creek can be as high as 72°F by mid-May (Small et al. 2004), barring late migrants from leaving the system in many years. Groundwater may also affect temperatures in Putah Creek; in some years it can contribute up to a quarter of total flow (EDAW 2005).

Other water quality stressors in Putah Creek include mercury, aquatic toxicity, and gross pollutants (trash) (EDAW 2005). One fish contamination study conducted by the Agency for Toxic Substances and Disease Registry found that all largemouth bass samples contained mercury and some contained concentrations that are a health concern to pregnant or nursing women (EDAW 2005). Another study conducted by the University of California, Davis confirmed that many of the Putah Creek fish species contained mercury concentrations at levels of potential concern (Slotton et al. 1999). Larger individuals of the top predatory species exhibited the highest contaminant concentrations. Additionally, contaminated crayfish may be a hazard for both human and wildlife consumption, and certain small or juvenile fish may be a chronic hazard to wildlife (Slotton et al. 1999).

2.1.6.3 Habitat Connectivity

Fish passage into Putah Creek is blocked for much of the year due the presence of the Los Rios Check Dam, a 12-foot-high, 30-foot-wide concrete structure fitted with wooden boards about 23 miles downstream of the Diversion Dam and 1.2 miles upstream of the Yolo Bypass (EDAW 2005; Yuba Basin Foundation and CDFW 2016). The Los Rios Check Dam blocks free passage of salmonids and other native species from entering Putah Creek (StreamWise 2021). Each year the flashboards must be manually removed to allow fish, mainly Chinook salmon, to move into the creek. Removal of the flashboards generally occurs once adult Chinook are observed in the Toe Drain (Small et al. 2004) and is timed to coincide with a 5-day attraction flow of approximately 50 cfs in late November or early December (Small et al. 2004; EDAW 2005). Due to the presence of this flashboard dam, fish that arrive early or in a different season do not have access to the spawning grounds on Putah Creek. At least one large fish kill has occurred after heavy rains and runoff attracted adult Chinook salmon to the area of the Los Rios Check Dam, which had the flashboards installed and resulted in fish congregating downstream of the check dam in water with low dissolved oxygen (Rabidoux et al 2022). Habitat downstream of the Los Rios Check Dam is not suitable for salmonid spawning and consists of a straightened ditch and a deep excavated channel (Yuba Basin Foundation and CDFW 2016). The flashboard dam can block migrating juvenile salmonids as well as adults. The flashboards are generally installed in the spring, during the juvenile outmigration season. The installation of the flashboards can strand the young of that year above the dam (Small et al 2004). Once the flashboards are installed, it is unlikely that young of that year would make it past the dam due to low flows and a drop of approximately 15 feet between the upstream and downstream water levels (Small et al 2004). There is potential for successful downstream passage at the flashboard dam in years with higher flows, but under low or normal flows the dam represents a significant barrier to outmigration (Small et al 2004). At Road 106A, a seasonal earthen road crossing is installed annually in the spring for farm operations, and then the culverts are removed in the fall to allow for fish passage upstream (EDAW 2005). Passage at Road 106A has the potential to be a barrier to fish passage when the crossing is in place (EDAW 2005). The Winters percolation dam—a 100-foot-wide concrete structure that was built in 1936 and collapsed during a flood in 1951—partially obstructs fish passage, especially during low flows or when debris clogs the passageways through the dam (EDAW 2005). In addition to the human-constructed passage barriers, beaver dams can also be a barrier to fish passage in Putah Creek. Beaver dams are typically broken up and washed downstream during high flow events, but during dry or more moderate periods the dams can persist for years (EDAW 2005). When flows are insufficient to overtop or bypass the beaver dams, fish may have difficulty in passing over or around them (EDAW 2005).

2.1.6.4 Invasive Species

There are numerous invasive species in the Putah Creek watershed. Arundo, eucalyptus, Himalayan blackberry, Eurasian watermilfoil, perennial pepperweed, tamarisk, tree-of-heaven, and yellow star thistle are the most abundant weed species in the riparian corridor (EDAW 2005). These invasive plants can restrict flows along waterways, resulting in channel scouring, increased water temperatures, interrupted sediment transport, and increased levee erosion (EDAW 2005). In addition to the invasive plants, Putah Creek has also been invaded by New Zealand mud snails (EDAW 2005). New Zealand mud snails can form dense populations, becoming the dominant macroinvertebrate in a stream by displacing and outcompeting native species. They affect foodweb structure, primary productivity, and predator-prey interactions (Brenneis et al. 2011; Ward and Sepulveda 2014). Given poor connectivity and low velocity, it is likely that invasive aquatic weeds are also a limiting factor in some reaches of Putah Creek; however, this has not been comprehensively assessed.

2.2 Off-Stream: Bypasses, Side Channels

This section builds upon the description of the flood basins and floodplain/wetland habitat in the 2017 Scientific Basis Report (State Water Board 2017) and focuses specifically on how the flood basins provide off-channel habitat and the associated limiting factors, with an emphasis on Chinook salmon but with consideration to other native species. There is an emphasis on the Yolo Bypass and Sutter Bypass (flood bypasses), as most of the research in the historic flood basins has been conducted there, particularly as it relates to floodplain habitat. However, the limiting factors described below apply somewhat or fully to other off-channel habitat in the project area such as the Butte Sink and Colusa Basin.

The extensive loss of seasonal floodplain habitat has contributed to the decline of Central Valley Chinook salmon (NMFS 2014). California's Central Valley was once characterized by extensive seasonal flooding; however, only 3% of historical freshwater wetland habitat remains in the Sacramento-San Joaquin Delta (Whipple et al. 2012). Widespread levee construction for flood control and agricultural development now prevents inundation of most of the historical floodplain except under extreme flooding (Opperman 2012). The loss of this seasonal habitat has likely had drastic ecosystem impacts, as seasonal floodplains drive key biological processes that maintain biodiversity in river ecosystems (Junk et al. 1989). Multiple studies have highlighted the benefits of off-channel habitat for many native Central Valley fishes, including Chinook salmon (Sommer et al. 2001a; Sommer et al. 2001b; Feyrer et al. 2006a; Jeffres et al. 2008).

The largest remaining floodplain-like habitats in the Central Valley are the flood bypasses, designed to divert floodwaters from the Sacramento, Feather, and American Rivers away from downstream population centers (Sommer et al. 2001b; Feyrer et al. 2006a). As such, the flood bypasses mimic some aspects of biologically defined floodplain habitat (e.g., seasonal inundation, shallow inundation, increased water residence time, productive foodwebs, rearing and spawning habitat for native fishes) but diverge in other aspects due to anthropogenic changes to the landscape. The bypasses are designed and maintained as flood conveyance channels, which severely limits hydrological and geomorphic processes as well as lateral connectivity to the rivers (Williams et al. 2009). Additionally, land use in the bypasses affects both hydrology, habitat types, and ecological processes normally associated with floodplains.

The Yolo Bypass floods, at least partially, in approximately 70% of years and can divert up to four times the flow of the Sacramento River, most of which flows over the Fremont Weir at the northern extent of the Yolo Bypass. Outside of the flood season, most land in the Yolo Bypass supports seasonal agriculture (e.g., sugar beets, rice, wild rice), while approximately one-third is maintained as wetland, riparian, and upland habitat for avian and wildlife species (Sommer et al. 2001b).

The Sutter Bypass floods, at least partially, in approximately 95% of years and receives water from Butte Creek, Feather River, and Sacramento River. The primary connection point to Sacramento River is Tisdale Weir, which on average spills 43 days per year (DWR 2020). Like Yolo Bypass, land use in Sutter Bypass is a mix of agriculture (primarily rice farming), managed wetlands, and wildlife areas/refuges. Unlike the Yolo Bypass, Sutter Bypass is a primary migration corridor for Chinook salmon; Butte Creek fall-run Chinook salmon and spring-run Chinook salmon pass through the bypass on their journey to and from the ocean.

Emigrating juvenile Chinook salmon from the Sacramento River and Feather River can access the flood bypasses during the flood stage, when flood weirs or levees are spilling or through the southern terminus of both bypasses, which are permanently connected to the Sacramento River. Studies have shown that the flood bypasses provide suitable juvenile Chinook salmon rearing habitat with higher prey densities than the adjacent Sacramento River (Sommer et al. 2001b; Sommer et al. 2001c; Sommer et al. 2005; Henery et al. 2010). While it has been hypothesized that juvenile Chinook salmon rearing in the bypasses incur survival benefits during outmigration and in the ocean due to higher growth rates, this has yet to be proven (Sommer et al. 2001b; Takata et al. 2017). Nonetheless, juvenile Chinook salmon rearing in the Yolo Bypass supports increased life history diversity, providing resilience for Central Valley Chinook salmon populations in the face of variable and uncertain environmental conditions (Takata et al. 2017; Goertler et al. 2018b).

2.2.1 Physical Habitat Loss or Alteration

Splittail spawning and rearing has been documented in the flood bypasses (Feyrer et al. 2006a), and splittail recruitment has been documented to correlate with inundated habitat in Yolo Bypass (Feyrer et al. 2006b). However, there is still uncertainty whether certain micro habitat types within the flood bypasses are preferred for spawning and rearing (Moyle et al. 2004).

Relatively little is known about micro habitat use or preference of juvenile salmonids rearing in the flood bypasses. Using purse seine sampling, Sommer et al. (2005) found juvenile salmon across all habitat types (‘natural,’ ‘riparian,’ and ‘agricultural’) in Yolo Bypass, but they only caught juvenile salmon in what was characterized as ‘low velocity areas.’ More recent work has shown that flooded agricultural fields in Yolo Bypass provide for high productivity of food resources (Corline et al. 2017; Jeffres et al. 2020) and rapid growth of hatchery fish released into the fields (Katz et al. 2017). It is reasonable to assume that restoring more natural floodplain habitat types in the flood bypasses would provide benefits to a suite of native aquatic and terrestrial species. However, it is unknown whether the current composition of habitat types is a limiting factor for juvenile salmon at present inundation regimes.

Due to the direct relationship between flow, connectivity, and fish access to the bypasses and inundated habitat, it is questionable whether rearing habitat within the bypasses is a limiting factor, as flow creates both access and habitat (DWR and Reclamation 2012).

2.2.2 Ecosystem Productivity and Food Supply

When inundated, the flood bypasses are extremely productive and support both in situ rearing of juvenile fish as well as foodweb exports to downstream habitats (Sommer et al. 2001c; Benigno and Sommer 2008; Cordoleani et al. 2022; Sturrock et al. 2022b). Ecosystem productivity is therefore not considered a limiting factor within the flood bypasses themselves. However, the productivity of the bypasses is affected by the lack of connectivity to the river, which is discussed in more detail below in Section 2.2.4, *Habitat Connectivity*.

2.2.3 Water Quality

Temperature and dissolved oxygen are primarily determined by season and flow, but drainage of rice fields and managed wetlands can exacerbate conditions, causing dissolved oxygen to decrease and water temperatures to increase (DWR 2019a). Optimal ranges for temperature and dissolved oxygen for salmonids (State Water Board 2017) are regularly exceeded when salmonids are present in the bypasses.

Presence of contaminants in Yolo Bypass is well documented in the literature (Smalling et al. 2007; Orlando et al. 2020), and bioaccumulation of methylmercury (Henery et al. 2010) and pesticide residues (Anzalone et al. 2022) has been discovered in juvenile Chinook salmon. Contaminant loading in the Sutter Bypass and Butte Sink is largely unknown and should be explored. Research in Yolo Bypass showed an increase in methylmercury concentration in water, foodwebs, and fishes in agricultural wetlands, as compared to permanent and seasonal wetlands, suggesting that water management within the bypass plays an important role in mercury cycling (Windham-Myers et al. 2014) as higher water temperatures and increased water residence time increases methylation. DWR (2019b) expects increased methylmercury production in Yolo Bypass because of Fremont Weir notch operations that would increase the extent and duration of shallow inundation. Conversely, increased Sacramento flow is expected to decrease concentrations of current use pesticides through dilution and degradation, while potentially increasing mobilization of legacy contaminants (DWR 2019b). The potential impacts of elevated contaminant levels are discussed in Section 4.3.1 of the 2017 Scientific Basis Report.

2.2.4 Habitat Connectivity

The primary limiting factor for Chinook salmon and other native migratory fish species is connectivity, both onto and off of the flood bypasses, but also within the individual flood bypasses (Feyrer et al. 2006a; DWR and Reclamation 2012; DWR 2019b). Connectivity between the rivers and the flood bypasses is limited by dam operations, levees, and flood control weirs that all reduce the inundation frequency and duration, as well as inhibit fish passage into and out of the bypasses. This lack of lateral connectivity prevents juvenile Chinook salmon from accessing approximately 75,000 acres of productive rearing habitat in Yolo Bypass and Sutter Bypass alone. Therefore, it is not necessarily a lack of floodplain-like habitat that is the limiting factor in terms of rearing habitat, but rather access to that habitat. Improving connectivity by increasing both the frequency and magnitude of flow entering the flood bypasses will also directly facilitate increased frequency and duration of inundated habitat, which is a secondary limiting factor.

For adult salmon (and other native migratory species), the lack of lateral connectivity means that individuals can become stranded or experience migratory delays when entering the flood bypasses. Adult salmon have been observed in Yolo Bypass from August to June and in Sutter Bypass from September to June. Stranding or migratory delays are risks both during low flow conditions and during flood events. As both flood bypasses are connected to the Sacramento River at their southern terminus, fish can enter dead-end sloughs in the flood bypasses during low flow conditions when the weirs are not spilling. The exceptions to this are Butte Creek salmon in Sutter Bypass and to a lesser extent Putah Creek salmon in Yolo Bypass, as they rely on the bypasses as primary migration corridors to reach their native streams. During high flow events, migratory fishes can become stranded as flood waters recede and the flood control weirs stop spilling. Sturgeons in particular have difficulty navigating the weirs, but the altered hydraulics and presence of barriers throughout the bypasses result in the stranding of both native and nonnative fish species (CDFW 2016a).

The lack of connectivity between the bypasses and the river prevents juvenile Chinook salmon from accessing rearing habitat and causes fish passage delays and stranding of all life stages for multiple species (CDFW 2016a, 2017). Water operations and water management infrastructure within the bypasses can also affect fish passage either by (1) directly impeding fish passage because of infrastructure or low flows, or (2) creating unnatural attraction flows, resulting in fish stranding in canals, fields, or wetlands (CDFW 2012; Gahan 2016; CDFW 2021). Several projects have been or are being implemented to increase fish passage at Fremont Weir and Sacramento Weir in Yolo Bypass and at Tisdale Weir in Sutter Bypass. However, it is not likely that these projects alone will eliminate the connectivity and fish passage issues in the flood bypasses. Significant resources have been allocated to prevent adult migratory fishes' straying into the Colusa Basin since 2012, primarily by constructing a fish exclusion barrier at Knights Landing Outfall Gates and a migration barrier and fish salvage facility at Wallace Weir. CDFW is conducting fish rescues in the flood bypasses in most years and is operating a permanent fish salvage facility at Wallace Weir in the northwestern end of Yolo Bypass. Fish rescued or salvaged in the flood bypasses are relocated back to the river. The survival, fitness, and reproductive success of rescued salmonids and sturgeons are subject to ongoing investigation (CDFW 2016a, 2022).

The primary limiting factor for fish once they enter the bypasses is reduced connectivity caused by physical infrastructure (e.g., weirs, berms, rice checks, drainage canals), water management, invasive aquatic weeds, and water quality. Stranding is primarily observed around human-made infrastructure (Sommer et al. 2005; CDFW 2012, 2016; Gahan 2016; CDFW 2021), but data collection is limited by access and timely surveys of the expansive areas of the bypasses. It is reasonable to assume that the documented fish stranding is a small proportion of the true number of fish that are lost in the bypasses. Studies investigating movement of adult fall-run Chinook salmon and white sturgeon (Johnston et al. 2020) determined that although a majority of fall-run Chinook salmon entering the Yolo Bypass exited the bypass again volitionally, white sturgeon were less likely to do so. Even when fish successfully exit the flood bypasses, it is unknown how the migratory delay affects their survival, fitness, and reproductive success. It is therefore critical that improvement, enhancement, or restoration actions in the bypasses account for both juvenile and adult life stages, particularly for Chinook salmon, Central Valley steelhead, green sturgeon, white sturgeon, splittail, and Pacific lamprey.

Reduced frequency and inundation of the flood bypasses also affect primary and secondary productivity, thereby reducing not only aquatic ecosystem foodweb productivity within the bypasses but also export of energy to downstream habitats (Lehman et al. 2008). Numerous research studies are investigating the potential to increase transport of productivity from floodplains and agricultural areas to downstream habitat (Sommer et al. 2020b; Frantzich et al. 2021; Sturrock et al. 2022b), but these are still in pilot phases and have yet to be proven effective at scale.

2.2.5 Invasive Species

Water hyacinth (*Eichhornia crassipes)* and water primrose (*Ludwigia peploides*) are rapidly expanding in both bypasses, clogging perennial canals and fish passage infrastructure, thereby limiting or blocking fish passage. The issue of nonnative plants is discussed in more detail in Section 4.4.3, *Aquatic Plants*, of the 2017 Scientific Basis Report (State Water Board 2017).

It is currently unknown if or to what extent predation by native (chiefly Sacramento pikeminnow) and nonnative (chiefly striped bass, catfishes, and black bass) fishes is a limiting factor in the flood bypasses. Sommer et al. (2001b) hypothesized that predator encounters may be lower in the Yolo Bypass. Unpublished data suggest that as flow decreases and temperature increases, survival of juvenile Chinook salmon decreases. Predation may be situational and dependent on environmental conditions (Ward and McReynolds 2004; DWR 2019). This limiting factor warrants further investigation.

2.3 Delta and San Francisco Bay-Delta Estuary

Native species in the San Francisco Bay-Delta Estuary ("Estuary" hereafter) are affected by numerous anthropogenic stressors that limit their population viability (State Water Board 2017).

2.3.1 Physical Habitat Loss or Alteration

As discussed in the 2017 Scientific Basis Report (State Water Board 2017), loss of habitat is a major stressor on all species within the estuary. The Delta historically had complex water channels with 450,000 acres of expansive wetland habitat, formed over time as floodwaters met the tides (Whipple et al. 2012; Robinson et al. 2014). These wetlands were bordered by riparian forests and grasslands, with transitional zones connecting the aquatic and terrestrial habitats. These habitats are important pieces in the Estuary's ecology as they provide myriad functions for wildlife including shelter, foodweb productivity, and landscape resiliency in the face of climate change and other anthropogenic changes (Lehman et al. 2010; Whipple et al. 2012; Brown et al. 2016a; Frantzich et al. 2018).

These expansive wetlands and connected terrestrial and riverine habitats have been mostly lost in the modern Delta. Major alterations include land conversion, subsidence, altered hydrology, channelization, and many other stressors. Tidal wetlands have experienced a 98% loss, dendritic channels a 93% loss, and seasonal wetlands an 85% loss (Robinson et al. 2014). The San Francisco Estuary Institute's *Delta Transformed* (Robinson et al. 2014) describes the historical state of the Delta and the changes it has undergone in detail.

Loss of non-flow habitat is intertwined with all the other stressors, including flow, since habitat is defined as the suite of environmental parameters in which a species can live. Loss of habitat includes not only the destruction of physical habitat features—including draining wetlands, channelizing sloughs, stabilizing banks, and cutting off floodplains—but also the alteration of natural processes that result in optimal water quality conditions. Reduction in flow disconnects patches of habitat from each other, limiting transport of food and sediment to downstream habitats as well as preventing migrating species from finding appropriate refuge habitats (Keeley et al. 2022). Removal of vegetation increases water temperatures (Crepeau and Miller 2014), changes topographic heterogeneity (Morzaria-Luna et al. 2004), and alters substrate characteristics (Baldwin et al. 2001; Sloey et al. 2015). Chinook salmon and steelhead rearing and foraging in the Estuary use cover (e.g., vegetation, woody debris) to avoid detection by and contact with predators. For example, emigrating Chinook salmon juveniles' use of natural shorelines compared with shorelines consisting primarily of rock revetment was significantly higher (Hellmair et al. 2018). Shoreline development has reduced juvenile Chinook salmon and steelhead access to floodplain rearing habitat in the Estuary (Boughton and Pike 2013).

Restoration of habitat in other systems has had measurable effects on populations of native fish species, though results vary widely (Roni 2019). For example, an intensive program of wetland and off-channel habitat restoration in the Colombia River estuary resulted in increased juvenile salmonid abundance, increased food resources, and increased growth (Diefenderfer et al. 2016). Watershed restoration in Puget Sound watershed has resulted in 2–5 times higher density of salmon and steelhead par and smolts; however, with limited restoration area, this only resulted in an estimated 5–7% increase in population (Roni et al. 2010)

Since 2017, there has been significant progress on tidal wetland restoration. The 2008 BiOp for the SWP and CVP operations required 8,000 acres of tidal wetland to be built in the Delta to address the decreased productivity (USFWS 2008). To date, 4,074 acres of tidal wetland restoration have been completed and an additional 2,975 acres are under construction. Monitoring associated with these restoration sites is starting to describe the benefits of these sites for native fish species, including invertebrate production, physical habitat, and refuge from predation (Tidal Wetlands PWT 2017; Contreras et al. 2018; Hartman et al. 2019; Hartman et al. 2022a). Recent research has identified that tidal wetland channels are used by longfin smelt as spawning and rearing habitat (Grimaldo et al. 2017). Spawning of longfin smelt can occur in tidal wetlands—including tributaries of the San Francisco Bay, Suisun Marsh, wetlands bordering Suisun Bay, the Cache Slough Complex, and the central and western Delta—when conditions are appropriate (Rosenfield and Baxter 2007; Merz et al. 2013; Grimaldo et al. 2017).

Estuarine wetlands are particularly important for rearing Chinook salmon. In the Pacific Northwest there is a long history of wetland restoration to benefit salmon, where wetland restoration has been conclusively linked to increased salmon population resiliency (Simenstad and Cordell 2000; Gray et al. 2002), mostly through increased foraging ability in tidal wetlands (David et al. 2016; Diefenderfer et al. 2016). In the Estuary, the Delta was previously thought to have relatively low survival rates compared to other parts of the Central Valley, so moving juvenile salmonids through the Delta as fast as possible was preferred (Baker and Morhardt 2001). However, recent research has found it is an important rearing habitat in a variety of water year types (Phillis et al. 2018), particularly in tidal slough complexes (Goertler et al. 2018a; Goertler et al. 2018b). Use of wetland habitat provides important foraging opportunities for these fishes and increases the life history diversity of the population (Goertler et al. 2018b; Sommer et al. 2001), and survival in the freshwater portion of the Delta may be higher than the mainstem Sacramento River or the brackish water reaches of the Estuary (Michel et al. 2015). Increasing habitat heterogeneity and life history diversity are important components in increasing the resiliency of Central Valley Chinook salmon populations, especially in the face of climate change (Goertler et al. 2017; Herbold et al. 2018). For example, during the most recent extreme drought, tidal sloughs of lower Yolo Bypass and the Cache Slough Complex supported large numbers of rearing salmon, which benefited from abundant food resources and higher feeding success (Goertler et al. 2018a). Similarly, using otolith analyses, Miller et al. (2010) suggested that estuary rearing was more important than originally thought. Findings detected evidence of prolonged rearing in brackish water in parr, smolt, and fry.

2.3.2 Ecosystem Productivity and Food Supply

Decreased food supply has been identified as a major stressor on fish populations. Primary productivity within the Delta and estuary has declined from historical levels, leading to declines in secondary production, including zooplankton and other key sources of fish food (Kimmerer et al. 1994; Orsi and Mecum 1996; Cloern et al. 2016). The Pelagic Organism Decline of the early 2000s had numerous interacting causes, but limited food supply was identified as one of the major factors causing the decline (Sommer et al. 2007; Mac Nally et al. 2010). Delta smelt, in particular, are food-limited across much of their range (Hammock et al. 2015), and the copepods and mysids that Delta smelt eat may also be food-limited (Orsi and Mecum 1996; Kimmerer et al. 2005; Gearty et al. 2021).

Primary productivity within the Delta and estuary is subject to greater seasonal and inter-annual variability than other estuarine and coastal systems (Cloern and Jassby 2010), and productivity in the Estuary is much lower than other estuaries with similar nutrient regimes (Cloern 2001). It is likely that phytoplankton production within the Delta has always been low in comparison to other estuaries, with much of the primary productivity coming from the historically extensive tidal wetlands (Whipple et al. 2012; Cloern et al. 2016). After the draining and conversion of most of the tidal wetlands within the Delta, this source of primary productivity was cut off, and the highly variable phytoplankton chlorophyll productivity was limited by the high turbidity of Delta waters. Productivity in Suisun Bay and the low salinity zone further declined after the invasion of the invasive overbite clam *Potamocorbula amurensis* in 1986, which has been linked to numerous phytoplankton and zooplankton declines (Kimmerer et al. 1994; Greene et al. 2011; Kimmerer and Lougee 2015; Lucas et al. 2016).

Much of the tidal wetland restoration being undertaken in the Delta is designed to reverse these trends by restoring high productivity shallow water habitat that was hypothesized to provide a subsidy of production to surrounding deep water habitats (Cloern 2007; USFWS 2008). Research on tidal wetlands has evolved since this restoration was mandated, and the current conceptual model focuses more on increased opportunities for fishes to access wetlands and forage within the tidal excursion of the sites (Sherman et al. 2017), since net export of production from wetlands is highly variable (Lehman et al. 2010; Kimmerer et al. 2018a; Yelton et al. 2022). However, even with this caveat, wetland habitat restoration may overall restore a modest portion of net primary productivity, with recent estimates of 12% recovery of historical primary productivity rates if planned habitat restoration goals are fully implemented (Cloern et al. 2021).

2.3.3 Water Quality

Fish habitat has two components. The first is the *stationary habitat* described in Section 2.3.1, *Physical Habitat Loss or Alteration*, such as tidal wetlands, channels, and off-channel habitat. The second is *dynamic habitat*, variable water quality parameters that allow optimal growth and survival within a given area of stationary habitat (Peterson 2003) (Figure 2-1). Variable habitat characteristics such as water temperature, turbidity, dissolved oxygen, pH, water velocity, food supply, and contaminant load influence the quality of habitat for fish (Sommer and Mejia 2013; Bever et al. 2016).

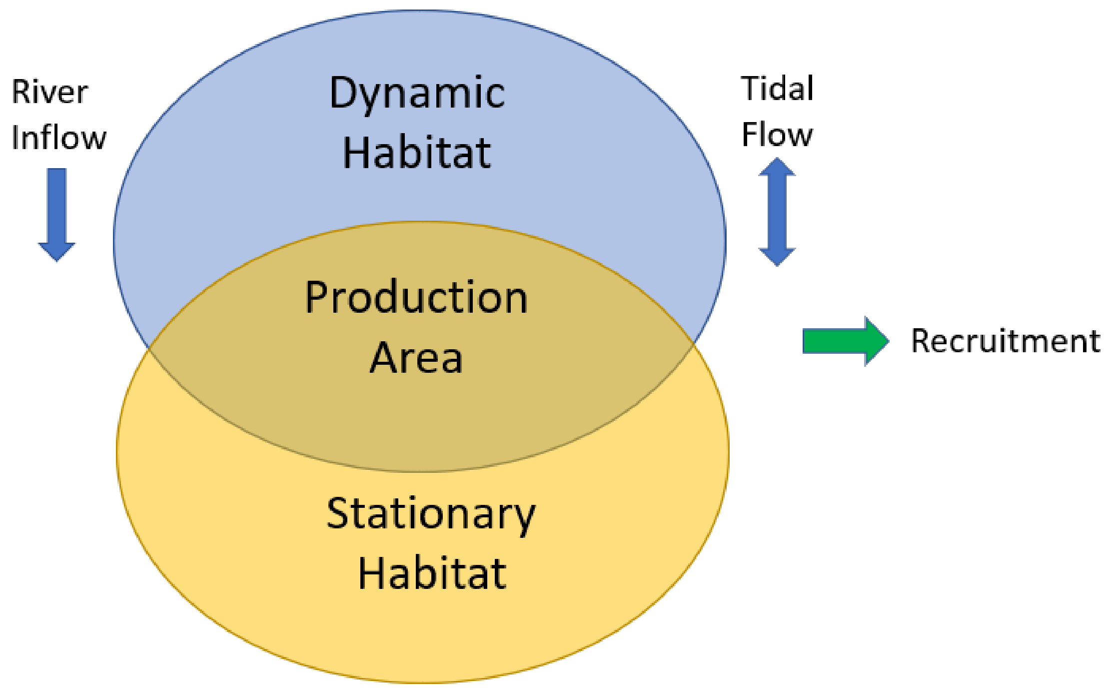

Figure 2-1. Conceptual Model of Dynamic Habitat (Water Quality) and Stationary Habitat (Physical Features) Coinciding to Produce Optimal Fish Production
Modified from Peterson (2003). Two overlapping circles show the production area, which is the intersection of stationary habitat (bottom circle) and dynamic habitat (top circle). An arrow on the left side shows decreasing unidirectional river inflow; an arrow on the top right side shows bidirectional tidal flow; and an arrow on the middle right side shows recruitment.

In the Delta, a declining trend in turbidity has limited the amount of optimal dynamic habitat available for native pelagic fishes (Schoellhamer 2011; Hestir et al. 2016; Work et al. 2020). Delta smelt prefer moderate-turbidity habitat, which allows them to forage efficiently and avoid predation (Hasenbein et al. 2013; Ferrari et al. 2014; Komoroske et al. 2016). Salmon also may use turbidity to avoid predation (Gregory and Levings 1998). However, the freshwater reaches of the Delta have become increasingly clear over time, which is attributed to a combination of decreased sediment supply due to upstream dams and increased coverage of submersed aquatic vegetation (Schoellhamer 2011; Hestir et al. 2016; Work et al. 2020). Turbidity is highly correlated with Delta outflow, with increasing water clarity under low flow conditions (Livsey et al. 2021), and the decrease in turbidity has occurred most strongly in low flow years (Stern et al. 2016). Extended shallow areas with high wind-wave activity, such as Grizzly Bay, also typically have higher turbidity habitat than wide, deep channels (Bever et al. 2018). Modeling of future climate scenarios suggests that an increased frequency and magnitude of large flow events (precipitation and precipitation variability) in the future may provide sediment transport into the Delta, increasing turbidity and habitat for native fishes (Stern et al. 2020). Given these trends, a combination of flow and restoration of shallow water non-flow habitat will most likely provide the greatest increase in optimal turbidity conditions.

Water temperature may be one of the crucial concerns for native aquatic species in the future. Climate change has increased the amount of time that the Estuary is above the optimal temperature for many native fishes (Brown et al. 2016b; Bashevkin et al. 2022). For example, the high flow year of 2017 was expected to provide good conditions for Delta smelt; however, their population continued to decline despite high flows, most likely due to high water temperatures (FLOAT-MAST 2021). Similarly, the area of Estuary habitat exceeding the Delta smelt critical thermal maximum temperature increased by 1.5 km^2 per year during 1985 to 2019 (Halverson et al. 2022). Under most climate change scenarios, droughts will become more severe and more frequent (Swain et al. 2018). While Delta inflow and water temperatures are negatively correlated most of the year (Bashevkin and Mahardja 2022), it is unknown if inflow has a causal influence on water temperatures in the Estuary. If it does, or if the causal driver of droughts is linked to water temperatures, more frequent droughts could lead to more frequent high temperatures, resulting in direct temperature stress and other temperature-related effects such as interactions with other stressors (Ghalambor et al. 2021; Herbold et al. 2022).

Water temperature conditions and salmonids' ability to access refuge in the Delta have impacts on rearing and migrating. Changes in water temperature modify the bioenergetic needs of the Delta fish community assemblage, and temperature thresholds play a role in establishing metabolic rates (reviewed by Richter and Kolmes 2005). For example, growth and consumption rates of striped bass, a widely distributed salmonid predator, increase with increasing temperatures within their thermal tolerance (Person-Le Ruyet et al. 2004). Largemouth bass have been shown to tolerate higher water temperatures than native fishes like Delta smelt (Davis et al. 2019a), and salmonids are sensitive to increasing water temperature conditions (review by Richter and Kolmes 2005). Largemouth bass consume Chinook salmon at significantly higher rates with increasing temperature, and when temperatures exceed 68°F, juvenile Chinook salmon survival in the Delta declines rapidly (Nobriga et al. 2021). Refuge habitats that provide relief from extreme temperatures will become more integral for a population's overall success. Occasional stratification may provide some refuge to fishes that can inhabit cooler bottom waters during these periods. Stratification was detected at levels that could be protective of Delta smelt in the Sacramento Deepwater Ship Channel (Mahardja et al. 2022).

As discussed in Section 4.3.1 of the 2017 Scientific Basis Report (State Water Board 2017), contaminant loading from urban and agricultural pesticides likely influences both fish and invertebrate health and abundance (Hammock et al. 2015; Hasenbein et al. 2018; Teh et al. 2019), but the extent to which this translates to population-level limitation remains unknown (Fong et al. 2016; Hasenbein et al. 2018; Connon et al. 2019). Concentration of contaminants is usually highest during high flow events when runoff from urban and agricultural sources transport contaminants into the waterways (Weston et al. 2015).

Along with anthropogenic contaminants, toxins produced by harmful cyanobacterial blooms (cyanoHABs) may be limiting native aquatic species. As discussed in the 2017 Scientific Basis Report (State Water Board 2017), numerous fish and invertebrates experience mortality and sublethal impacts when exposed to the toxogenic cyanobacteria *Microcystis*. Since 2017, severity and distribution of cyanoHABs have continued to increase, with numerous genera of cyanobacteria, including *Aphanizomenon, Dolichospermum*, and *Planktothrix,* along with *Microcystis* (Lehman et al. 2021). CyanoHABs in the Delta are more frequent and more severe in dry years (Hartman et al. 2022b; Lehman et al. 2022), so increases to flow may alleviate the impacts of cyanoHABs. However, cyanoHABs also increase in frequency during years with higher temperatures (Hartman et al.

2022b; Lehman et al. 2022), so increases in temperatures caused by climate change may counteract the benefits of increased flow.

2.3.4 Habitat Connectivity

The Sacramento River watershed's riverine habitat has become highly modified and simplified, influenced by water withdrawals and an expanding human footprint both in the Central Valley and elsewhere in California. Construction of levees and maintenance projects have disconnected rivers from the floodplain, an important habitat for outmigrating Chinook salmon and steelhead that provides habitat connectivity and complexity between the river and the Estuary. Over time, this modification has created a degraded and simplified aquatic habitat for all life stages of Chinook salmon and steelhead. As Chinook salmon and steelhead migrate from the upper watershed through the middle Sacramento River, they experience unidirectional riverine flows. However, once they enter the Delta, bidirectional flows created by tidal influence make the relationship between flow and migration (and subsequently routing and survival) more complex (Zabel et al. 1998; Smith et al. 2002; Perry et al. 2018).

For anadromous and semi-anadromous species, the loss of habitat combined with changes in flow has resulted in altered habitat connectivity (Keeley et al. 2022). The remaining wetland habitat is highly fragmented, meaning migratory species have few opportunities to rest and grow on their way to the ocean. Migrating through the main channels of the Delta, which are mostly lined with rip-rap, provides opportunities for predators to prey upon juvenile salmonids.

Changes in the Central Valley have decreased habitat connectivity for Chinook salmon and steelhead. Historical records from monitoring locations indicate winter-run Chinook salmon juveniles begin entering the Delta in October and continue until April. The timing of smolt outmigration to the Delta is correlated with pulse flows that occur in the Sacramento River (del Rosario et al. 2013). Fry and smolt that are cued to migrate travel downstream may spend time foraging and rearing in the Estuary before entering the ocean (Sturrock et al. 2015), including in the tidal sloughs of the Yolo Bypass (Sommer et al. 2001c; Sommer et al. 2005; Goertler et al. 2017). Changes to flows through the upper and middle Sacramento River alter migration cues, which are dampened by a decrease in flow. Additionally, decreased flow may shift the timing of Delta entry and ocean entry, causing some proportion of a population to be exposed to poor environmental conditions (e.g., entry does not correspond with peak productivity or temperatures in the Delta are too high), which can change population-level mortality rates (Weitkamp et al. 2015; Notch et al. 2020; Singer et al. 2020). By using flow actions to connect wetland and floodplain restoration sites within the Sacramento Basin, North Delta, and Suisun March, fish will have greater access to highly productive rearing habitat that may increase their likelihood of survival.

2.3.5 Invasive Species

Invasive fishes, zooplankton, benthic invertebrates, aquatic vegetation, and phytoplankton are all sources of stress for native species in the Delta and estuary. For example, invasive fishes make up 60%–90% of individuals in the freshwater Delta (Brown 2003). Many of these introduced, invasive fishes are from the southeastern United States, and they have been thriving in the Estuary where flows have been altered, water temperatures are warming, and vegetation is spreading (Conrad et al. 2016; Young et al. 2018). This topic is covered extensively in the 2017 Scientific Basis Report, but there are a few notable updates.

The degree to which predation by invasive fishes has a population-level effect on salmonids and smelt remains contentious, but additional research is helping to determine locational and water quality predictors of predation events. Michel et al. (2020a) identified several areas along the lower San Joaquin River, Mildred Island, and Old River as particularly hazardous for juvenile salmon. Temperature, turbidity, and presence of invasive weeds are still considered major factors in probability of predation events (Michel et al. 2020a; Nobriga et al. 2021), and more study is needed on the impact of artificial structures and lighting in altering predation dynamics (Lehman et al. 2019). Restoration of tidal wetlands and riparian areas may help to mitigate the effects of predatory fishes, but only if they avoid becoming filled with submerged aquatic vegetation. An increase in flows may provide relief from predation pressures by mobilizing increased sediment load into and within the Delta and decreasing the number of fish routing through the central Delta and south Delta, where temperatures are higher, turbidity is lower, and predation is higher (Perry et al. 2018; Michel et al. 2020a).

Section 4.4.1 of the 2017 Scientific Basis Report recommends assessing the cost-effectiveness of not salvaging nonnative species from fish rescue facilities at the CVP and SWP (State Water Board 2017). Mahardja and Sommer (2017) found that removing nonnative striped bass at the salvage facilities was not likely to have an impact on the population. Experimental removal of predatory fishes has also been relatively ineffective on the large scale (Michel et al. 2020b), though more effective in closed systems such as the Tracy Fish Collection Facility (Bridges et al. 2019).

Mahardja et al. (2020) also documented an invasive fish that has recently become established in the Delta, the bluefin killifish (*Lucania goodei*). However, it is currently unknown what effect this invasive fish might have on native fishes.

Nonnative aquatic vegetation has remained high since the 2017 Scientific Basis Report and continues to alter water quality for pelagic fishes (Hestir et al. 2016); provide habitat for nonnative fishes, including black bass and striped bass (Conrad et al. 2016); increase predation risk by decreasing turbidity (Ferrari et al. 2014; Hestir et al. 2016; Work et al. 2020; Michel et al. 2020a); and block waterways (Caudill et al. 2021). Previous research hypothesized that the increase of submerged aquatic vegetation between 2014 and 2016 was caused by drought conditions (Kimmerer et al. 2019), but wet years of 2017 and 2019 did not reduce submerged aquatic vegetation coverage (Hartman et al. 2022b; Khanna et al. 2022).

Nonnative invertebrates continue to dominate the zooplankton community. The nonnative mysid *Hyperacanthomysis longirostris* is smaller, and therefore less nutritious than the native mysid *Neomysis mercedis*, but it has dominated over the past 20 years potentially due to its smaller size at maturity and higher temperature tolerances (Avila and Hartman 2020). Other nonnative zooplankters, such as the copepod *Pseudodiaptomus forbesi*, have replaced native copepods in the diets of Delta smelt (Slater et al. 2019; Jungbluth et al. 2021), though *Eurytemora affinis* is still important in diets of longfin smelt in the south San Francisco Bay (Jungbluth et al. 2021; Barros et al. 2022).

The invasive clams *Potamocorbula amurensis* and *Corbicula fluminea* still dominate the benthic community, and abundances of *Potamocorbula* in the brackish regions of the Estuary (Suisun Bay and Suisun Marsh) have increased dramatically since 2000 (Crauder et al. 2016). However, *Potamocorbula* is much less abundant in the smaller sloughs in Suisun Marsh than the larger sloughs (Baumsteiger et al. 2017), providing hope that restoration in smaller sloughs may be more effective at increasing primary productivity without it being consumed by clams.

2.4 Other Stressors

Native fish species are affected by other stressors throughout the Central Valley within the tributaries and the Estuary. Stressors affect fishes across life stages to varying degrees. Three such additional stressors are direct take, disease, and climate change.

2.4.1 Direct Take

Direct take of native fish species occurs chiefly through fishing (salmonids and sturgeon) and entrainment in water diversions (all species). Flow actions may transport fish past areas where they are subject to entrainment, therefore reducing entrainment risk. Creation of habitat in the form of restoration sites may provide resting areas for rearing and foraging fish away from diversions. The 2017 Scientific Basis Report (State Water Board 2017) discussed factors affecting entrainment both at unscreened, smaller diversions upstream of the Estuary and at the major SWP and CVP facilities in the Delta.

The degree to which these are limiting factors in fish population growth is the topic of debate, and likely varies by species. Kimmerer and Rose (2018) found that Delta smelt population growth rates could be increased by as much as 39% if entrainment-related mortality was removed. However, a recent model of longfin smelt found that entrainment-related mortality only accounted for up to 1.5% of the population (Kimmerer and Gross 2022). A separate study estimated that proportional entrainment was negligible in extreme wet years, and approximately 2% in a moderately dry year (Gross et al. 2022). Changes to water project operations to be more protective of native fishes has reduced salmonid take considerably, and use of improved modeling has the potential for reducing entrainment still further (Tillotson et al. 2022).

Varying levels of flow can cause juvenile salmonids migrating down the mainstem Sacramento River to be routed through different pathways, some more optimal than others for fish survival and eventual entrainment (Perry et al. 2018, Hance et al. 2022, Singer et al. 2020). Entry into the interior Delta increases with decreasing Sacramento River flow (Perry et al. 2018; Hance et al. 2022). Entry into the Delta Cross Channel and Georgiana Slough routes salmonids into the central and interior Delta, an area which has decreased survival rates compared with remaining in the mainstem Sacramento River and the Delta (Brandes and McLain 2001; Newman and Brandes 2010). Sacramento River origin fish entering the interior Delta have greater potential to move into the hydrodynamic footprint of SWP Banks and CVP Jones pumping plants and will experience net reverse flows if entering the Old and Middle River corridor. Reverse flows in this corridor may result in an increased travel time, indirect mortality through predation, and mortality through direct loss at the Delta fish collection facilities (see summary by Vogel 2011:103–105).

2.4.2 Disease

Disease is a growing concern in the Sacramento River and its tributaries, particularly for Chinook salmon (Foott 2014, 2016a, 2016b; Lehman et al. 2020). Susceptibility of fishes to disease is related to several factors that occur in the environment, including fish species and their densities, water quality conditions, decreased flows, and the amount of pathogens in the environment (Foott 2016a). Although pathogens occur naturally in the environment, the operations of dams may have produced environmental conditions where fish are more susceptible to disease (NMFS 2016). Impediments to upstream migration and lack of sufficient flow can delay upstream migration and increase residence time, therefore increasing pathogen exposure and decreasing survival.

The National Wild Fish Health Survey is a program conducted by the U.S. Fish and Wildlife Service (USFWS) Fish Health Center to assess the prevalence and distribution of major fish pathogens in wild fish populations. One focus of the California/Nevada Fish Health Center's National Wild Fish Health Survey efforts was with juvenile fall-run Chinook pathogens (particularly *Ceratomyxa shasta* and *Parvicapsula minibicornis*), smolt development (gill Na-KATPase activity), and response to organophosphates (Brain AChE activity) in the Sacramento River. In 2013, 2014, 2015, and 2016, *Ceratomyxa shasta* infection was detected in juvenile Chinook salmon collected from the lower Sacramento River. In 2014, 74% of Chinook juveniles examined were infected with *Ceratomyxa shasta* (Foott 2014). Research in the Klamath River has documented significant juvenile Chinook mortality in some years (Foott et al. 2004) as well as a better understanding of the complex interaction of parasite's life cycle (fish and polychaete worm hosts) with environmental factors such as temperature, flow, and nutrients (Stocking et al. 2006). The prognosis of myxosporean infections in natural Chinook and their effect on survival should be evaluated.

2.4.3 Climate Change

The effects of climate change will exacerbate all the above stressors in a variety of ways. Physical changes to ocean, river, and stream environments along the West Coast are predicted, including warmer atmospheric temperatures, diminished snowpack resulting in altered streamflow volume and timing, lower late summer flows, a continued rise in stream temperatures, and increased sea-surface temperatures and ocean acidity, resulting in altered marine and freshwater food-chain dynamics (Herbold et al. 2022). Experts predict these changes in the hydrology and water temperature in the Central Valley, including the Delta and Estuary, will have negative effects on future Chinook salmon populations (NMFS 2014a; Lindley et al. 2009) and Delta smelt populations (Brown et al. 2016b; Halverson et al. 2022), as well as many other native California fishes (Moyle et al. 2013). Increases in air temperature directly affect water temperature, and with increased water temperature fish will have increased food needs. Food limitation may become more severe and predation pressure may also increase.

Drought years are predicted to occur with greater frequency in the Sacramento Valley with climate change (Swain et al. 2018). In the San Francisco Estuary, the effects of recurring drought and drought-managed flows are likely to have outsized impact on pelagic fishes, which have already seen marked declines, because these species do not recover from drought-managed flows in all years and littoral fishes are more resistant to conditions resulting from drought management (Mahardja et al. 2021).

The effects of climate change are already being seen. Median annual freshwater flow in the Estuary has not significantly changed over the past 100 years, though seasonal patterns have changed and there has been increased variability in current Delta outflow conditions compared with predevelopment flow conditions (Hutton et al. 2021). Bashevkin et al. (2022) reported a general warming pattern in water temperature for most months and areas modeled in the Estuary over the past 50 years, noting spatio-seasonal variability in that pattern. Restoring components of a natural flow regime and restoring physical habitats may be important components of increasing resiliency to these changes.

Chapter 3
Description of Flow and Non-Flow Assets

3.1 Tributary Assets

Tributary assets described below include flow and non-flow assets negotiated as of March 29, 2022 and outlined in Appendices 1 and 2 of the VA Term Sheet. Flow assets are new contributions to tributary flow that are additive to the baseline and will be provided January through June. The baseline is considered Delta outflows required by D-1641 and resulting from the 2019 BiOps, although the 2019 BiOps may be modified, including to resolve litigation concerning those opinions. These flows may be shaped in timing and seasonality, to test biological hypotheses, and to respond to hydrologic conditions while reasonably protecting beneficial uses. Such shaping will occur through the Governance Program (Section 9 of the VA Term Sheet) and will be subject to the Implementing Agreements and applicable regulatory requirements. A portion of the volumes of water described below will be managed with a priority of providing increased flows in the months of April and May in Dry, Below Normal, and Above Normal water years to replicate average outflow resulting from the Inflow/Export ratio in the 2009 NMFS BiOp as modeled (NMFS 2009). Flows made available through reservoir reoperations will be subject to accounting procedures described in the VA Term Sheet, and all flows will be verified as a contribution above baseline using these accounting procedures. An assessment based on the accounting procedures will be developed (pursuant to Section 8.4 of the VA Term Sheet) and conducted prior to year 8 of the VAs to determine if the flows described below have materialized on average above baseline by water year type. If this analysis does not demonstrate that flows have materialized as described below, then the VAs will be subject to VA Term Sheet provisions of Section 7.4(B)(ii) or (iii). Off-ramps for flows during Critical years are subject to negotiation, but flows described below reflect average critical year contributions over the term of the VAs. The habitat restoration measures described below will be additive to physical conditions and regulatory requirements existing as of December 2018, when the State Water Board adopted Resolution 2018-0059. Implementation of such measures by Parties after that date, but prior to execution of the VAs, will be considered as contributing toward implementation of the Narrative Salmon Objective and Narrative Viability Objective. The habitat restoration described below represents the sum of habitat restoration commitments proposed in the Planning Agreement and habitat restoration acres identified in the State's VA Framework from February 2020, modified to reflect the 8-year VA term, discussions with participants, and modeling analysis.

Table 3-1 represents the minimum additive contribution to off-stream habitat restoration, in acres and by general location, proposed in the State's VA Framework, within the 8-year VA term. This acreage is in addition to those listed above for instream restoration. These efforts include a number of activities, including levee setbacks, breaches, side-channel improvements, and other improvements based on site-specific objectives. Proposed projects have been developed to provide habitat at a frequency, magnitude, and duration necessary to produce biological benefits for species such as fall-run Chinook salmon. Collectively, they seek to improve rearing capacity for juvenile salmonids, as well as other native fish, by enhancing the quantity and quality of available habitat. Additional habitat improvement actions (e.g., removal of barriers or invasive aquatic weeds) might be pursued, if it is determined that such actions would contribute toward meeting the objectives of the VAs by addressing one or more of the limiting factors described in Chapter 2.

Table 3-1. Summary of VA Tributary Habitat Restoration Commitments by Habitat Type and Watershed

Watershed	Spawning (acres)	Instream Rearing (acres)	Floodplain Rearing (acres)
Sacramento River	113.5	137.5	-
Sutter Bypass, Butte Sink, and Colusa Basin	-	-	20,000
Feather River	15	5.25	1,655
Yuba River	-	50	100
American River	25	75	-
Mokelumne River	-	1	25
Putah Creek	1.4	-	-

Source: Voluntary Agreements Parties 2022.
Flow assets are described in Table 4-1.

3.1.1 Sacramento River

The Sacramento River has both flow and non-flow assets identified. Flow assets for the Sacramento River have been identified as 2 thousand acre-feet (TAF) in Critical years, 102 TAF in Dry years, and 100 TAF in Below and Above Normal years. No additional water will be available from the Sacramento River in Wet years. Non-flow assets for the Sacramento River include restoration of 137.5 acres of instream habitat and 113.5 acres of spawning habitat.

No direct flow assets are proposed for flood basins, although the flow assets for the Sacramento River are expected to increase inundation in Sutter Bypass. Non-flow assets for three flood basins (Sutter Bypass, Butte Sink, and Colusa Basin) include more frequent inundation of 20,000 acres of flood basin habitat and 20,000 acres of land for fish food production. This habitat will be generated via modifications to Tisdale Weir and other infrastructure modifications and will be subject to analysis showing that the acreage meets suitability criteria. The fish food production program will be subject to analysis of effectiveness. Water will be pumped out onto rice fields, held for a period of time to allow fish food production (e.g., zooplankton) and then discharged to the river for the benefit of native fishes downstream. These actions will mainly focus on fish passage improvements, food production, and enhancement of rearing habitat quantity and quality.

There are currently at least six distinct project efforts identified within this region, for implementation within the VA term, four of which are intended to begin implementation by 2024.

3.1.2 American River

The American River has both flow and non-flow assets identified. Flow assets for the American River have been identified in Critical, Dry, Below Normal, and Above Normal years of 30, 40, 10, and 10 TAF respectively. No additional water will be available from the American River in Wet years. These flow assets are contingent on funding for groundwater substitution infrastructure which would be completed by a subsequent year. In addition to flows, restoration of 25 acres of spawning habitat and 75 acres of rearing habitat would be completed on the American River.

3.1.3 Yuba River

The Yuba River has both flow and non-flow assets identified. Flow assets for the Yuba River have been identified as 60 TAF in Dry, Below Normal, and Above Normal years. No additional water will be available from the Yuba River in Critical or Wet years. Non-flow assets for the Yuba River include restoration of 50 acres of instream habitat and 100 acres of floodplain habitat. This constructed floodplain would be activated at 2,000 cfs.

There are approximately five distinct projects identified in this region that seek to improve fish access to enhanced quality and quantity off-channel rearing habitat, four of which are intended to initiate implementation by 2024.

3.1.4 Feather River

The Feather River has both flow and non-flow assets identified. Flow assets for the Feather River have been identified as 60 TAF in Dry, Below Normal, and Above Normal years. No additional water will be available from the Feather River in Critical or Wet years. Non-flow assets for the Feather River include restoration of 5.25 acres of instream habitat, 15 acres of spawning habitat, and 1,655 acres of floodplain habitat. This consists of added instream habitat complexity and side-channel improvements.

Currently, there are approximately seven projects identified within this region that include improved fish access to off-channel rearing habitat through enhancement or restoration, at least four of which are intended to begin implementation by 2024.

3.1.5 Putah Creek

Putah Creek has both flow and non-flow assets identified. Flow assets for Putah Creek have been identified in Critical, Dry, Below Normal, and Above Normal years. In Critical years 7 TAF would be available, while 6 TAF would be available in Dry, Below Normal, and Above Normal years. No additional water will be available in Wet years. In addition to flows, restoration of 1.4 acres of spawning habitat would be done on Putah Creek.

3.1.6 Friant System

Flow assets have been identified for the Friant system of 50 TAF of additional water in Dry, Below Normal, and Above Normal years. No additional water will be available from Friant in Critical or Wet water years. No new restoration is proposed for this area.

3.1.7 Mokelumne River

The Mokelumne River has both flow and non-flow assets identified. Flow assets have been identified for the Mokelumne River in Dry, Below Normal, and Above Normal years of 5, 5, and 7 TAF, respectively. No additional water will be available in Critical or Wet Years. Funding to partially support PWA water purchases will also be provided. In addition to flows, restoration of 1 acre of instream habitat and 25 acres of floodplain habitat would be done on the Mokelumne River. This restoration would target creation of habitat to improve rearing capacity.

The creation of floodplain habitat to enhance rearing capacity is identified in one project that is intended to begin implementation by 2024.

3.2 Delta and Estuary Assets

3.2.1 Habitat Actions in the Delta

The VA Term Sheet includes restoring a total of 5,227.5 acres of tidal wetland and associated floodplain habitats within the North Delta Arc and Suisun Marsh regions. These restoration projects would target the creation and enhancement of a mosaic of habitats, including floodplain, tidal, and riparian, to restore ecological functions and improve fish passage, access to higher quality and quantity spawning and rearing habitat, and food production. Restoration objectives for the Delta are sited and designed to improve conditions for native species, including Delta smelt, longfin smelt, splittail, and salmonids.

Among the various efforts proposed for the Delta, there are approximately 10 projects identified through the VA planning process.

3.2.2 Foregone Exports

Contributions to Delta and estuary flow assets from foregone exports would total 125 TAF in both Dry and Below Normal water year types, and 175 TAF in Above Normal water year types.

3.2.3 Water Purchases

Permanent state water purchases would total 65 TAF in Critical, 108 TAF in Dry, 9 TAF in Below Normal, 52 TAF in Above Normal, and 123 TAF in Wet water year types.

The PWA Water Purchase Fixed Price Program would total 3 TAF in Critical, 63.5 TAF in Dry, 84.5 TAF in Below Normal, 99.5 TAF in Above Normal, and 27 TAF in Wet water year types. This program is intended to purchase water at a fixed price from known sellers.

PWA Water Purchase Market Price Program would total 50 TAF in Dry, 60 TAF in Below Normal, and 83 TAF in Above Normal water year types. This program would purchase water at market rates from sellers on the water transfer market and would include updated volumes resulting from the Mokelumne VA Term Sheet addendum (August 2022).

Chapter 4
Hydrology and Operations Modeling Methods and Results

4.1 Background

The following are the assumptions for the CalSim 3 VA Draft Model released on November 16, 2022.

In March 2022, the VA Parties released an updated MOU (2022 VA Term Sheet) with updated information on the VA flow and non-flow assets. The updated 2022 VA flow assets can be found in Table 4-1 below.

Please note that not all VA flow assets listed in the 2022 VA Term Sheet are represented in this updated modeling, and those commitments that were not modeled are indicated by the grey shading in Table 4-1. Future refinements to this modeling will include those VAs as details are developed. The CalSim 3 VA model and model assumptions are still under review and subject to change.

Table 4-1. 2022 Voluntary Agreements (Values in Thousand Acre-Feet, TAF)[0]

Number	Tributary	Season	Source	C	D	BN	AN	W
1	Sacramento River	Spring/Summer	Land fallowing	2	102	100	100	0
2	Feather River	Spring/Summer	Land fallowing	0	60	60	60	0
3	Yuba River[1]	Spring	Reservoir storage	0	60	60	60	0
4	American River	Spring	GWS, reservoir storage	30	40	10	10	0
5	Friant System[2]	Mar–May	Reduction in San Joaquin River Restoration Project recapture	0	50	50	50	0
6	Mokelumne River[3]	Mar–May, Oct	Reservoir release	0	5	5	7	0
7	Putah Creek[3]	Nov–May	Reservoir release	7	6	6	6	0
8	CVP/SWP Export Reduction (Delta)	Spring	Export reduction	0	125	125	175	0
9	PWA Water Purchase: Fixed Price	-	-	3	63.5	84.5	99.5	27
9a	PWA Fixed Price: Sac Valley NOD[4]	-	-	0	10	10	10	0
9b	PWA Fixed Price: CVP SOD[4]	-	-	0	12.5	24.5	35	0
9c	PWA Fixed Price: WWD SOD[4]	-	-	3	6	15	19.5	27
9d	PWA Fixed Price: Add CVP SOD[4]	-	-	0	5	5	5	0
9e	PWA Fixed Price: SWP SOD[4]	-	-	0	30	30	30	0
10	PWA Water Purchase: Market Price[5]	-	-	0	50	60	83	0
11	Permanent State Water Purchases[5]	-	-	65	108	9	52	123
12	Lower San Joaquin River Placeholder[5]	-	-	48	156	181	122	0
	Total			155	825.5	750.5	824.5	150

[0]Additional information can be found in the 2022 VA Term Sheet. The primary focus was the January through June period. Water year type is based on Sacramento Valley, unless otherwise stated.

[1]Only 50 TAF was included in the CalSim 3 model.

[2]Only reduction in recaptured San Joaquin River Restoration Project flows with current facilities in the Delta were considered (no flood flows or future potential recapture). Based on the San Joaquin River Restoration Project water year types.

[3]Flow contributions are considered as re-operated water and not protected as Delta outflow, as discussions for these VAs are still underway. Mokelumne VA reflects updated volumes from the Mokelumne VA Term Sheet addendum (August 2022); Mokelumne VA based on Joint Settlement Agreement water year types.

[4]Subcategories for the PWA Fixed Price Water Purchases (No. 9).

[5]VAs for the San Joaquin tributaries were not modeled, but are placeholder volumes from the VA Term Sheet MOU and included updated volumes from the Mokelumne VA Term Sheet addendum (August 2022). The placeholder volumes are not currently fully committed to by MOU signatories.

4.2 Baseline Model

The CalSim 3 VA baseline model includes D-1641 and the 2019 BiOps. The 2020 Incidental Take Permit (ITP) for the SWP is removed from the baseline model. As discussed in Section 4.12, *Postprocessing of Delta Outflow*, the baseline model does not fully reflect the Delta outflow conditions of the environmental baseline documented in the 2017 Scientific Basis Report and experienced by the ecosystem under the recent historical conditions of the last decade. Accordingly, model results for Delta outflow were postprocessed to more accurately reflect the recent historical conditions that serve as the environmental baseline for the Sacramento/Delta Update to the Bay-Delta Plan and the conditions analyzed in the 2017 Scientific Basis Report.

4.3 Sacramento River VA

The Sacramento VA contains two measures to augment flows and implement non-flow habitat measures:

- Provide flows for Delta outflow from Land Fallowing in Above Normal, Below Normal, Dry, and Critical years (based on April water year type).

Water Year Type	Quantity (TAF)
Above Normal	100
Below Normal	100
Dry	102
Critical	2

- In Above Normal/Below Normal years, 100 TAF of water will be released evenly on April/May or Jun/July/August based on End-of-March Shasta Storage.

Shasta End-of-March Reservoir Storage	Sacramento VA Pulse Flow
Equal to or Greater than 3,800 TAF	50 TAF each in Apr/May
Less than 3,800 TAF	33.33 TAF each in Jun/Jul/Aug

- In Dry and Critical years, the water will be available as instream flow based on the delivery pattern of the fallowed land.
- Tisdale Weir Notch for Sutter Bypass Habitat
  - A notch in Tisdale Weir is anticipated to be operated from December 1 through March 15. The notch will pass 45% of Sacramento River flows between 9,000 cfs and 15,550 cfs. Between 15,500 cfs and 22,000 cfs, the notch will pass 3,000 cfs of Sacramento River flows. The entire weir will be activated at flows over 22,000 cfs and can pass 75% of flows.

Modeled changes to Sacramento River inflow resulting from the VA are depicted in Figure 4-1 and Table 4-2. Sacramento River inflow is summarized as the total of Sacramento River flow at Knights Landing, inflow from the Sutter Bypass, and inflow to the Knights Landing Ridge Cut from the Colusa Basin Drain. Monthly flows in Figure 4-1 and subsequent figures are shown as box plots; the bold horizontal line shows the median, the box shows the interquartile range (25^{th} to 75^{th} percentiles), and the whiskers show the full range of values over the modeled hydrologic record.

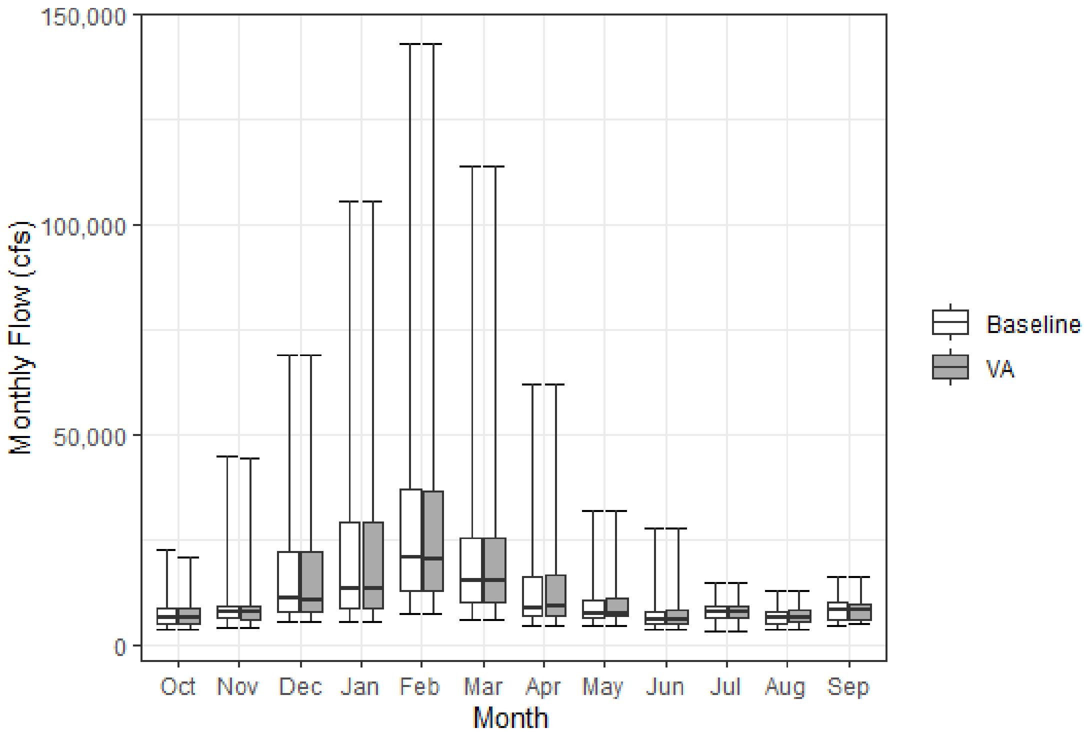

Figure 4-1. Baseline and VA Modeled Sacramento River Inflow (CFS)

Table 4-2. Water Year Type Averaged January–June Total Baseline Flow and VA Change From Baseline (TAF), Sacramento River Inflow

Water Year Type	Baseline	VA
W	10,708	-12
AN	7,030	62
BN	4,133	59
D	3,779	43
C	2,983	-9
All	6,232	26

These results also include flows from the NOD Fixed Price Water Purchase (10 TAF AN/BN/D) since the NOD Fixed Price Water Purchase was included in the Sac Valley Land Fallowing, see Table 4-8.

4.4 Feather River VA

The Feather VA provides 60 TAF/yr of Delta outflow in Above Normal, Below Normal, and Dry years (based on April water year type) predominantly through land idling, crop shifting, and/or reservoir reoperation within the Feather River service areas (the model assumes all water is made available through land fallowing). The VA flows provide 30 TAF each in April and May for Delta outflow.

Modeled changes to Feather River flow resulting from the VA are depicted in Figure 4-2 and Table 4-3.

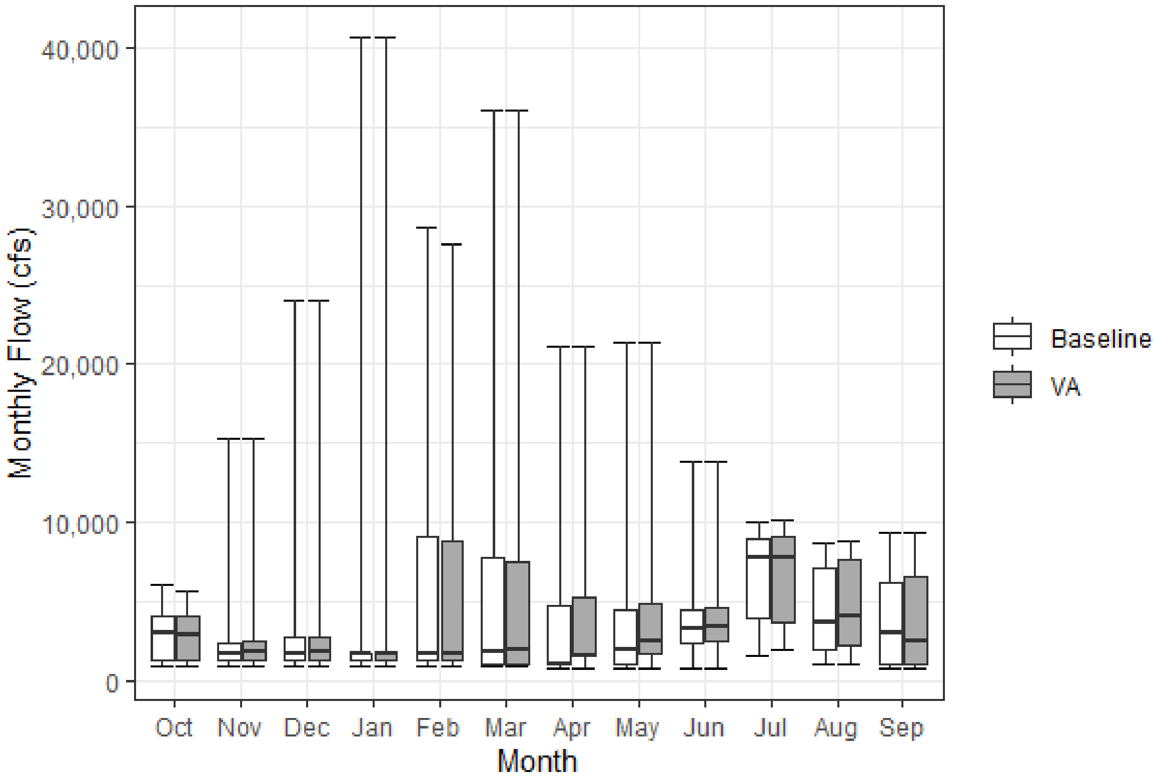

Figure 4-2. Baseline and VA Modeled Flow (CFS), Feather River below Thermalito

Table 4-3. Water Year Type Averaged January–June Total Baseline Flow and VA Change from Baseline (TAF), Feather River below Thermalito

Water Year Type	Baseline	VA
W	3,404	-10
AN	1,690	51
BN	789	75
D	612	91
C	564	16
All	1,609	40

4.5 Yuba River VA

Yuba Water Agency (YWA) proposes to provide a Delta flow component of about 50 TAF per year during Above Normal, Below Normal, and Dry years, as measured at the Marysville gage. The flow proposal in the YWA VA Project is founded on the lower Yuba River Accord-based flows, including the requirements for instream flows specified in the Yuba Accord Fisheries Agreement and the State Water Board's Corrected Order WR 2008-0014, and transfer operations and accounting provisions of the Yuba Accord Water Purchase Agreement. YWA VA Project operations would be supplemental to the Yuba Accord flows and associated Yuba River Development Project operations.

The YWA VA Project includes two quantifiable water components that would provide about 50 TAF of additional Bay-Delta inflows in Above Normal, Below Normal, and Dry year types through the following changes in Yuba River Development Project operations:

a. All Yuba Accord transfer releases in April, May, and June that cannot be backed into Lake Oroville or exported by DWR would be repurposed from potential in-basin use and Delta exports to Bay-Delta outflows (YWA VA Project Component 1).

b. Additional storage releases from New Bullards Bar Dam would occur by operating to a new target September 30 storage level of 600 TAF, which is 50 TAF below the Yuba Accord target September 30 storage level of 650 TAF (YWA VA Project Component 2). The YWA VA Project also includes accounting for refill of storage releases from YWA VA Project Component A and B that exceed 9 TAF annually in Above Normal, Below Normal, and Dry year types.

Please note that the Yuba Accord and Yuba VA Project operations are modeled externally using the Yuba River Development Project model and included as timeseries inputs in the CalSim 3 model at the Marysville gage. The Yuba VA flows are routed through the river system and are protected as Delta outflow. Any changes to the underlying Yuba Accord flows due to impacts on storage from VA contributions are modeled as re-operated water.

Modeled changes to Yuba River flow resulting from the VA are depicted in Figure 4-3 and Table 4-4.

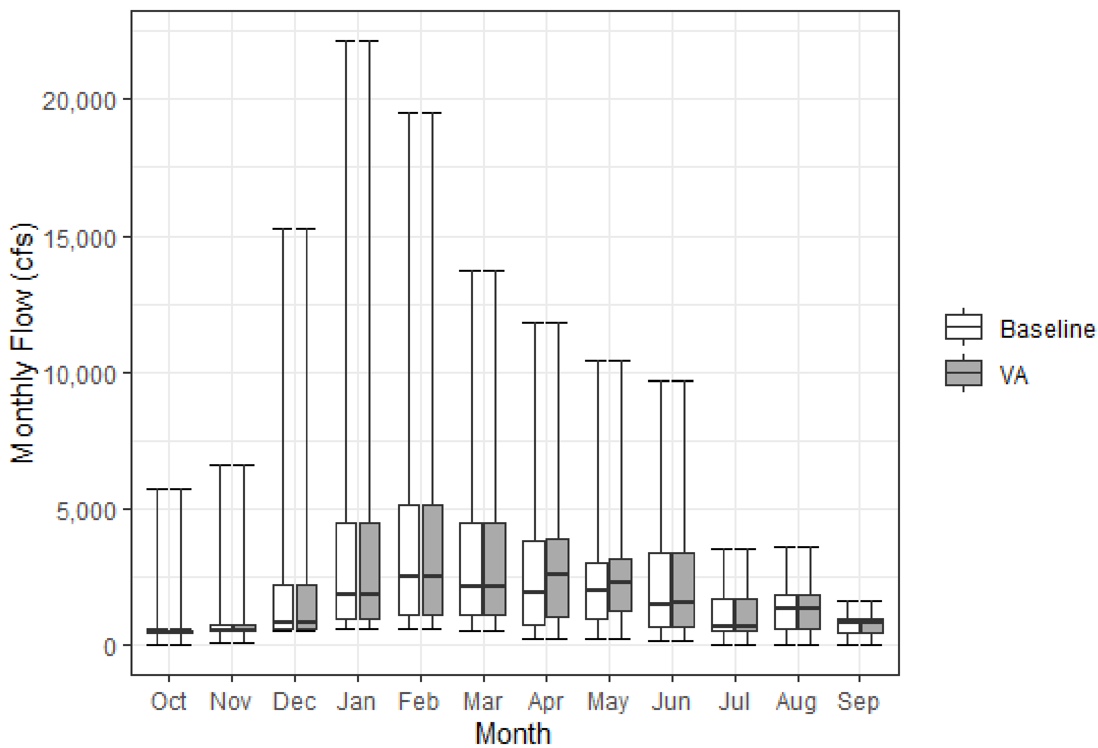

Figure 4-3. Baseline and VA Modeled Flow (CFS), Yuba River at Mouth

Table 4-4. Water Year Type Averaged January–June Total Baseline Flow and VA Change from Baseline (TAF), Yuba River at Mouth

Water Year Type	Baseline	VA
W	1,982	10
AN	1,298	30
BN	649	57
D	496	32
C	317	10
All	1,056	27

4.6 American River VA

The American River VA is to augment flows and implement habitat measures. The following proposed actions are implemented into the model:

- Action Above Normal and Below Normal water year types
  - 10 TAF of water made available by CVP settlement contractors through reservoir reoperations of the upper American River. This water is distributed evenly with 3.33 TAF in March, April, and May and includes accounting for refill of storage.
- Action Dry water year types
  - 10 TAF of water made available by CVP settlement contractors through reservoir reoperations of the upper American River. This water is distributed evenly with 3.33 TAF in March, April, and May and includes accounting for refill of storage.
- Action Critical and Dry water year types
  - 30 TAF of water is made available by CVP settlement contractors through groundwater substitution. The 30 TAF will be distributed evenly with a 10 TAF pulse in March, April, and May.

The water year types are based on the April water year type, and VA flows in March are based on a perfect foresight of the April water year type.

Modeled changes to American River flow resulting from the VA are depicted in Figure 4-4 and Table 4-5.

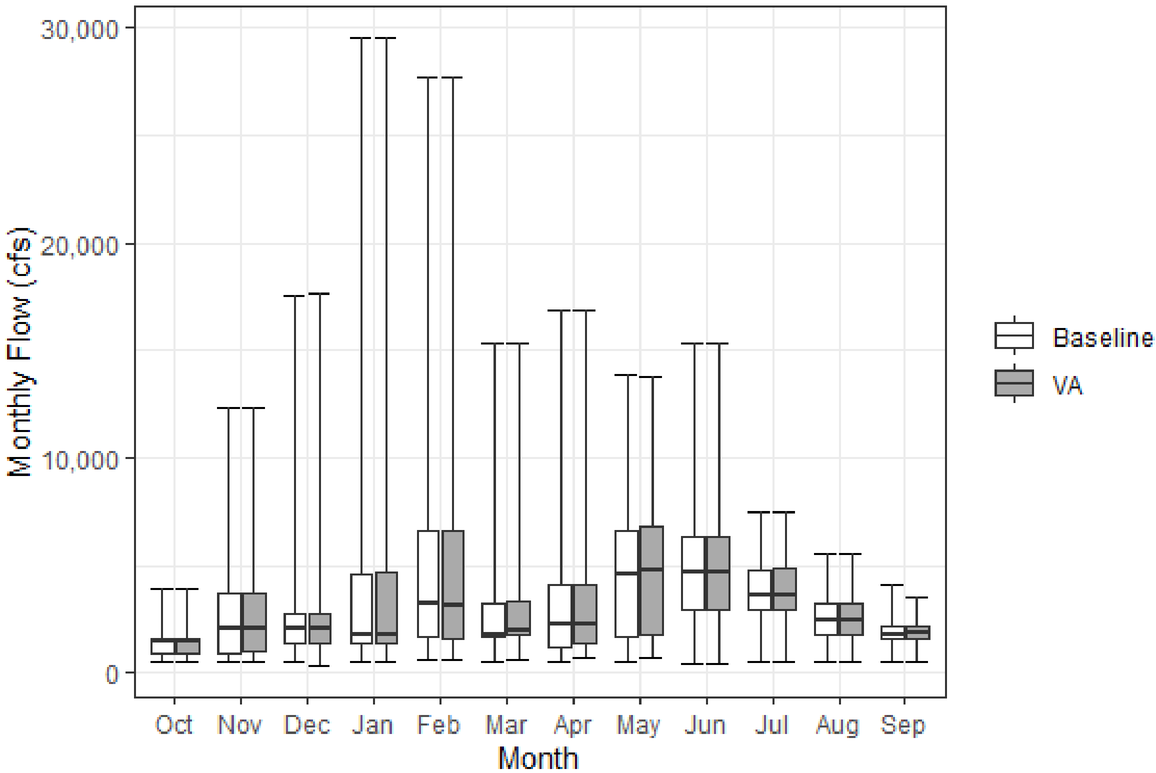

Figure 4-4. Baseline and VA Modeled Flow (CFS), American River below Natomas

Table 4-5. Water Year Type Averaged January–June Total Baseline Flow and VA Change from Baseline (TAF), American River below Natomas

Water Year Type	Baseline	VA
W	2,725	-4
AN	1,747	3
BN	941	9
D	816	40
C	533	30
All	1,494	13

4.7 Friant VA

The Friant VA includes reduction of recaptured San Joaquin River Restoration Project flows in the Delta. In all years, except for those determined to be Wet, Critical-High, or Critical-Low under the San Joaquin River Restoration Settlement, the Friant VA reduces the recapture of restoration flows to the extent necessary to achieve a goal of total Delta outflows during the period of February through May.

- Reduction of Restoration Recapture:

- ○ Recapture in the Delta can be reduced by up to 50% during the period of February through May. (This was not modeled.)
- ○ Restoration recapture in the Delta is reduced to achieve the 50 TAF Delta outflow goal.

Modeled changes to flow resulting from the Friant VA are captured in the summary of changes to Delta outflow (see Section 4.12).

4.8 Mokelumne River VA

The Mokelumne River VA includes increased minimum instream flows generated from re-operated water. The Mokelumne River VA operations are modeled on top of the Joint Settlement Agreement flows. The Mokelumne River VA flows are as follows:

- 45 TAF in Normal and Above Normal Joint Settlement Agreement water year types.
- 20 TAF in Below Normal Joint Settlement Agreement water year types.
- 10 TAF in Dry Joint Settlement Agreement water year types.
- 13% of flows are in March, 37% flows are in April, 29% of flows are in May, and the remaining 21% of flows are in October.
- Period for determining VA Year type is based on watershed unimpaired runoff (April to September year type setting).

Modeled changes to Mokelumne River flow resulting from the VA are depicted in Figure 4-5 and Table 4-6. The values identified in Table 4-1 represent the additional flow from the VA based on preliminary modeling, and may be revised consistent with refined modeling and flow accounting procedures to be developed for the VAs.

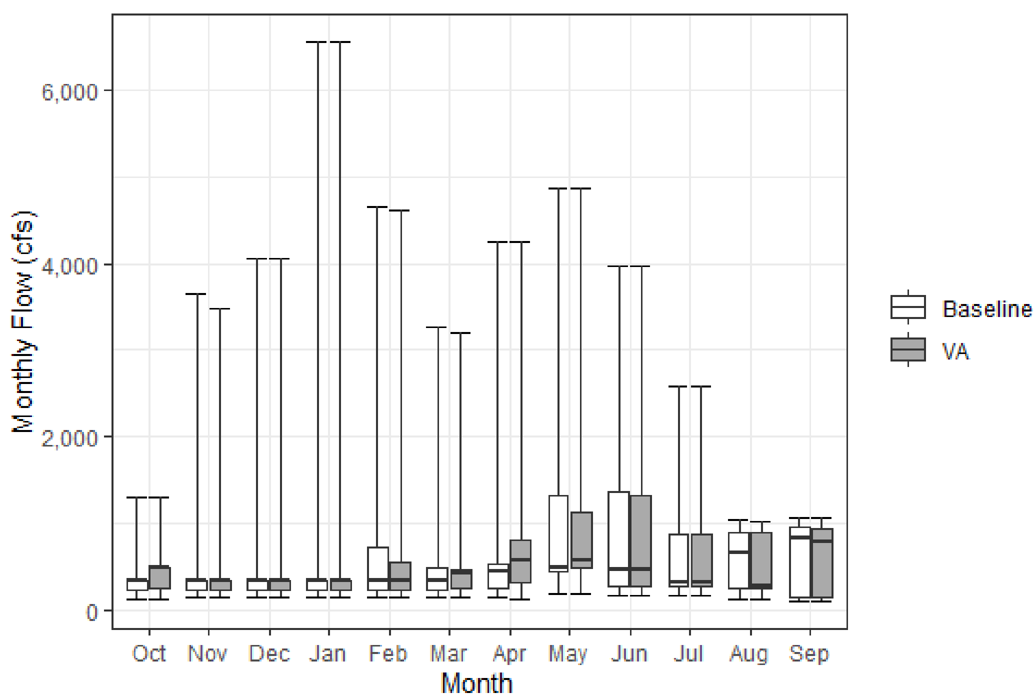

Figure 4-5. Baseline and VA Modeled Flow (CFS), Mokelumne River below Camanche

Table 4-6. Water Year Type Averaged January–June Total Baseline Flow and VA Change from Baseline (TAF), Mokelumne River below Camanche

Water Year Type	Baseline	VA
W	549	-1
AN	267	-2
BN	131	9
D	115	7
C	89	6
All	262	4

4.9 Putah Creek VA

The Putah Creek VA includes re-operated water and is not protected from in-basin use or Delta exports. The Putah Creek VA provides flows of about 6 TAF/yr between November and May during all water year types except Wet using the following flow schedule:

- 2.5 TAF “Pulse Flows” released between November 1 and December 15
- 2.5 TAF “Ramp Down Flows” released immediately following Pulse Flow releases and continuing through March 31
- 1 TAF “Flushing Flows” released from Apr. 1 through May 31

Putah Creek VA operations are modeled on top of the minimum instream flow requirements and are distributed proportionately based on the period and the number of days in that month. For example, the “Pulse Flows” of 2.5 TAF between November 1 and December 15 are 2/3 in November and 1/3 in December.

Modeled changes to Putah Creek flow resulting from the VA are depicted in Figure 4-6 and Table 4-7.

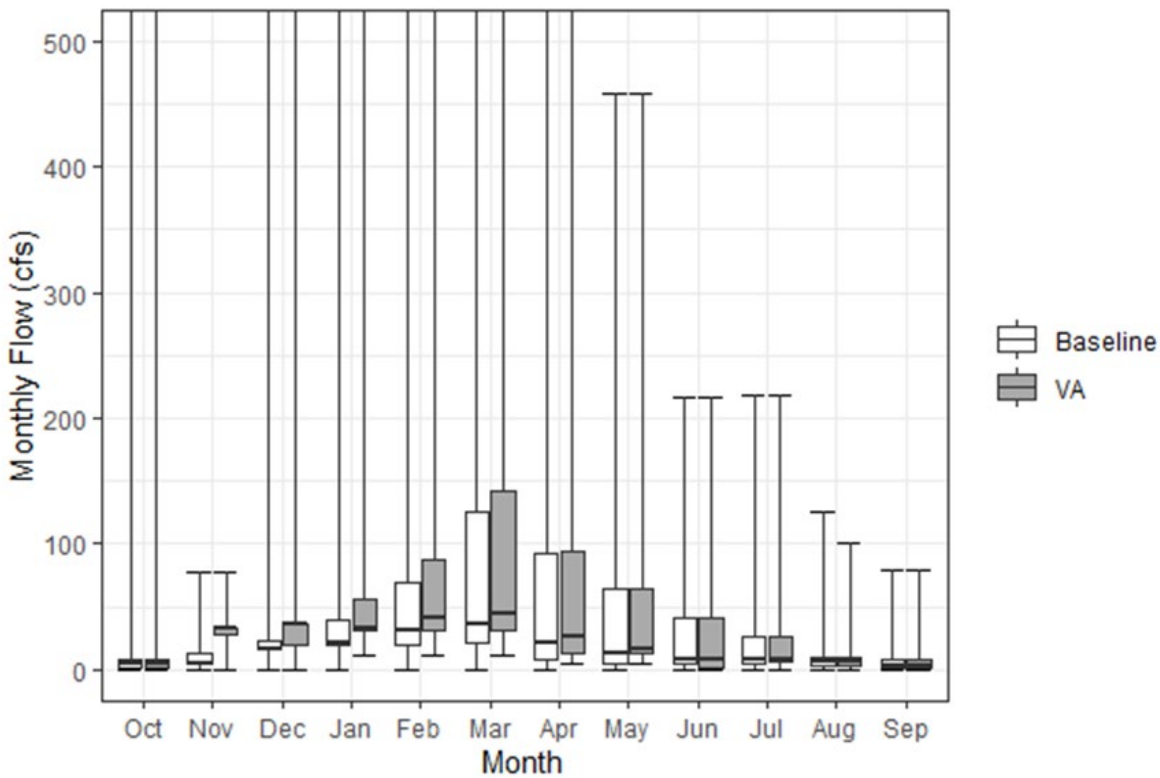

Figure 4-6. Baseline and VA Modeled Flow (CFS), Putah Creek near Davis
Note that the y-axis is truncated; maximum modeled flows range from approximately 1,000 CFS in October to nearly 7,000 CFS in February and March, and they are not substantially changed by the VA.

Table 4-7. Water Year Type Averaged January–June Total Baseline Flow and VA Change from Baseline (TAF), Putah Creek near Davis

Water Year Type	Baseline	VA
W	199.9	-6.5
AN	30.6	-0.8
BN	7.2	2.2
D	5.8	1.9
C	4.6	2.9
All	64.1	-0.7

4.10 CVP/SWP Export Reduction VA

The CVP and SWP Export Reduction VA provides VA flows for Delta outflow by reducing CVP/SWP exports of unstored water. The VA provides the following:

- Above Normal years: 175 TAF during April and May.
- Below Normal and Dry years: 125 TAF during March through May.

- April and May exports are maintained at the Health and Safety level of 1,500 cfs (in other words, no VA action if CVP plus SWP exports are at or below 1,500 cfs).
- March exports are maintained at 3,000 cfs (in other words, no VA action if CVP plus SWP exports are at or below 3,000 cfs).

The water year types are based on the April water year type and the Below Normal and Dry year VA export cuts in March are based on a perfect foresight of the April water year type.

Modeled changes to flow resulting from the CVP/SWP export reductions are captured in the summary of changes to Delta outflow (see Section 4.12).

4.11 Water Purchases

The water purchases described in the 2022 VA Term Sheet were not explicit on how that water would be developed. Therefore, considering the time schedule for this effort and using existing VAs already in the CalSim 3 VA model, only the Fixed Price Water Purchases were modeled and included into the Sacramento and CVP/SWP Export Reduction VAs. The Market Price and Permanent State Water Purchases were not included in the CalSim 3 model. The specific Fixed Price Water Purchase volumes that fell into the Sacramento and CVP/SWP Export Reduction VAs are shown in Table 4-8 below.

Table 4-8. Sacramento and CVP/SWP Export Reduction VAs with Fixed Price Water Purchases

Number	Tributary	Season	Source	Application	W	AN	BN	D	C
Sacramento VA with Water Purchases									
1	PWA Fixed Price: Sac Valley NOD	-	-	-	0	10	10	10	0
2	Sacramento VA	Spring/Summer	Land Fallowing	Block	0	100	100	102	2
3 = 1 + 2	Total Sacramento VA with Water Purchases	Spring/Summer	Land Fallowing	Block	0	110	110	112	2
CVP/SWP Export Reduction VA with Water Purchases									
4	PWA Fixed Price: CVP SOD	-	-	-	0	35	24.5	12.5	0
5	PWA Fixed Price: WWD SOD	-	-	-	27	19.5	15	6	3
6	PWA Fixed Price: Add CVP SOD	-	-	-	0	5	5	5	0
7	PWA Fixed Price: SWP SOD	-	-	-	0	30	30	30	0
8	CVP/SWP Export Reduction VA	Spring	Export Reduction	Block	0	175	125	125	0
9 = 4 + 5 + 6 + 7 + 8	Total CVP/SWP Export Reduction VA with Water Purchases	Spring	Export Reduction	Block	27	265	200	179	3

Please note this is a modeling assumption only and was only made to represent the Fixed Price Water Purchases in the CalSim 3 VA model in a simplified manner. Actual Water Purchase commitments and the development of such water will be based on the 2022 VA Term Sheet and discussions between the VA Parties.
Changes to flow resulting from water purchases are captured in the postprocessing of changes to Delta outflow (see Section 4.12).

4.12 Postprocessing of Delta Outflow

The VA Term Sheet states that VA flows "will be additive to the Delta outflows required by D-1641 and resulting from the 2019 BiOps, although the 2019 BiOps may be modified, including to resolve litigation concerning those opinions." (Section 4.1 of the VA Term Sheet). However, the 2017 Scientific Basis Report considered expected Delta outflow resulting from the possible changes to the Bay-Delta Plan being considered at the time additive to the 2008/09 BiOp. To be consistent with the environmental analysis in the 2017 Scientific Basis Report, expected Delta outflow resulting from the VA flows was postprocessed as described below.

Similarly, the CalSim 3 VA model does not include a subset of the VA flow actions (Table 4-1, rows 9–12), since the source tributaries for water purchases and lower San Joaquin tributary flows are not known at the time of preparation of this report. For the purposes of assessing changes in Delta outflow, these flows are also included through a postprocessing exercise.

4.12.1 Baseline Postprocessing

As modeled, the 2019 BiOps affect Delta outflow during the January–June period in two main ways: (1) the removal of export constraints based on San Joaquin River inflow during April and May results in a reduction in Delta outflow due to increased exports during those months; and (2) reductions in overall environmental flow obligations of project reservoirs result in higher reservoir storage at the beginning of the wet season, contributing to increased spill for flood control, generally during January through March. The modeled monthly changes in Delta outflow associated with these changes are shown in Table 4-9. The model results presented here are summarized from the CalSim II model scenarios that were developed by DWR during the consultation that resulted in the 2020 ITP.

Table 4-9. Water Year Type (WYT) Averaged Change In Net Delta Outflow (TAF) Resulting from 2019 Biological Opinions, As Modeled in CalSim II

WYT	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
W	-27	-226	139	90	69	70	-229	-265	3	8	2	-371
AN	-21	-211	7	64	87	158	-221	-250	38	-6	0	57
BN	-20	-171	7	59	106	85	-175	-168	43	29	1	-3
D	-25	-128	-4	-24	-15	76	-111	-62	11	0	-3	0
C	12	-121	17	-38	16	-9	-29	-12	0	3	-3	-1

The biological results presented in the current report are presented on a water year type averaged basis and rely on seasonal average flows during January through June. Accordingly, the environmental baseline for these seasonal flows was estimated by calculating the water year type averaged seasonal changes in flow from Table 4-9, and correcting the corresponding seasonal flows in the CalSim 3 baseline scenario. For example, the 2019 BiOps as modeled results in a net reduction in Delta outflow of 123 TAF during January through June of the average Above Normal year. This reduction was added to the modeled January through June Delta outflow of the CalSim 3 baseline scenario to represent the environmental baseline described above. The results of this calculation for the January through June period are shown in Table 4-10.

Table 4-10. CalSim 3 Baseline and Postprocessed Baseline Delta Outflow (TAF) for January through June by Water Year Type

Water Year Type	CalSim 3 Baseline	Postprocessed Baseline
W	23,331	23,593
AN	12,796	12,919
BN	6,085	6,135
D	5,273	5,398
C	3,601	3,673

4.12.2 VA Postprocessing

A postprocessing exercise is also used to account for the Delta outflow effects of water purchases and lower San Joaquin tributary VA flow actions that are not modeled in the CalSim 3 VA scenario. Water purchases are assumed to be provided in the quantities reflected in Table 4-1 by Sacramento water year type. Since San Joaquin VA flows are more likely to be provided according to water year types reflecting the hydrology of that basin, lower San Joaquin tributary VA flows were weighted by San Joaquin water year types and averaged according to Sacramento water year types to estimate the change in Delta outflow by Sacramento water year type. Because San Joaquin VA flow commitments have not been fully committed to by all parties and have not been fully modeled, results are presented with and without San Joaquin VA flows.

In general, VA flow actions are intended to be concentrated during April and May, which are generally the most impaired months with respect to inflow to and outflow from the Delta. For the purposes of this report, both water purchases and lower San Joaquin flows are assumed to be provided in April and May, although they may be deployed differently if VAs are implemented. The results of the postprocessing steps described above for each of the seasons for which flow-abundance relationships are evaluated in Chapters 5 and 6 are presented in Table 4-11.

Table 4-11. Delta Outflow Postprocessing Results (TAF)

Season	Water Year Type	CalSim 3 Baseline	Postprocessed Baseline	VA without lower San Joaquin	VA with lower San Joaquin
Feb–May	W	16,593	16,948	16,742	16,795
Feb–May	AN	9,130	9,355	9,712	9,835
Feb–May	BN	4,567	4,719	5,070	5,176
Feb–May	D	4,005	4,118	4,527	4,632
Feb–May	C	2,605	2,639	2,734	2,788
Jan–Jun	W	23,331	23,593	23,460	23,513
Jan–Jun	AN	12,796	12,919	13,376	13,500
Jan–Jun	BN	6,085	6,135	6,601	6,707
Jan–Jun	D	5,273	5,398	5,823	5,928
Jan–Jun	C	3,601	3,673	3,735	3,788
Mar–Jun	W	12,178	12,598	12,331	12,384
Mar–Jun	AN	7,145	7,420	7,736	7,860

Season	Water Year Type	CalSim 3 Baseline	Postprocessed Baseline	VA without lower San Joaquin	VA with lower San Joaquin
Mar–Jun	BN	3,496	3,710	4,009	4,115
Mar–Jun	D	3,252	3,339	3,804	3,910
Mar–Jun	C	2,113	2,164	2,233	2,286
Mar–May	W	10,773	11,197	10,927	10,981
Mar–May	AN	6,207	6,520	6,801	6,924
Mar–May	BN	3,025	3,283	3,530	3,636
Mar–May	D	2,777	2,875	3,301	3,406
Mar–May	C	1,756	1,806	1,876	1,929

Chapter 5
Analytical Approach to Evaluating Assets

To evaluate the adequacy of the VA package, quantitative modeling was combined with qualitative literature review and analysis. These analyses provide estimates of potential population changes for longfin smelt, Delta smelt, and salmonids. They also provide a qualitative description of trajectories of population benefits and ecosystem improvements that are expected by habitat restoration and additional flows contributing to a more natural flow regime, but for which no quantitative models exist. Because the VAs have some flexibility for when flow and non-flow assets will be provided, the evaluation of benefits for target species has some inherent uncertainty and is subject to assumptions, which are described below in Chapter 7, *Conclusions and Uncertainties*.

The overall analysis is described in Figure 5-1. To describe the changes in habitat in the Delta, Suisun, and San Francisco Bay, operations results from CalSim II were combined with more detailed Delta Simulation Model 2 (DSM2) models of gate operations, historical temperature, historical turbidity, and potential habitat restoration sites. These analyses were completed in 2019, and subsequent to the analysis several changes have been made to flow and non-flow habitat commitments, so observed results may vary from model results. However, minor changes to flow and modeling assumptions should not substantially affect the adequacy of the package, and current habitat restoration commitments are higher than what was modeled.

To describe changes in spawning and instream rearing habitat, operations results were combined with models of usable habitat at each flow level. Area of spawning and rearing habitat were then compared to the amount of habitat required to achieve the salmonid doubling goal. While the target for the 8-year term of the VAs is to provide habitat necessary to support approximately 25% of the offspring of the doubling goal populations for each tributary (Section 1.3), VA habitat benefits are presented relative to a range of percentages of the full doubling goal: 25% (the target), 50%, 75%, and 100%. To describe the changes in off-stream habitat on the tributaries, operations results were combined with habitat restoration to model the number of meaningful floodplain events expected at each level of flow. The operations modeling was also used with established flow-abundance relationships for populations of several native fish species to calculate potential increase in population with increased flow (State Water Board 2017).

Flow-abundance relationships can provide predictions of population changes, and there are models to assess the quantitative benefit of spawning and rearing habitat in the tributaries. However, researchers have not yet developed quantitative relationships between fish populations and many types of habitat restoration, including floodplain habitat and tidal wetland habitat. Many uncertainties remain in how effective increases in both flow and non-flow habitat will be in restoring native fish populations. Therefore, an extensive review of literature is included to describe the conceptual model for why the VA package will provide benefits to native species.

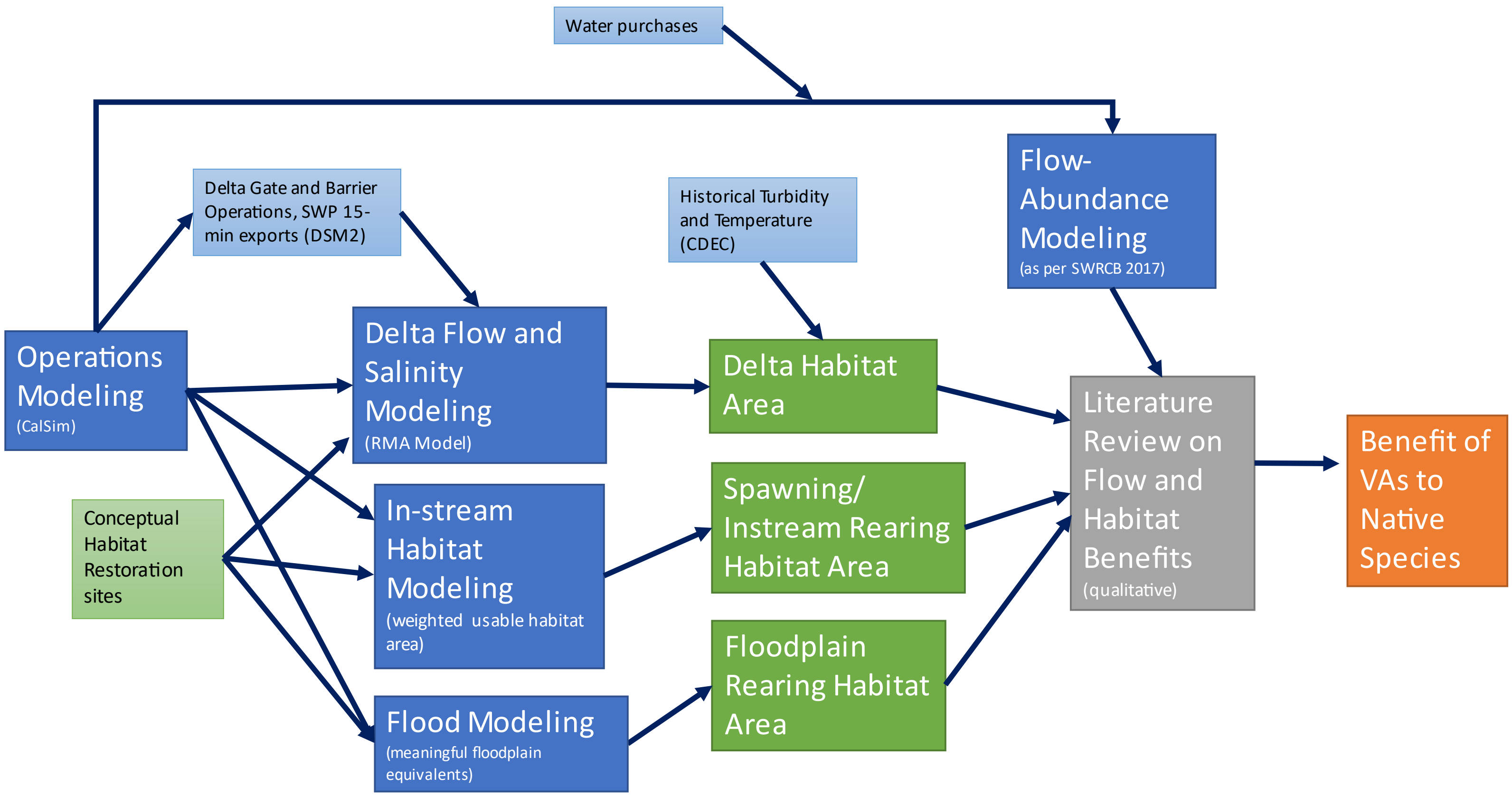

Figure 5-1. Diagram Showing Workflow Used to Evaluate VA Assets
The diagram demonstrates a qualitative and quantitative assessment. The connection between inputs and output is described using arrows (e.g., "historical turbidity and temperature" information and "Delta flow and salinity modeling (the RMA model)" are two inputs into "Delta habitat area").

5.1 Flow: Area Relationships (Tributaries, Off-Stream)

5.1.1 Suitable Habitat Quantification

This section explains the source of and process to acquire data used as inputs to the analysis of non-flow assets conducted to support the VA process. Non-flow assets include constructed spawning, instream rearing, and floodplain rearing habitat for fall-run Chinook salmon (Table 3-1) and were evaluated under different flow scenarios. The analysis compared the VA flow and non-flow assets to baseline conditions.

The fall-run rearing period is defined as February through June, which is consistent with analyses in the 2017 Scientific Basis Report (State Water Board 2017) and represents the time period that could potentially benefit rearing juvenile salmonids by increasing rearing habitat. Modeled average monthly flow outputs from CalSim 3 were used to predict the available spawning and instream rearing habitat as well as the frequency and magnitude of floodplain inundation events during the February through June time period in the Sacramento, Feather, Yuba, Mokelumne, and American Rivers under baseline and VA flow scenarios.

The scenarios were evaluated in terms of providing measurable, biologically important benefits of additional suitable spawning, instream rearing, and floodplain rearing habitat to fall-run Chinook salmon consistent with the suitable habitat quantification for the Central Valley Project Improvement Act (CVPIA). Analyses are focused on habitat for fall-run Chinook salmon, and it is expected that habitat created for fall run will also provide ancillary benefits to other runs and other native fish populations because of similar habitat suitability. For comparing VA assets to existing and potential future conditions, estimates were generated of the habitat needed to support the doubling goal population established in the CVPIA, AFRP. These estimates were calculated using assumptions from the Emigrating Salmonoid Habitat Estimation (ESHE) model as applied in the Central Valley Flood Protection Plan Conservation Strategy.

5.1.2 Calculating Habitat Needed to Support Doubling Goal Population

To evaluate how existing habitat and habitat proposed in the VAs meet the AFRP doubling goal, the amount of habitat needed to support the doubling goal was calculated. The AFRP doubling goal is the doubled (average) natural production during the 1967–1991 time period. *Natural production* is defined as the portion of production that is not produced in hatcheries. The *total production* is the sum of harvest and escapement. The escapement values associated with the doubling goal are used as the targeted spawners abundance (Table 5-1). The escapement values from Table 3-Xa-1 in the Working Paper on Restoration Needs Volume 3 (USFWS 1995) were used to determine the amount of rearing habitat that would be necessary to support doubled populations (Table 5-2).

Table 5-1. Input Parameters Used to Calculate the Rearing and Spawning Habitat Area Needed to Support the Doubling Goal Population

Region	Spawner Sex Ratio	Fecundity	Egg-to-Fry Survival	Territory Requirement (m^2)	Redd Size (m^2)
Sacramento Valley	0.5	5,000	0.38	0.05423379	9.29
Source: Central Valley Flood Protection Board 2016.					

The total amount of required suitable rearing habitat is defined as the maximum habitat need between the February to June period estimated to achieve the doubling goal. This calculation applies the fry rearing territory size requirement to all of the fry produced by the doubled number of adults, before any growth, movement, or juvenile mortality factors are applied. Growth, movement, and juvenile mortality factors are not included because they vary significantly in quality and availability across the VA watersheds. This simplified approach results in a greater total habitat need than using the ESHE model's current conditions survival and growth rate.

The territory requirement is based off Grant and Kramer (1990) territory size and fork length relationship as applied in the Sacramento River ESHE model (Hinkleman et al. 2018). Fork lengths are assumed to be between 37.5 and 42 millimeters following CVPIA habitat analysis. Actual habitat area may be somewhat different than estimated here, since Grant and Kramer (1990) used Atlantic salmon in small streams or artificial habitat as a source for much of their data, and habitat quality was another important factor in determining habitat size, but was not considered here. Therefore, these analyses may not be generalizable to Chinook salmon rearing in major river systems (Williams 2006). It is also assumed that all habitat developed in the VA actions will be high quality, but actual quality is likely to vary.

The spawning habitat need (acres, H_s) is calculated as the product of the spawner sex ratio (0.5) and redd size (9.29 m^2) equaling 4.65 m^2 and the doubled escapement (E), divided by 4,047 (to convert m^2 to acres).

$$H_s = \frac{0.5 * 9.29 * E}{4047} \tag{1}$$

The number of juveniles (J) is calculated as the product of the spawner sex ratio (0.5), fecundity (5,000), egg-to-fry survival (0.38), and target escapement (E).

$$J = 0.5 * 5{,}000 * 0.38 * E \tag{2}$$

The suitable rearing habit need (acres) is calculated as the product of the number of juveniles (J) and the territory requirement (0.05423379 m^2) divided by 4,047 (to convert m^2 to acres).

$$H_r = \frac{0.054233790.05J}{4047} \tag{3}$$

Table 5-2. Summary of the Doubled Escapement, Number of Juveniles, Rearing and Spawning Habitat Needed to Support the Doubled Escapement

Watershed	Doubled Escapement	Juveniles Produced	Rearing Area (acres)	Spawning Area (acres)
Sacramento River	154,000	146,300,000	1,961	177
Feather River	98,000	93,100,000	1,248	112
Yuba River	26,000	24,700,000	331	30
American River	82,000	77,900,000	1,044	94
Mokelumne River	6,600	6,270,000	84	8

5.2 Spawning and Instream Rearing Habitat Evaluation

5.2.1 Existing Habitat Quantification

Existing spawning and instream rearing habitat inputs (i.e., habitat used in the baseline scenario) are sourced from a repository of flow to suitable area relationships (Gill and Tompkins n.d.[a]). In 2017, FlowWest met with Mark Gard (CDFW) to catalog and document the available habitat models as well as acquire the data from the various studies. FlowWest processed the data into a consistent format and published the habitat repository as an R package on GitHub (Gill and Tompkins n.d.[b]). On behalf of the CVPIA Science Integration Team, FlowWest hosted several expert elicitation workshops (CVPIA Science Integration Team n.d.). In attendance were representatives from USFWS, CDFW, Reclamation, DWR, non-governmental organizations, and other stakeholders with expertise on watersheds within the Central Valley. During these meetings, the flow to habitat relationships were presented and experts evaluated the modeling veracity compared to their on-the-ground observations. FlowWest used this feedback to refine some of the estimates and included additional datasets made available through the workshops. Additionally, workshop participants provided the habitat extents for spawning and rearing within the Central Valley. The technical lead(s) for each watershed then confirmed the source of existing non-flow habitat information was the best available.

The studies referenced by Gard report suitable habitat as weighted usable area in square feet per 1,000 feet of channel length as a function of flow in cubic feet per second. For the analysis, the weighted usable area was calculated for each of the modeled hydrology scenarios time series and then converted to suitable areas by multiplying the suitable habitat rate by the total spawning or rearing extent length. This calculation results in a time series of suitable habitat areas as a function of modeled hydrology.

5.2.2 VA Habitat Quantification

VA habitat was not quantified using the same methodology as existing habitat. The Assets to Outcomes workgroup participants then to identified a watershed representative for each VA watershed. These watershed representatives were given the criteria to define non-flow assets (e.g., constructed habitat) for VA analysis. The watershed representative then identified the appropriate technical lead(s) to provide the best available scientific information on VA pledged non-flow assets satisfying these criteria to describe VA non-flow habitat. Suitable habitat for the evaluation of VA proposed habitat was defined as physical habitat within specified depth and velocity ranges (Table

5-3) identified by the Conservation Planning Foundation for Restoring Chinook Salmon and *O. mykiss* in the Stanislaus River (Anchor QEA, LLC 2019), which served as the reference for the VA Biological and Environmental Target Working Group on Proposed Implementation Criteria (2019). While water quality parameters such as dissolved oxygen and water temperature are key attributes of suitable habitat, they were not included in the suitability criteria for VA habitat. However, they were also not included in the assessment of baseline habitat, allowing for a direct comparison of baseline vs VA habitat.

Table 5-3. Description of Hydraulic Suitability Criteria Used to Define VA Suitable Spawning and Rearing Habitat

Habitat Type	Depth Suitability Range (ft)	Velocity Suitability Range (fps)
Spawning	1.0–2.5	1.0–4.0
Instream and Floodplain Rearing	0.5–4.0	0.0–3.0

Instream rearing and floodplain habitat are defined by the same depth and velocity criteria, though VA floodplain habitat analysis also considers inundation duration and frequency. VA suitability criteria are based on the Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* in the Stanislaus River (Anchor QEA, LLC 2019).

Whenever possible, VA habitat was described as a function of flow for each tributary (Table 5-4, Table 5-5, and Table 5-6 in Section 5.2.3, *Spawning and Instream Rearing Habitat Evaluation and* Section 5.3.1, *Floodplain Rearing Data Sources*). The VA habitat data source provided areas of suitable VA habitat at different flow levels, including at least a minimum, maximum, and target or other intermediate flows over which habitat area was assumed to change. A linear interpolation was then applied across those flows to create a function over the range of flows within the CalSim modeled data for that watershed/scenario. This function was then used to estimate the additional VA habitat area for the flows provided by CalSim, for each year in the CalSim outputs. Once the assets were in units of suitable habitat area, the proposed VA non-flow habitat area in acres was added to the existing suitable habitat area for each watershed evaluated in the VA flow scenario. Data sources for VA habitat were developed in 2019 and are assumed to be the best available information. In 2022, VA habitat data sources were modified to reflect the revised 8-year VA term.

5.2.3 Spawning and Instream Rearing Habitat Evaluation

Spawning and instream rearing habitat timeseries were modeled using CalSim 3 for each year of the 94-year modeling period between 1921 and 2015. Model outputs of suitable habitat area under each scenario were compared by filtering the data set to months when spawning (October–December) or rearing (February–June) was likely to occur, then calculating the median suitable habitat area for each year and then the median across the entire time series. Median suitable habitat area was used to account for skewed distributions of habitat across the modeling period.

Percent change was used as a metric to compare median suitable habitat area across the baseline and VA scenarios for each spawning and rearing season within a water year. Water year is defined as the 12-month period beginning October 1, for any given year, through September 30 of the following year. Increases in median suitable habitat were evaluated based on the associated expected biological outcomes.

Spawning habitat was evaluated for the Sacramento, Feather, and American Rivers. The Putah Creek VA includes 1 acre of spawning habitat, but it was not included in the analysis because currently no existing suitable habitat data is available for comparison. Instream rearing habitat was evaluated for the Sacramento, Feather, Yuba, American, and Mokelumne Rivers. Rearing habitat was evaluated for instream habitat alone, and for the combination of instream and floodplain habitat.

5.2.3.1 Spawning Data Sources

Table 5-4. Sources for Spawning Habitat Versus Flow Relationships and Modified Spawning Habitat Availability as Proposed in the VA

River	Existing Habitat Source	VA Habitat Source
Sacramento	USFWS 2003 (pg. 29–31)[1,2]	John Hannon, U.S. Bureau of Reclamation Assumptions: • VA habitat is all suitable habitat. • A flow-to-area relationship was not provided, and all 113.5 acres of VA habitat were added to existing habitat consistently across all flows. Added to existing habitat at the Red Bluff to Deer Creek reach.
Feather	Phase 2 Report Evaluation Of Project Effects on Instream Flows and Fish Habitat SP-F16, DWR 2004 (pg. 35–36)[3,4]	Jason Kindopp, DWR Assumptions: • DWR provided the number of acres at minimum (70% of proposed acres suitable at 650 cfs), maximum (80% of proposed acres suitable at 1,100 cfs), and target (90% of proposed acres suitable at 850 cfs) flow. Added to existing habitat on the Low Flow Channel.
Yuba	Paul Bratovich, Steve Grinnel, HDR, Inc.	*No spawning habitat committed.*
American	Lower American River Biological Rationale, Development and Performance of the Modified Flow Management Standard 2017 (pg. 91–107)[5,6]	Tom Gohring, CBEC Eco Engineering Assumptions: • VA habitat is all suitable habitat. • A flow-to-area relationship was not provided, and all 25 acres of VA habitat were added to existing habitat consistently across all flows. Added to existing spawning habitat.
Mokelumne	EBMUD	*No spawning habitat committed.*

For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.
[1,2] USFWS 2003; Gill and Thompkins 2020a.
[3,4] DWR 2004; Gill and Thompkins 2020b.
[5,6] Bratovich et al. 2017; Gill and Thompkins 2020c.

5.2.3.2 Instream Rearing Data Sources

Table 5-5. Sources for Instream Rearing Habitat Versus Flow Relationships and Modified Instream Rearing Habitat Availability as Proposed in the VA

River	Existing Habitat Source	VA Habitat Source
Sacramento	Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model[1,2]	John Hannon, U.S. Bureau of Reclamation Assumptions: • Reclamation provided the number of acres of new side-channel habitat and how many of those acres were suitable at three flow levels (60% of proposed acres suitable below 8,000 cfs; 100% of proposed acres suitable at 8,000 cfs; 80% of proposed acres suitable above 8,000 cfs). • Reclamation provided the number of acres of new instream habitat and how many of those acres were suitable at two flow levels (0% of proposed acres suitable below 15,000 cfs; 25% of proposed acres suitable above 15,000 cfs). Added to existing instream habitat.
Feather	Addendum to Phase 2 Report Evaluation of Project Effects on Instream Flows and Fish Habitat SP-F16, DWR 2005 (pg. 2-7 and 2-9)[3,4]	Jason Kindopp, DWR Assumptions: • DWR provided the number of acres at minimum (80% of proposed acres suitable at 650 cfs), maximum (50% of proposed acres suitable at 3,000 cfs) and target (90% of proposed acres suitable at 725 cfs) flow. Added to existing habitat on the Low Flow Channel.
Yuba	Paul Bratovich, HDR – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team	Paul Bratovich, HDR, Inc. – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team Assumptions: • HDR provided the number of acres for flows at several points between 0 and 5,000 cfs for each reach for both existing and VA habitat.
American	Chris Hammersmark, CBEC Eco Engineering	Chris Hammersmark, CBEC Eco Engineering Assumptions: • CBEC provided the number of acres for flows at several points between 500 and 20,000 cfs with a target flow of 7,500 cfs and 100% suitability. Added to existing instream habitat.
Mokelumne	EBMUD	Robyn Bilski, EBMUD Assumptions: • EBMUD provided the number of acres for flows at several points between 100 and 1,000 cfs. Added to existing instream habitat.

For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.
[1,2] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020a.
[3,4] DWR 2005; Gill and Thompkins 2020b.

5.3 Floodplain Habitat Evaluation

To represent existing floodplain habitat relationships with flow, the best available flow to suitable area relationships generated from the results of floodplain hydraulic modeling studies were acquired. To analyze proposed VA actions of constructed habitat assets, water districts, CDFW, DWR, and Reclamation provided clarified modeling assumptions. If the habitat is seasonally inundated, the districts were asked to provide the flow at which the area is inundated and the percent of high suitability area inundated that they will design to. Data sources for VA habitat were developed in 2019 and are assumed to be the best available information. In 2022 VA habitat data sources were modified to reflect the revised 8-year VA term.

5.3.1 Floodplain Rearing Data Sources

Table 5-6. Sources for Floodplain Habitat Versus Flow Relationships and Modified Floodplain Habitat Availability as Proposed in the VA.

River	Existing Habitat Source	VA Habitat Source
Sacramento	Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run Chinook Salmon life cycle model[1,2]	*No floodplain habitat committed.*
Sutter Bypass	Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model refined for use in the NOAA-NMFS Winter Run[3,4]	Lee Bergfeld, MBK Engineers Assumptions: • Number of acres for flows at several points between 0 to 10,000 cfs with a target flow of 5,000 cfs. Habitat is accessible to fish and is all suitable habitat when inundated.
Colusa Basin	Joe Thomas (consultant to RD108)	Lee Bergfeld, MBK Engineers
Feather	Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model[5,6]	Jason Kindopp, California DWR Assumptions: • DWR provided number acres by flow for several areas of flow with varying acreage of habitat based on flow (550 acres of proposed acres will be inundated at 3,000 cfs; 850 acres of proposed acres will be inundated at 4,000 cfs; 1,655 acres of proposed acres will be inundated at 30,000 cfs). Unsuitable habitat was removed from the MFE calculations. Added to existing habitat, and all habitat is suitable when inundated.

River	Existing Habitat Source	VA Habitat Source
Yuba	Paul Bratovich, HDR – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team	Paul Bratovich, HDR, Inc. – Lower Yuba River Management Team; Steve Grinnel, HDR – Lower Yuba River Management Team Assumptions: • A flow to area relationship for VA floodplain habitat was not provided, and all 100 acres of VA habitat was added to existing habitat beginning at 2,000 cfs (assumes inundation at 2,000 cfs). • The Yuba habitat analysis was done by reach because of differing flows and habitat in each reach. The proponent did not provide the amount of VA floodplain habitat by reach, so it was assumed that the VA habitat would be divided proportional to the amount of existing floodplain habitat at each reach. All habitat was assumed suitable when inundated.
American	Chris Hammersmark, CBEC Eco Engineering	*No floodplain habitat committed.*
Mokelumne	EBMUD	Robyn Bilski, EBMUD • EBMUD provided number of acres for flows at several points between 400 and 1,700 cfs, with the greatest habitat available between 1,300 and 1,700 cfs. • Inundation beginning at 800 cfs. Added to existing habitat. All new habitat was assumed suitable when inundated.

[1,2] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020a.
[3,4] Queda Consulting, LLC et al. 2017; Gill and Thompkins 2020d.
[5,6] Wood Rogers 2014; Gill and Thompkins 2020b.
For each VA habitat source, the identified contact provided the number of acres of new VA habitat at select flow levels. VA habitat acreage was then linearly interpolated across these flow values to create a relationship between flow and habitat across the entire flow range.

5.3.2 Floodplain Evaluation Criteria

Typically, monthly floodplain habitat under baseline conditions across watersheds is 0 acres, which makes providing a percent change in habitat (as was done for the other habitat types) nonsensical. One option is to provide an acre-day analysis comparing the frequency during the 94-year modeling period (1921–2015) that floodplain flows are achieved across scenarios where significant benefits are defined as a 10% change in frequency and are validated through professional judgment (2017 Scientific Basis Report). While this analysis provides a high-level assessment of floodplain habitat availability, it does not acknowledge differences in the quality of floodplain habitat in terms of critical dimensions of duration, magnitude, and frequency.

Alternatively, a multidimensional metric is provided to communicate floodplain habitat under the baseline and VA scenarios. Floodplain habitat is analyzed using the Meaningful Floodplain Event (MFE) approach. The MFE was developed to evaluate the VA based on literature recommending longer inundation periods and repeated pulses throughout the year and inter-annually (Grosholz and Gallo 2006; Opperman 2012; Takata et al. 2017). The MFE accounts for four dimensions of floodplain habitat.

In addition to the hydraulic criteria described above (e.g., Table 5-3), also important to providing suitable habitat are hydrologic criteria, including the frequency of floodplain flows and their duration and magnitude. Longer periods of floodplain inundation contribute to increased juvenile Chinook salmon growth in the Central Valley (Takata et al. 2017) driven by enhanced organic matter and nutrient recycling leading to high prey densities (Sommer et al. 2001; Sommer et al. 2004; Grosholz and Gallo 2006). Repeated flood pulses of sufficient duration have also been found to support native fishes (Grosholz and Gallo 2006).

Instead, the MFE analysis developed for this report evaluates floodplain flows in terms of magnitude, inter-annual frequency, intra-annual frequency, and duration.

- **Magnitude** is the area inundated by a floodplain event based on hydrology.
- **Inter-annual frequency** is the long-term average in which cohorts are exposed to floodplains. The targeted inter-annual frequency is a desired inundated area occurring 2 out of every 3 years. Inter-annual frequency is important to account for natural variation in population size, as salmon cohorts may vary between years.
- **Intra-annual frequency** is the number of distinct floodplain events in a given rearing season. The targeted intra-annual frequency is a desired inundated area occurring in at least two months during the rearing season. Intra-annual frequency ensures that habitat is available throughout the rearing season to support life history diversity.
- **Duration** is the number of days the area is inundated during a floodplain event. Based on the literature, at least 7 days are needed and after 21 days there is minimal additional gain. For the purposes of modeling MFEs, it is assumed that an event will last at least 30 days because CalSim provides a monthly timestep and this is a more conservative metric for floodplain benefit.

The MFE is calculated for four given areas (i.e., magnitudes): the area needed to support 25% (the target for the Vas), 50%, 75%, and 100% of the doubling goal population (see Section 5.1.1, *Suitable Habitat Quantification*). The proportion of MFE occurrence throughout the model period is compared for baseline and VA scenarios. A 10% difference or greater between the baseline and VA is determined to be substantial. The parameters chosen for MFE are somewhat conservative, so actual benefits may be greater than model results suggest.

While the MFE addresses the multidimensionality of floodplain events while still retaining interpretability, the calculation does involve multiple steps summarized below:

1. Define floodplain magnitude criteria:
   - e.g., 50% of the habitat needed (acres) to support the doubling goal juvenile population.
2. Determine if the intra-annual floodplain frequency is met.
   - Is the floodplain magnitude met during at least 2 of the 5 months of the rearing period (February–June)?
3. Determine if the inter-annual floodplain frequency is met.
   - Is the floodplain magnitude met during at least 2 of the 5 months of the rearing period and at least 2 out of every 3 years?

4. Determine the proportion of MFE event occurrence.
   - What proportion of years were the MFE criteria met during the modeled hydrology period? This is calculated using a center-aligned, rolling 3-year window, meaning that there will be a window for each year except the first (1922) and last (2015) year.

The MFE analysis was used to assess flooding on the Feather, Mokelumne, and Yuba Rivers and assumes all VA floodplain habitat is suitable habitat when inundated.

Variability in the MFE analysis was evaluated by comparing the proportion of MFE occurrence using the metrics described above, with upper and lower bounds using more relaxed and restrictive metrics, respectively. The lower bounds were defined as the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of every 5 years, and the upper bounds were defined as the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of every 2 years.

Among the three flood basins (Sutter Bypass, Butte Sink, and Colusa Basin), the Sutter Bypass will have more frequent inundation due to the changes to Tisdale Weir. Infrastructure changes to increase fish access, inundation frequency, and duration are being explored in these flood basins. The change in spill over the Tisdale Weir (achieved by a Tisdale Weir Notch) was analyzed in addition to using the MFE analysis, and a similar approach will be used to evaluate actions in Butte Sink and the Colusa Basin.

Because specific projects have not yet been identified in these flood basins, a simplifying assumption was made that topographic changes to the Sutter Bypass would create suitable depth and velocity conditions in all 20,000 acres for juvenile salmon rearing at flows similar to existing habitat. The Sutter Bypass MFE analysis assumes up to 20,000 acres of additional suitable habitat will be generated within the Sutter Bypass between 0 and 10,000 cfs, where the maximum habitat area occurs at 5,000 cfs. This assumption is based on the existing suitable rearing habitat. Figure 5-2 shows the existing suitable rearing habitat by reach and flow within the Sutter Bypass and cumulatively across reaches, with a peak of 11,348 acres at a flow of 5,000 cfs in the bypass. This scenario (VA—proposed topography) was compared to existing habitat under baseline conditions as well as existing habitat under VA conditions, which captures flow modifications to the weir (VA—Tisdale Weir). Expected benefits from projects occurring outside the specific footprint of the Sutter Bypass would be similar.

The additional floodplain habitat provided under the VAs in these flood basins could provide rearing habitat to juvenile fish from the Sacramento River and its tributaries upstream, and, based on the assumptions described above, it would exceed the rearing habitat doubling goal for the Sacramento River (1,961 acres). This analysis assumes this habitat is physically accessible by juvenile fish; however, current access to these flood basins is limited. Enhancing connectivity between these flood basins and the Sacramento and Feather Rivers to improve juvenile salmon access to rearing habitat and/or improve adult fish passage is currently being explored. Such modifications will require project-specific analyses not included in this report.

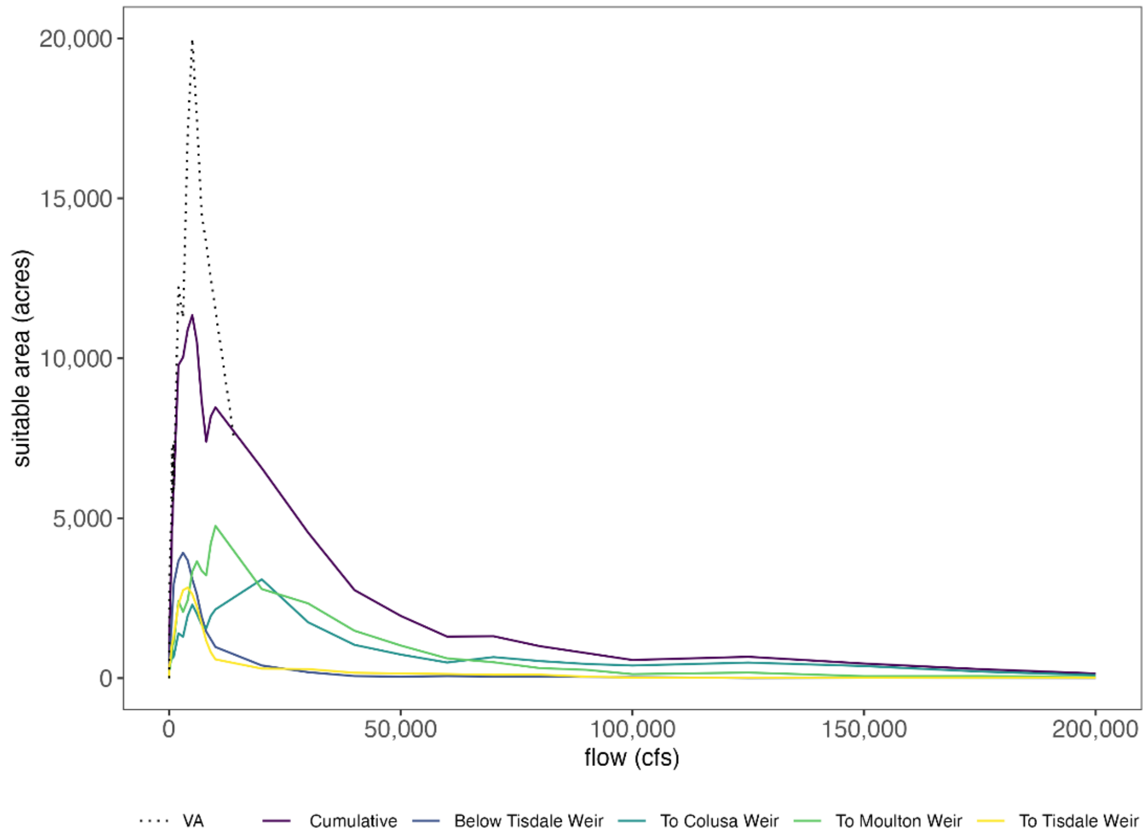

Figure 5-2. Flow (cfs) to Suitable Area (Acres) Curves for Four Sections of the Sutter Bypass, Including to Moulton Weir (Green), to Colusa Weir (Light Blue), to Tisdale Weir (Yellow), below Tisdale Weir (Blue), Cumulatively across All Sections (Purple), and Additional VA Habitat (Black, Dotted).

5.4 Flow-Abundance Relationships

Flow-abundance models were fit with the same data and structure as in the 2017 Scientific Basis Report (State Water Board 2017). Briefly, abundance indices of estuarine species (California Bay shrimp, longfin smelt, Sacramento splittail, and starry flounder) were obtained from the CDFW Fall Midwater Trawl (CDFW 2016b) and San Francisco Bay Study otter trawl (Hieb 2017) surveys. Delta outflow data were obtained from Dayflow (DWR 2017). Analyses were conducted with the R statistical programming language (R Core Team 2022). Each abundance index was then modeled as a function of year, using a linear regression with log-transformations (or log(x+1) for the abundance index if it included 0) applied to both the abundance index and outflow. For species that experienced a substantial decline immediately following the introduction of *Potamocorbula amurensis* (1987) or the Pelagic Organism Decline (2002), step changes were introduced for each applicable event. The *P. amurensis* step change was included for starry flounder, and both step changes were included for longfin smelt.

To estimate the effect of outflow changes from the VAs on species abundance while quantifying uncertainty in those predictions, bootstrapping was applied with the R package *car* (Fox and

Weisberg 2019). For each model, 1,000 bootstrapped samples were created of the model parameters. From each sample, the predicted species abundances were calculated with the baseline and VA outflow values (see Section 4.12, *Postprocessing of Delta Outflow*), and then the percent change from baseline to VAs was calculated from those values. The 1,000 bootstrapped samples of percent change were then aggregated to the 2.5%, 50% (median), and 97.5% quantiles to quantify the uncertainty and central tendency of the predictions.

Model results (and their uncertainty) only represent the expected impact of VA annual outflow changes on species abundance. They do not account for any other factors that may also change with the VAs. They further assume a linear, causal relationship between log outflow and log abundance at the annual timestep for each species (with corrections for step changes for a few species). Consistent with this, uncertainty estimates represent uncertainty in the expected outcomes from changes in annual outflow resulting from the VAs, where annual outflow is the only difference between the VA and baseline scenarios.

5.5 Two-Dimensional Hydrodynamic Analysis (Delta and Estuary)

5.5.1 RMA Bay-Delta Model

The Resource Management Associates (RMA) Bay-Delta model was used to simulate flow and salinity. This information was combined with representative temperature and turbidity fields to estimate habitat changes associated with VA alternatives. This section presents an overview of the RMA Bay-Delta Model, description of the geometric and boundary conditions used for the analysis, and the habitat analysis approach.

The model evaluation was conducted using the RMA Bay-Delta model for flow and salinity. The model extends from Golden Gate up the Sacramento River above the confluence with the American River, and up the San Joaquin River near Vernalis. A two-dimensional depth-averaged approximation is used to represent the San Francisco Bay, Suisun Bay region, portions of Suisun Marsh, the Sacramento-San Joaquin confluence area, Sherman Lake, the Sacramento River up to Rio Vista, Cache Slough, Liberty Island, Shag Slough, portions of Lindsey Slough, the Sacramento River Deep Water Ship Channel and Miner Slough, Big Break, the San Joaquin River up to its confluence with Middle River, False River, Frank's Tract and surrounding channels, Mildred Island, Old River south of Frank's Tract, the Delta Cross Channel area, and all tidal marsh restoration sites. The other Delta and Suisun Marsh channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation. The model has undergone continual development through dozens of projects since 1997 (e.g., RMA 2012; RMA 2015a, 2015b).

All major Delta and Suisun Marsh control structures are represented in the model (e.g., cross-channel, Suisun Marsh Salinity Control Gates), and the Delta Island Consumptive Use is based upon DWR's DSM2.

The model uses the finite element method to simulate two-dimensional depth-averaged/one-dimensional cross-sectionally averaged flow and salinity for a 7.5-minute computational time step. The RMA Bay-Delta model is capable of producing a wide variety of model outputs, including flow, velocity, depth, electrical conductivity (EC; a measure of salinity), residence time, and particle tracking. For the current study, the model application has focused upon velocity, depth, and EC.

5.5.2 Bathymetry

The RMA Bay-Delta model grid and bathymetry has been continually updated over the years as new and better bathymetry data become available. For all areas of the model grid, the most current, best quality bathymetric data were used to set grid elevations (Figure 5-3), as follows.

- Most recently, elevations were set using data collected in the Cache Slough Complex during 2015, 2017, and 2018 by the U.S. Geological Survey (Fregoso et al. 2020).
- In Cache Slough and Sutter Slough, elevations were set using data collected by Environmental Data Solutions (2012).
- Coarsely spaced single beam transects were available from the CVFED program for upper Cache Slough, Hass Slough, and Lindsey Slough. Additionally, the CVFED multibeam data were used to update the bathymetry of the Sacramento River above the Georgiana Slough confluence, above the American River confluence to the crossing of Interstate 5. Data are available on the DWR Delta Bathymetry website (DWR 2022a).
- For the San Francisco Bay and Suisun Bay, DWR's 2012 10m San Francisco Bay and Sacramento-San Joaquin Delta DEM version 3 was used (DWR 2012).
- The model grid includes elevations based on the multibeam bathymetry surveys performed by DWR for selected Delta channels and posted on the DWR Delta Bathymetry website (DWR 2018).
- For all areas not covered by more recent data sets listed above, bottom elevations and the extent of mudflats were based on bathymetry data collected by the National Oceanic and Atmospheric Administration, DWR, U.S. Army Corps of Engineers, and U.S. Geological Survey. These datasets have been compiled by DWR and can be downloaded from DWR's Cross Section Development Program websites (DWR 2022b).
- Topography data from DWR's Delta LiDAR survey was used (DWR 2022c).

Different versions of the model grid were developed to represent different tidal marsh restoration scenarios, which are discussed in the following sections of this report. Geometry of future tidal marsh restoration sites was based on the most recent available designs at the time of grid generation.

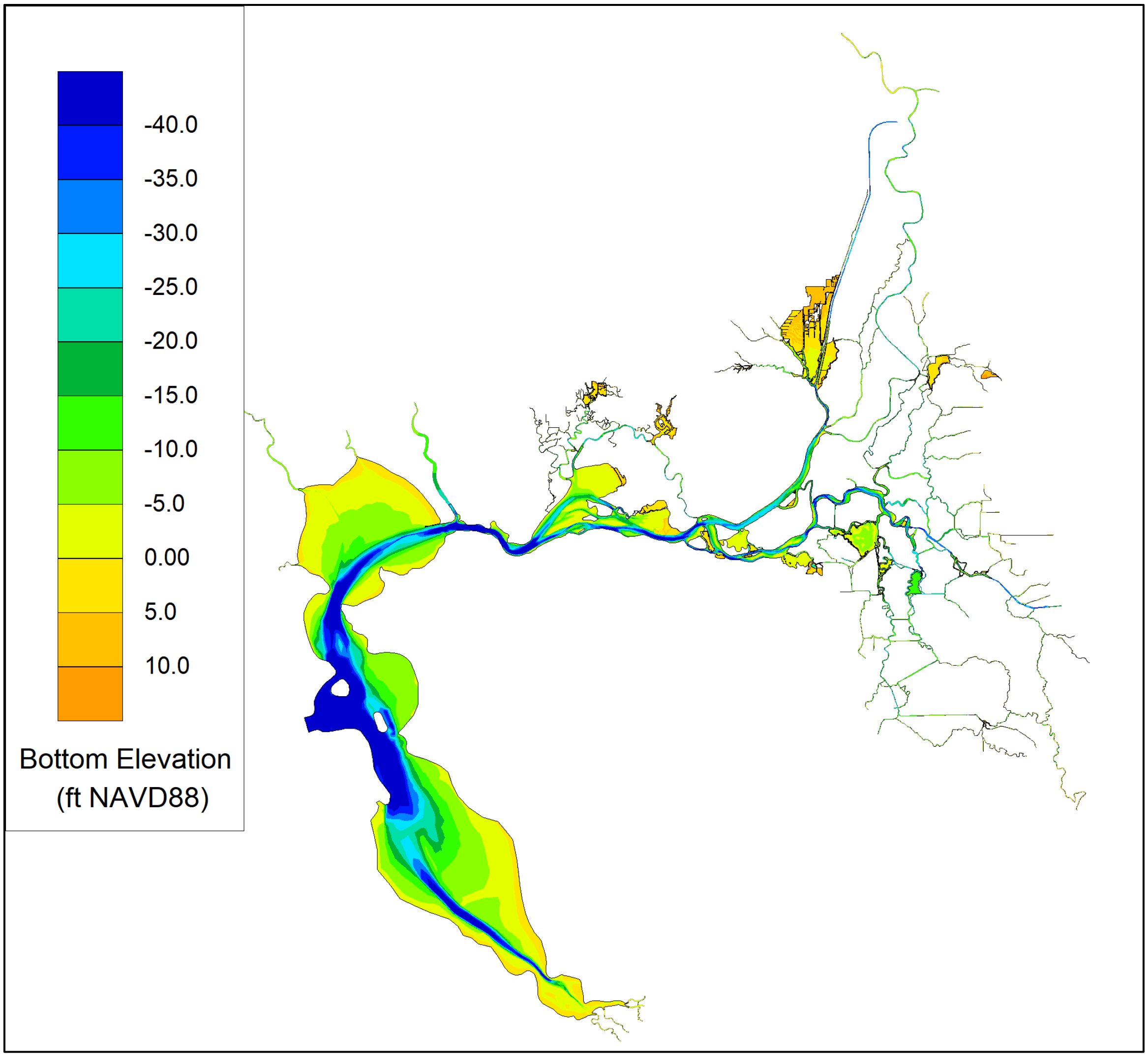

Figure 5-3. RMA Bay-Delta Model Bathymetry
A bathymetric map of the Bay-Delta symbolized using bottom elevation (NAVD88, feet) with a scale ranging from about 10 to about -40.

5.5.3 Model Application to Voluntary Agreement Habitat Analysis

The modeling approach, illustrated in a flow chart in Figure 5-4, included operations modeling (CalSim II) to generate flow boundary conditions, DSM2 modeling to generate Clifton Court intake flows and Delta gate and barrier operations, and Delta flow and salinity modeling with the RMA Bay-Delta model, using boundary condition data from the operations models and DSM2.

These analyses were run in 2019, prior to finalization of the VA Term Sheet and prior to the update from CalSim II to CalSim 3. CalSim 3 was used in the rest of the modeling presented above, but CalSim II remains a viable alternative. Typically, it is best to use these models in a comparison mode, where compatible scenarios using the same CalSim version are compared to evaluate changes due to an alternative condition like VA flow effect on outflow. Even though these are different models, the incremental change in those differences between compatible scenarios created with the same CalSim model would be small.

All models were run for the period of 1975–1991, with 1975 serving as a spin-up period only and was not included in the analyses. This period was chosen because it is the DSM2 planning period and includes a variety of conditions, including an extreme drought (1976–1977) and an extreme wet year (1983). This period will provide an estimate of potential habitat conditions. However, this estimate may not characterize the increased frequency of extreme events seen in more recent years as climate change has altered hydrology in California.

The operations model simulations were run by DWR, and output was provided to RMA. DSM2 and the RMA Bay-Delta model simulations were run by RMA. While the 17-year period ran relatively quickly in the one-dimensional DSM2, the multidimensional RMA Bay-Delta model simulations required several central processing unit (CPU) days per year of simulated time. To complete the large modeling task in a reasonable amount of time, year-long hydrodynamic simulations were run in parallel on the Amazon Cloud, while the less computationally demanding water quality simulations were run locally on RMA compute servers.

The RMA Bay-Delta model results, combined with observed data, were processed to calculate acres of suitable habitat in the Bay, Suisun, and Delta for Delta smelt, longfin smelt, and salmonid rearing. Suitable habitat differs by species and is defined by combinations of one or more of the following parameters: salinity, temperature, turbidity, depth, and velocity. This approach is similar to the habitat modeling approach undertaken in the tributaries that used the FlowWest model, with the addition of water quality parameters. This modeling approach does NOT evaluate survival, abundance, or production (similar to the FlowWest model). Specific details on the habitat area calculations and metrics are provided below. The habitat model results are presented as seasonal time series.

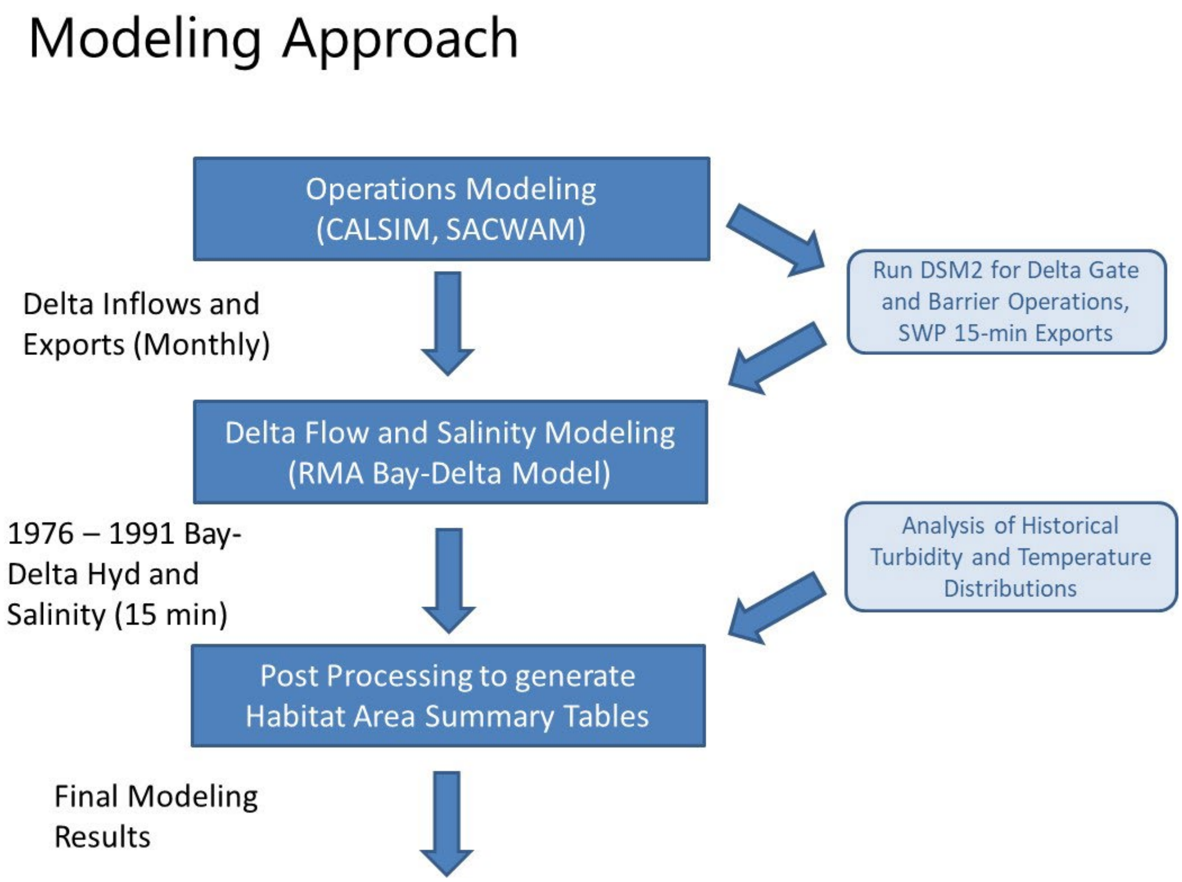

Figure 5-4. Modeling Approach Flow Chart
A flow chart of boxes and arrows shows the modeling approach.

5.5.3.1 Model Configurations

Three different model geometry configurations, shown in Figure 5-5, were used to represent different habitat restoration timelines.

The "baseline" geometry included 2,433 acres of newly constructed marsh habitat restoration at Tule Red, Flyway Farms, Decker Island, Dutch Slough, and Lindsey Slough, along with 11,097 acres of habitat restoration sites under active construction or planning: Prospect Island, McCormack-Williamson Tract, Lookout Slough, Lower Yolo Ranch, Bradmoor Island, Arnold Slough, Wings Landing, Chipps Island, Grizzly Slough, Winter Island, and Hill Slough.

The "VA" geometry included, in addition to baseline restoration, 4,074 acres of proposed tidal habitat restoration with Little Egbert Tract, Grizzly King, and Potrero Marsh. These particular sites have not been committed to restoration under the VAs, but they are proposed sites and are used here for illustrative purposes only. Other sites may result in slightly different changes to appropriate habitat area (e.g., salinity, turbidity), but not enough to impact overall effectiveness of the VA package. Due to the significant influence of the tides in the Delta, restoration site geometry (e.g., location, topography/bathymetry) is a key factor in informing the RMA model configuration. Therefore, model geometries were used that had been previously generated under other efforts for several existing tidal restoration sites located within the North Delta Arc.

Habitat areas do not include the Yolo Bypass (except for areas of the Bypass that are tidally influenced). Changes in flow may result in changes to frequency and amount of inundation in the Yolo Bypass, but they were not modeled as part of this analysis.

An additional 1,153.5 acres of tidal wetlands and associated floodplain habitat have been added to the VA package since the completion of this modeling work. This, and any additional tidal wetland habitat, will result in larger increases to available habitat than presented here.

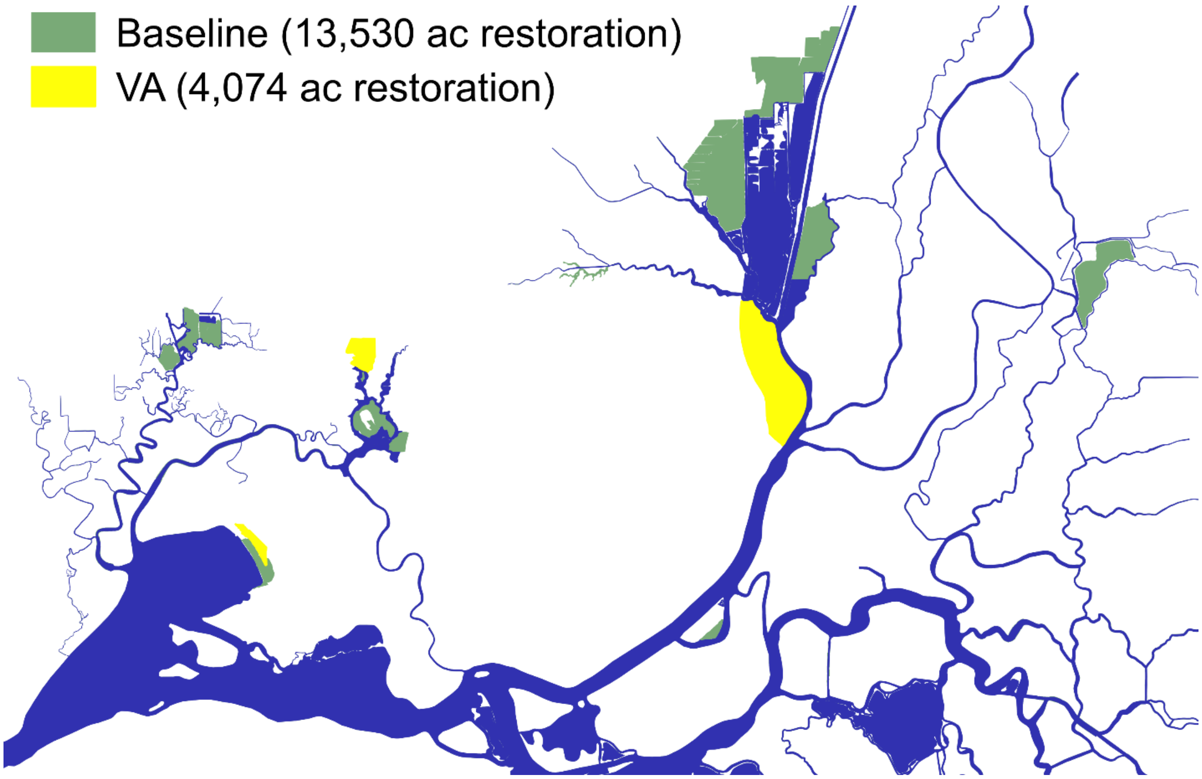

Figure 5-5. Model Habitat Restoration Configurations
A figure shows the RMA model area symbolized by yellow (VAs—with 4,074 acres of planned restoration) and green (baseline—with 13,530 acres of planned restoration)

5.5.3.2 Analysis Scenarios

Analysis scenarios were a combination of model habitat restoration configuration and model boundary conditions to represent possible future conditions. CalSim II was used to develop the flow boundary conditions. The matrix of possible habitat restoration configurations and future flow scenarios was large, and it was impractical to simulate all combinations with the RMA Bay-Delta model. The following scenarios were selected for final analysis.

- Baseline habitat and CalSim baseline flows
- VA habitat and CalSim VA flows

5.5.4 Model Boundary Conditions

Figure 5-6 shows the location of the model boundary conditions. Each model inflow boundary condition requires a corresponding EC value be specified. The model boundary conditions are:

- Tidal Boundary at Golden Gate (National Oceanic and Atmospheric Administration Predicted Tide)
- Inflows (CalSim II)
  - Sacramento River
  - San Joaquin River near Vernalis
  - Yolo Bypass
  - Mokelumne River
  - Cosumnes River
  - Calaveras River
- Exports/Diversions
  - SWP, Clifton Court Forebay gates (DSM2). While daily SWP exports are available from the operations models, the 15-minute output from DSM2 is required to run the RMA Bay-Delta model.
  - CVP Tracy Pumping Plant (CalSim II)
  - Contra Costa Water District intakes at Rock Slough, Old River, and Victoria Canal (CalSim II)
  - North Bay Aqueduct, Barker Slough Pumping Plant (CalSim II)
  - DICU, throughout Delta (DSM2)
- Major Control Structures (DSM2)
  - Delta Cross Channel gates
  - Suisun Marsh Salinity Control Gate
  - South Delta Temporary Barriers
  - Old River near Tracy (DMC) temporary barrier
  - Head of Old River barrier
  - Middle River temporary barrier
  - Grant Line Canal temporary barrier

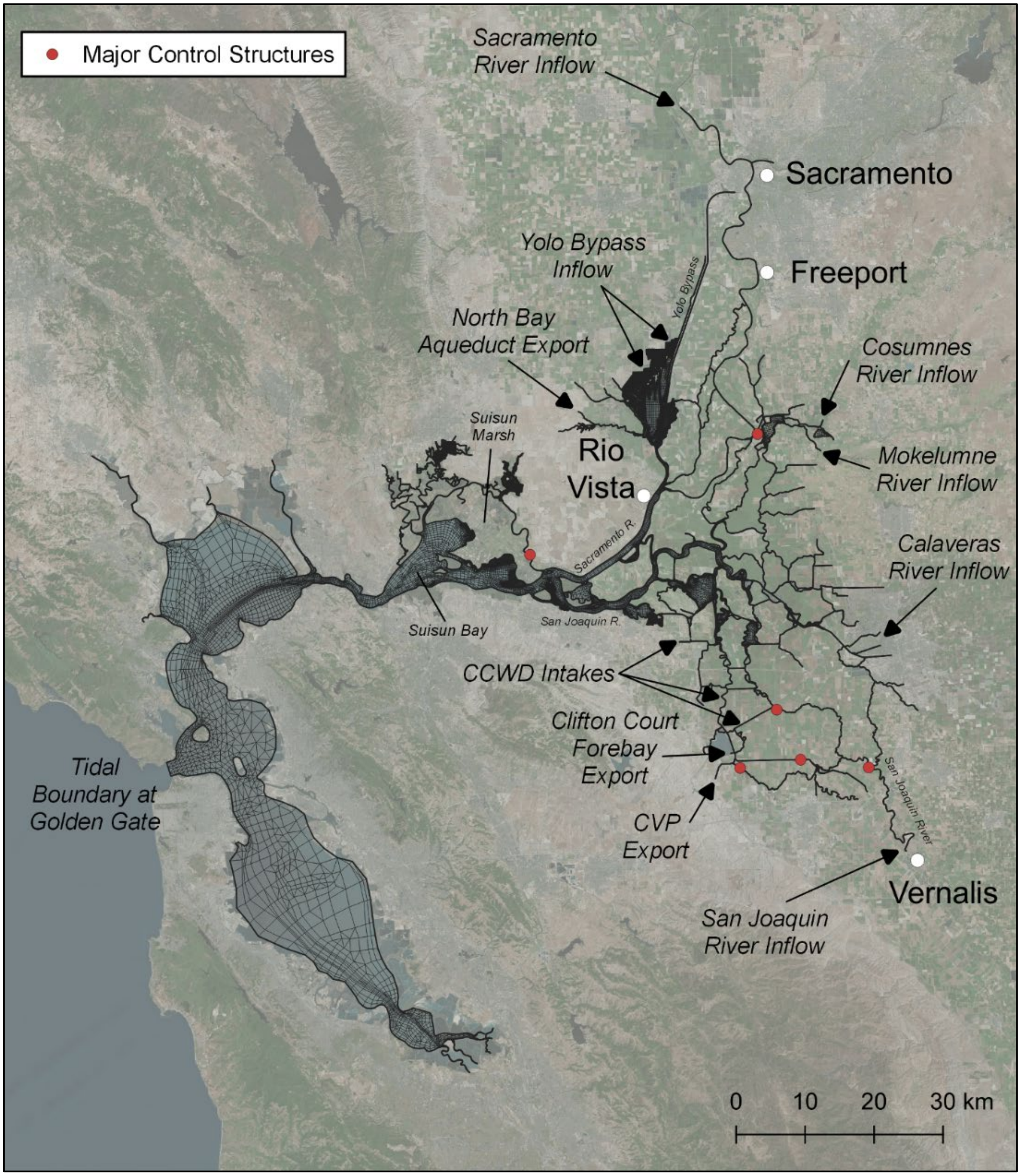

Figure 5-6. RMA Bay-Delta Model Boundary Conditions
A map with labels shows the model boundary conditions. Major control structures are symbolized with red dots.

5.5.5 Habitat Area Calculations

Habitat area calculations were performed for discrete regions within the Bay-Delta and based on a combination of model output (hydrodynamics and EC/salinity) and observed data (temperature and turbidity). Observed data were the same for the VA and baseline scenarios, and only model outputs differed between scenarios. Habitat criteria varied seasonally and by fish species.

Criteria were set for each fish species (see below), and data layers were developed to represent all areas in the model domain where each criterion was met. The intersection of all data layers, where all criteria were met, was considered habitat. It is important to note that these criteria are based entirely on water quality parameters and water depth. Other important habitat characteristics, such as food supply, refuge habitat, and vegetation, were not included.

5.5.5.1 Data

Temperature and turbidity data were compiled throughout the Bay and Delta from continuous water quality sensors maintained by DWR and the U.S. Geological Survey and were shared publicly on the California Environmental Data Center. Monthly averages were computed for all available data for 2010–2019. While it is assumed that the VA assets generally do not alter these metrics, they do serve an informative bounding function to appropriately limit habitat suitability, especially seasonally.

The 2010–2019 observed data period was selected to represent modern conditions in the Delta since temperature and turbidity have changed since the 1976–1991 simulation period. Changes in sediment loads and increases in aquatic vegetation over time have lowered turbidity in the Delta (Schoellhamer 2011; Hestir et al. 2016). Climate change, among other factors, has increased water temperature (Bashevkin et al. 2022). Additionally, data availability is poor for the 1976–1991 simulation period. Because the 2010–2019 data do not specifically represent the modeled periods, statistics were computed to develop a range of values for application to the habitat criteria calculations.

Observed data processing steps were as follows:

1. Downloaded and cleaned available temperate and turbidity data for the 2010–2019 period (data from the California Environmental Data Center; see Appendix A, Figure 1 and Figure 142 for station location maps).
2. Computed monthly averages of all data.
3. From the monthly averages, computed mean, 25th quantile, and 75th quantile monthly average for each month of the year (e.g., for all Junes for the 2010–2019 period).
4. Set these known values in the model and computed diffusion solutions for each month of the year and each statistical value to generate data layers with continuous fields of temperature and turbidity over the model domain for each condition. These data layers were then applied in habitat area calculations.

Further detail is available in the *Observed Data Processing* section of Appendix A, *RMA Modeling Methods*.

5.5.5.2 Model Output

Modeled EC, velocity, and depth for 1976–1991 were monthly averaged for application to the habitat criteria calculations. These averages were used in the habitat calculations as a continuous EC field over the model domain.

5.5.6 Species

Habitat areas were computed by species for each month and season of the 1976–1991 simulation period. Species-relevant seasonal averages were reported. Habitat criteria and relevant seasons are listed below for each species. Spring is defined as March–May. Summer is defined as June–August. Fall is defined as September–November. Winter is defined as December–February.

Mean, most restrictive, and least restrictive habitat conditions were computed to address the uncertainty introduced by the use of 2010–2019 temperature and turbidity data.

5.5.6.1 Delta Smelt: Spring and Summer–Fall (March–May and June–November)

For Delta smelt habitat area, the area below the critical thermal maximum of 77ºF was evaluated (Swanson et al. 2000; Yanagitsuru et al. 2022). It is important to note that this is not the temperature range where Delta smelt experience optimal conditions, but it does provide an upper limit for habitat suitability. It also provides a point of comparison for changes in suitable habitat with and without the VAs. The more restrictive habitat conditions (75th quartile below 77ºF) may be a better representation of optimal conditions for Delta smelt. Salinity and turbidity tolerances were from Bever et al. (2016).

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity < 6 ppt (EC < 10,600 µS/cm)
- Overall monthly average turbidity > 12 NTU
- Overall monthly average temperature < 77ºF

Most restrictive habitat conditions—the areas where the following criteria are met:

- Monthly average salinity < 6 ppt (EC < 10,600 µS/cm)
- 25th quantile of overall monthly average turbidity > 12 NTU
- 75th quantile of overall monthly average temperature < 77ºF

Least restrictive habitat conditions—the areas where the following criteria are met:

- Monthly average salinity < 6 ppt (EC < 10,600 µS/cm)
- 75th quantile of overall monthly average turbidity > 12 NTU
- 25th quantile of overall monthly average temperature < 77ºF

5.5.6.2 Longfin Smelt: Spring–Summer (March–August)

Longfin smelt habitat analyses used a salinity range of 0–12 ppt as the salinity tolerance of larval longfin smelt as documented by (Grimaldo et al. 2017). This salinity tolerance is most relevant in the winter and spring when longfin are spawning, since juvenile longfin have a much wider salinity tolerance (Baxter 1999; Merz et al. 2013). Depth, turbidity, or temperature thresholds were not included because no thresholds had been established at the time of modeling.

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average salinity < 12 ppt (EC < 20,137 µS/cm)

5.5.6.3 Salmonid Rearing: Winter–Spring (December–May)

Evaluation of salmonid rearing habitat used an upper thermal limit of 73ºF based on laboratory evaluations of juvenile Chinook salmon growth at controlled temperatures (Brett 1982, Marine and Cech 2004) and a more recent meta-analysis of temperature-dependent growth that evaluated data from 11 data sources spanning Chinook salmon populations from the Northwest coast to the American River (Perry et al. 2015a; Perry et al. 2015b). This meta-analysis found an upper thermal limit for juvenile salmon growth of 77ºF, and the value for optimal growth was 66ºF. Therefore, the value used for estimation of habitat area here is greater than optimal conditions but below a value that is prohibitive for growth or causes direct temperature-induced mortality based on laboratory studies. Additionally, a field study on the Cosumnes River floodplain reported high growth rates at average temperatures of 70ºF and up to a maximum temperature of 77ºF on the Cosumnes River floodplain (Jeffres et al. 2008). Generally, higher growth rates occur in Central Valley floodplain habitats compared with riverine habitats because of the shallower water (Sommer et al. 2001c), but with warmer temperatures predation risk can be higher (Sommer et al. 2020b; Nobriga et al. 2021). Taken together, field and laboratory studies on appropriate temperatures for rearing juvenile Chinook salmon indicate that the most restrictive habitat conditions described below may be closer to optimal thermal conditions. Similarly, the most restrictive habitat conditions would also be more suitable for adult salmonids migrating through the Delta.

Mean habitat conditions—the areas where the following criteria are met:

- Monthly average depth between 0.28 and 1.32 m
- Overall monthly average velocity < 0.24 m/s
- Overall monthly average temperature < 73ºF

Most restrictive habitat conditions—the areas where the following criteria are met:

- Monthly average depth between 0.28 and 1.32 m
- Overall monthly average velocity < 0.24 m/s
- 75th quantile of overall monthly average temperature < 73ºF

Least restrictive habitat conditions—the areas where the following criteria are met:

- Monthly average depth between 0.28 and 1.32 m
- Overall monthly average velocity < 0.24 m/s
- 25th quantile of overall monthly average temperature < 73ºF

5.5.7 Spatial Considerations

For the purposes of this analysis, results were evaluated for discrete regions, including the Bay, Suisun Marsh, Delta, and the combined Delta and Suisun Marsh regions (see Figure 5-7).

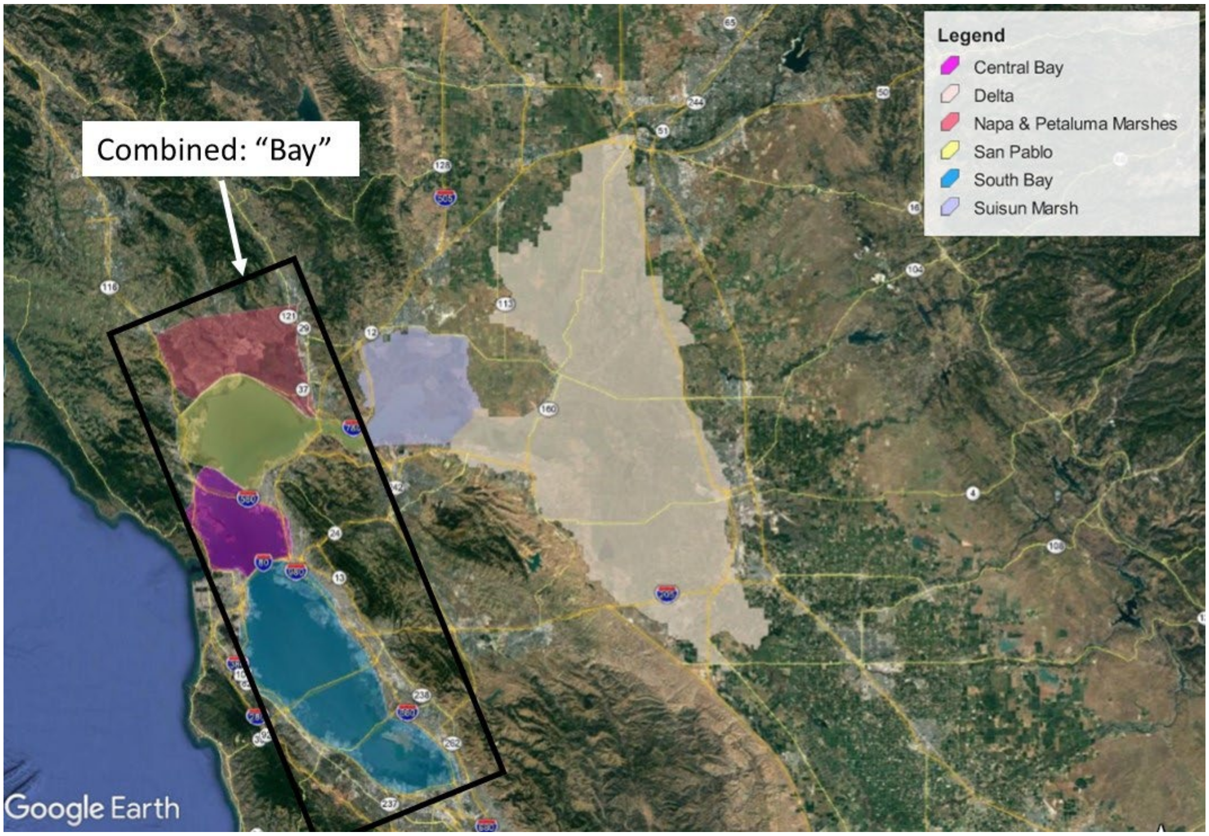

Figure 5-7. Regions for Habitat Area Calculations: Delta, Suisun Marsh, Suisun Marsh + Delta, and Bay.

A map shows analysis regions: combined "Bay" encompasses South Bay, Central Bay, San Pablo Bay, and Napa and Petaluma Marshes. Other areas including Delta and Suisun Marsh are symbolized.

Chapter 6
Anticipated Biological and Environmental Outcomes

6.1 Tributaries—Species and Habitat

The results of the habitat analysis indicate that VA non-flow assets produce more suitable habitat for fall-run Chinook salmon during spawning and rearing as compared to the baseline scenarios. For spawning habitat, both existing and VA habitat in all watersheds exceed the habitat necessary to support approximately 25% of the offspring of the doubling goal populations (the target of the 8-year term of the VAs), and the VA habitat exceeds 60% of the required habitat in all watersheds. Rearing habitat improvements varied by tributary, with the 25% target being met on the Mokelumne River (which already exceeded the target in the baseline) and Yuba River, but not the Sacramento, Feather, or American Rivers. Additional floodplain acreage is planned on the Sacramento Rivers to achieve the 25% rearing habitat target (see Section 6.1.2, *Salmonid Habitat Results: Rearing*).

Spawning is limited by the availability of suitable habitat since a finite number of redds can be constructed in a given area. The development of additional spawning habitat, through constructed habitat and habitat restoration, provides more opportunities for spawning (Merz 2004; Roni et al. 2008; McManamay et al. 2010) and consequently an increase in the number of juveniles.

Juvenile salmon and steelhead require access to suitable rearing habitat, and suitable food resources during rearing. Expanding habitat availability, both spatially and temporally, for juvenile salmon is expected to improve abundance, productivity, diversity, and spatial structure of Central Valley salmon populations, and it may also lead to incidental benefits for other native fish species (State Water Board and California Environmental Protection Agency 2018).

Suitable rearing habitat for juvenile fall-run Chinook salmon supports growth and survival during outmigration (Maslin et al. 1997; Limm and Marchetti 2009). Phillis et al. (2018) found that Sacramento River winter-run Chinook salmon rely on a more diverse suite of rearing habitats than previously thought, therefore motivating the need to restore instream rearing habitat in the Sacramento River and its contributing tributaries.

6.1.1 Salmonid Habitat Results: Spawning

The proposed habitat restoration commitments identified in the State's VA Framework include spawning habitat for the Sacramento River (113.5 acres), Feather River (15 acres), American River (25 acres), and Putah River (1.4 acres). Numerous studies have found an increase in the number of salmon or steelhead redds or spawners following habitat improvement efforts, such as gravel addition (Merz 2004; Roni et al. 2008; McManamay et al. 2010). Across 14 studies reviewed by Roni et al. (2008), 70% showed an increase in adult salmon to the placement of instream structures for habitat improvement (Roni et al. 2014).

Figure 6-1 provides the median spawning habitat area across all modeled years (1922–2015) under the baseline and VA scenarios. The labels below the bars represent the median amount of habitat as a percentage of the habitat needed to support the doubling goal. Existing habitat for all watersheds exceeds the VA target of 25% of the doubling goal for spawning habitat in all water year types. In the

Mokelumne, Sacramento, and Yuba Rivers, this was over 100%, indicating that the VA scenario (as well as the baseline for Mokelumne and Yuba Rivers) provides enough spawning habitat to support the doubling goal.

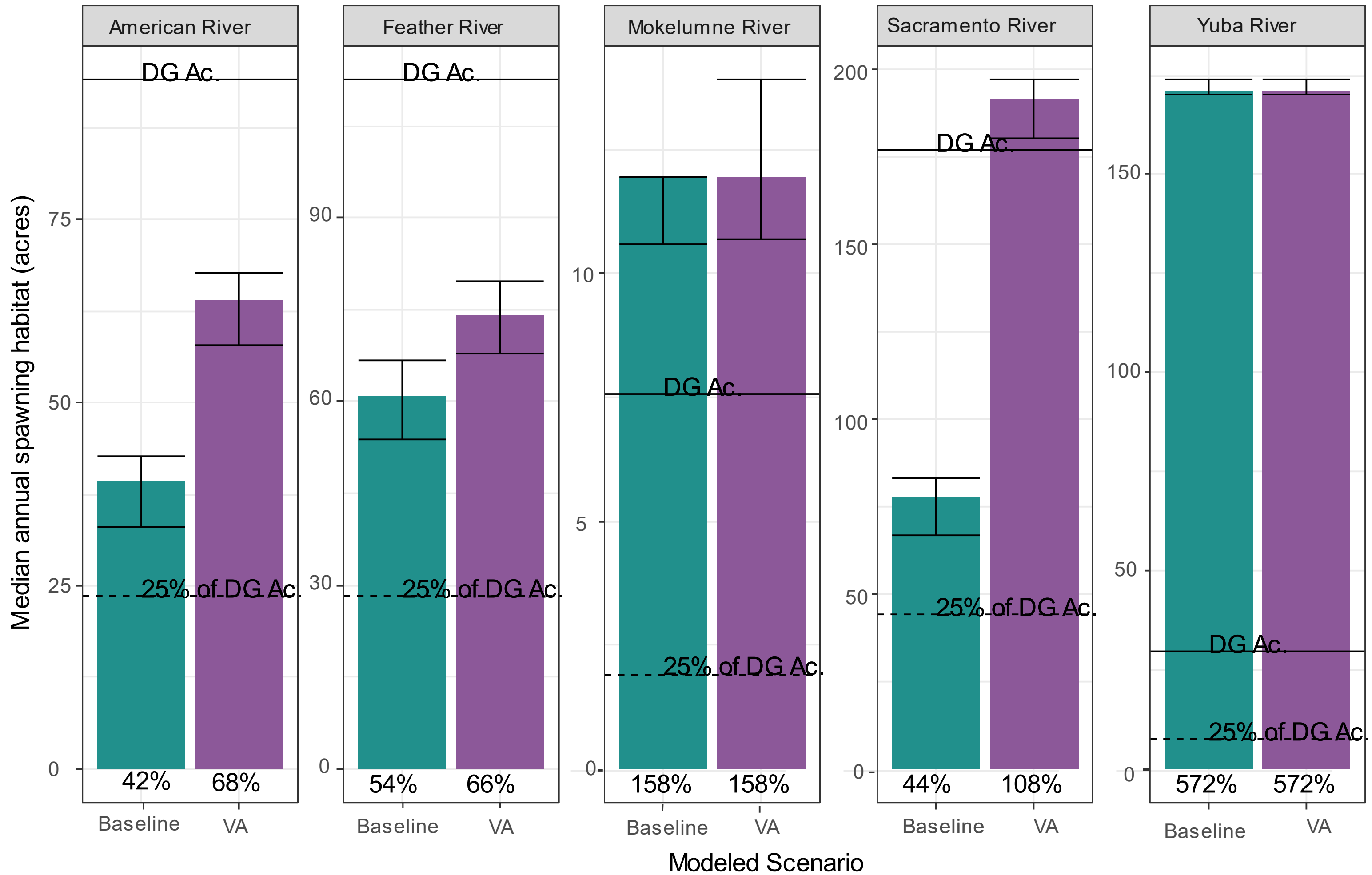

Figure 6-1. Median (Across All Years) Spawning Habitat (Acres) under Baseline (Green) and VA (Purple) Scenarios for Each Watershed
Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25% of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is printed below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Figure 6-2 shows the median annual spawning habitat (acres) for the baseline and VA scenario by watershed and water year type. Across all water year types, the VAs offer more spawning habitat (October through December) than the baseline conditions in the American, Feather, and Sacramento Rivers. Across Critical to Wet water year types, the VAs offer 59–73% more spawning habitat (61–67 acres) in the American River; 19–22% more spawning habitat in the Feather River (73–78 acres); and 137–164% more spawning habitat in the Sacramento River (183–196 acres) (Table 6-1; Figure 6-2).

Table 6-1. Median Percent Change between the Baseline and VA Scenarios (Estimated Using CalSim) for Suitable Spawning Habitat by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	64%	59%	61%	65%	73%
Feather River	22%	22%	21%	19%	21%
Sacramento River	137%	139%	146%	153%	164%

Note: Yuba and Mokelumne Rivers are excluded from this table, as they have sufficient habitat to meet the doubling goal.

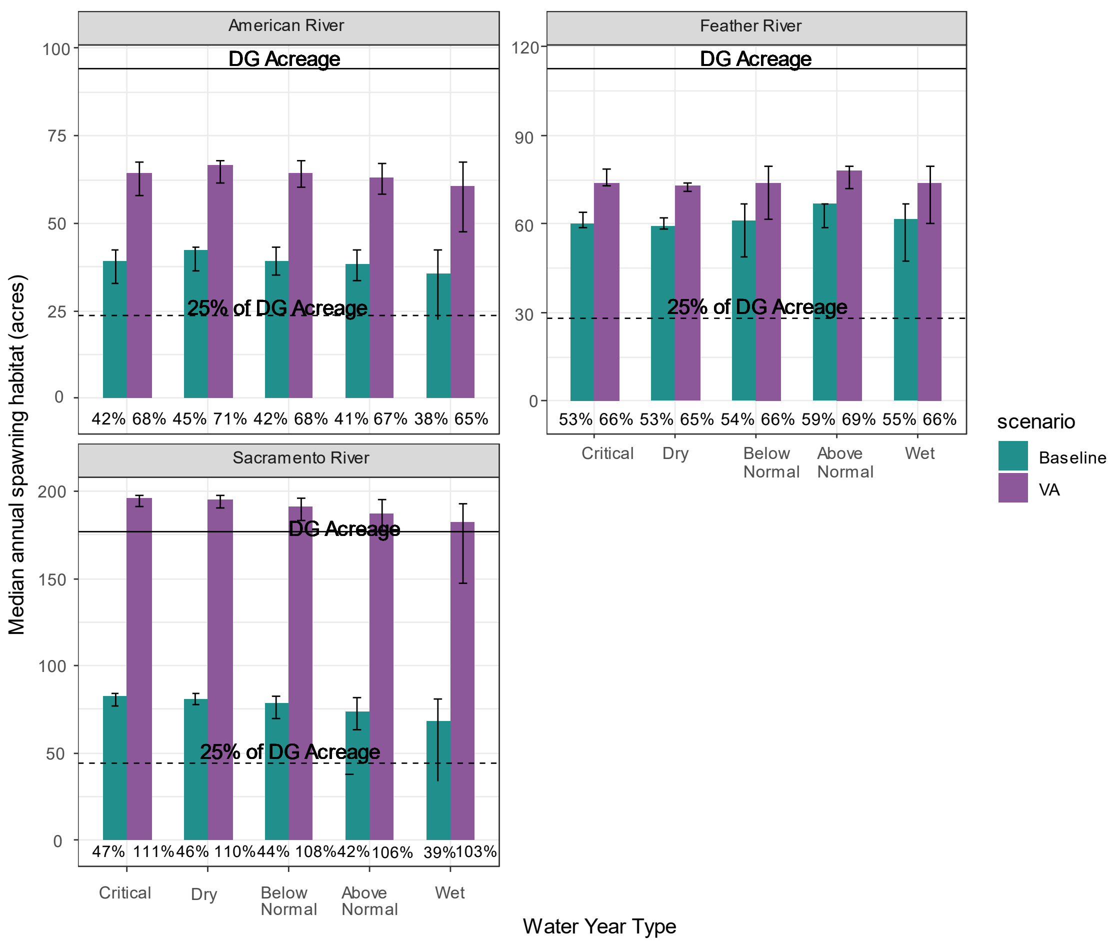

Figure 6-2. Median (Across All Years Modeled) Annual Spawning Habitat (Acres)
Error bars represent the upper and lower quartiles by watershed for the baseline and VA scenarios for watersheds with spawning habitat restoration commitments in the VAs. The amount of habitat

as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Habitat area was estimated using CalSim and summarized by water year type across all years in the modeling period. This three-panel figure shows three tributaries (top row left American River, top row right Feather River, bottom row left Sacramento River). The y-axis is median annual spawning habitat (acres), and the x-axis shows results by water year type (Critical, Dry, Below Normal, Above Normal, and Wet, based on CalSim 3 water year type for April). Colored bars show baseline (green) and VA (purple) scenarios. The solid line represents the spawning area required to support the doubling goal, and the dashed line represents 25% of the doubling goal area.

For the Yuba and Mokelumne Rivers, median annual spawning habitat is the same for the baseline and VA scenarios because there were no spawning habitat commitments in the VAs. Under baseline conditions, the Yuba and Mokelumne Rivers exceed the habitat area needed to support 100% of the doubling goal for the spawner population target (Figure 6-1).

Increasing the amount of spawning habitat will support a greater number of redds and therefore potentially greater production of juveniles. In areas with insufficient suitable spawning area, more spawning pairs may arrive than the existing habitat can support, and lack of spawning habitat has been identified by the CVPIA as a limiting factor by the Science Integration Team model (Reclamation and USFWS 2020). Increases in suitable spawning habitat through habitat improvement efforts such as gravel addition supports a greater number of redds or spawners (Roni et al. 2014), leading to an increased capacity to produce more juveniles.

6.1.2 Salmonid Habitat Results: Rearing

Rearing habitat was evaluated for instream habitat alone, floodplain habitat alone, and for the combination of instream and floodplain habitat.

6.1.2.1 In-Channel Rearing

The proposed habitat restoration commitments identified in the State's VA Framework include in-channel habitat for the Sacramento River (137.5 acres), Feather River (5.25 acres), Yuba River (50 acres), American River (75 acres), and Mokelumne River (1 acre). Across 99 studies reviewed by Roni et al. (2008), more than 60% showed an increase in juvenile salmon to the placement of instream structures for habitat improvement (as cited by Roni et al. 2014). Increases in suitable instream rearing habitat through habitat improvement efforts led to an increased capacity to produce more juveniles. The instream rearing habitat committed to in the VAs met the 25% of doubling goal threshold in the Mokelumne River (which also met the goal in baseline), but not the American, Feather, Yuba, or Sacramento Rivers (Figure 6-3). The effect of flow on habitat availability means that not all the restored habitat is available in all water year types, but additional rearing habitat is available in floodplains during higher flow years (see Section 6.1.2.3, *Combined Rearing Habitat*).

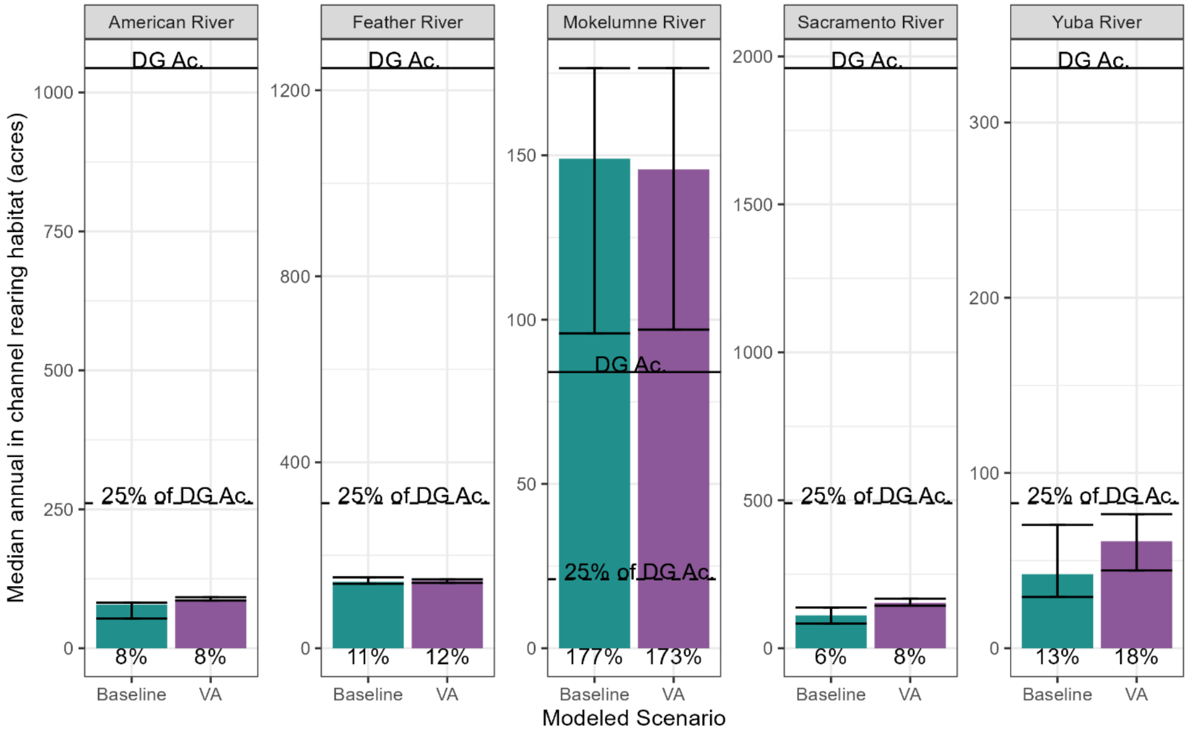

Figure 6-3. Median (Across All Years) In-Channel Rearing Habitat (Acres) under Baseline (Green) and VA (Purple) Scenarios for Each Watershed
Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25% of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is noted below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes.

Figure 6-4 shows the median annual in-channel habitat area (acres) for the baseline and VA scenario by watershed and water year type. Across all the water year types, the VAs offer more in-channel rearing habitat (February through June) than baseline conditions in the American, Feather, Sacramento, and Yuba Rivers, but reduced in-channel rearing habitat in the Mokelumne River. The VAs offer 5–152% more in-channel rearing habitat (86–92 acres) in the American River; 2–3% more in the Feather River (140–161 acres); 7–57% more in the Sacramento River (145–185 acres); 29–50% more in the Yuba River (38–105 acres); and 0–4% less in the Mokelumne River (Table 6-2; Figure 6-4).

These analyses show reductions in in-channel rearing habitat with increased flow in the Sacramento, American, Mokelumne, and Feather Rivers, which may seem counter-intuitive. However, in wetter years, velocities and depths become less suitable in the channels, particularly when the flows are confined by levees. These results highlight the importance of restoring floodplain and off-channel habitat to provide lower-velocity refugia during high flow years. In the Yuba River, higher flows during wetter water years resulted in greater acreages of instream rearing habitat.

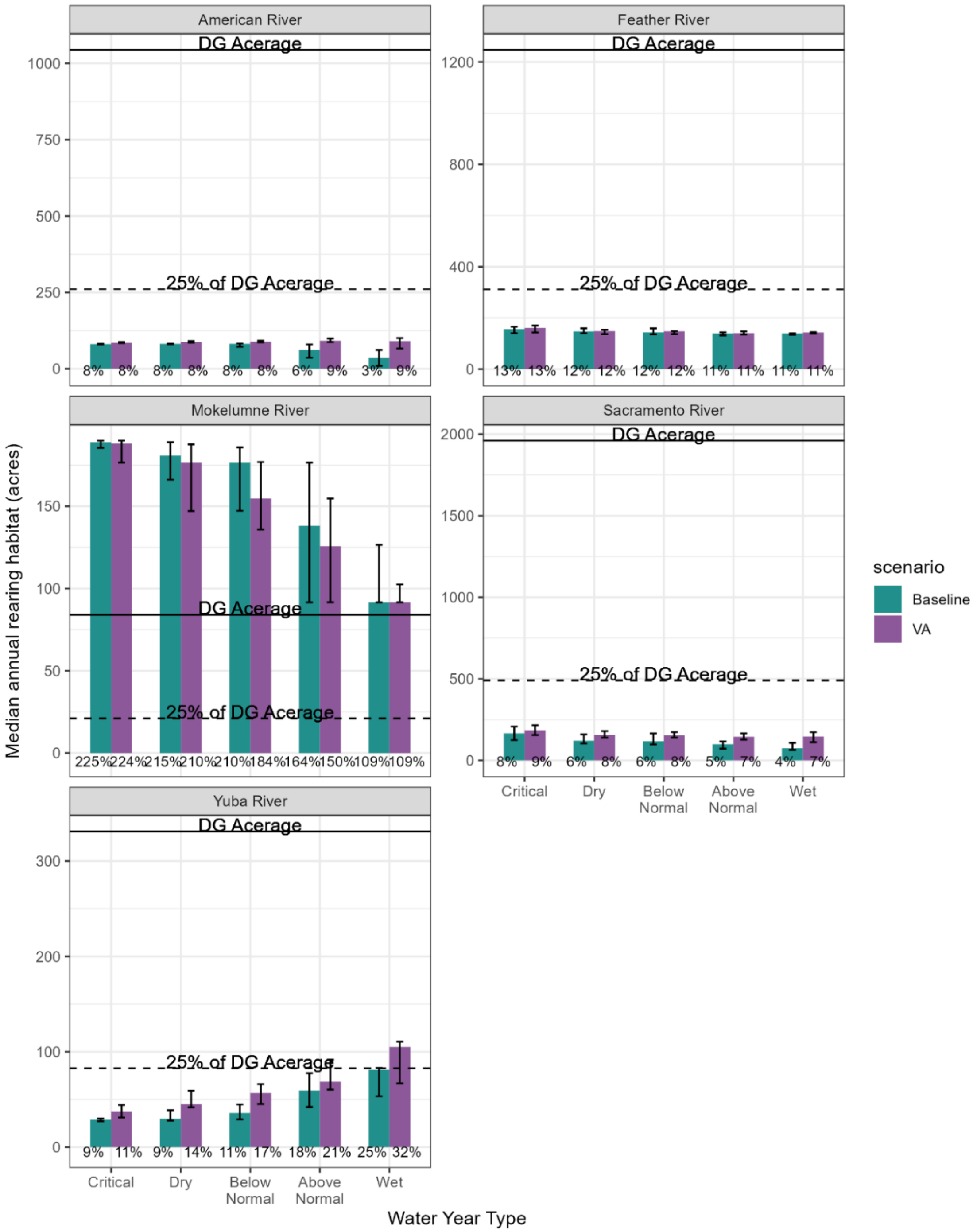

Figure 6-4. Median Annual In-Channel Rearing Habitat (Acres) with Upper and Lower Quartiles by Watershed for the Baseline (Green) and VA (Purple) Scenarios

Solid lines represent area of habitat required to support the doubling goal (DG) population, and dashed lines represent 25% of the doubling goal area. The amount of habitat as a percentage of the habitat needed to support the doubling goal is noted below each bar. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Habitat area was estimated using CalSim and averaged by water year type across all years in the modeling period.

Table 6-2. Median Percent Change between the Baseline and VA Scenarios (Estimated Using CalSim) for Suitable Instream Rearing Habitat by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	5%	6%	9%	48%	152%
Feather River	3%	3%	3%	2%	3%
Mokelumne River	0%	-1%	-4%	0%	0%
Sacramento River	7%	13%	18%	51%	57%
Yuba River	29%	45%	50%	33%	33%

The additional habitat on the Mokelumne River is offset, and in some cases reduced, due to changes in flow in the CalSim model between baseline and VA scenarios and the inverse relationship between flow and existing rearing habitat on the Mokelumne River (Gill and Thompkins 2020e). Under baseline conditions, the Mokelumne River exceeds the habitat area needed to support 100% of the doubling goal for the juvenile population target (Figure 6-3). There is a small difference in the median annual in-channel rearing habitat for the baseline and VA scenarios for Feather River reflective of the in-channel habitat commitment in the VAs.

6.1.2.2 Floodplain and Fish Food Production

The survival of juvenile Chinook salmon is affected by the spatial and temporal availability of suitable habitat, as well as the nutritional opportunities provided. Extensive seasonal floodplains and wetlands historically supported significant production of native fish species (Ahearn et al. 2006). Improving habitat availability, including floodplain inundation regimes in which native fish species are adapted, is critical for juvenile salmon rearing (Herbold et al. 2018; Sturrock et al. 2022b), as well as other natives fishes (Sommer et al. 2002). Dynamic connectivity between rivers and their floodplains improves nutrient and organic matter mobilization and exchange (Junk et al. 1989), and inundation of floodplain areas creates access to foraging habitat and provides refuge from high velocities during high flow events (Moyle et al. 2007). Fish yields have also been found to increase with water surface area in floodplains (Bayley 1991 as cited in Jeffres et al. 2008; USFWS 2014). Life history diversity in salmonids is also enhanced with access to floodplain habitat (Goertler et al. 2018a) and is recognized as a critical component of population viability (Carlson and Satterthwaite 2011).

The proposed floodplain and flood basin actions identified in the VA Term Sheet include floodplain habitat and/or fish food production for the Sutter Bypass, Butte Sink, and Colusa Basin (20,000 acres); Feather River (1,655 acres); Yuba River (100 acres); and Mokelumne River (25 acres). Juveniles in shallow, low velocity habitats supported by floodplain inundation have been found to grow more rapidly than juveniles in deeper, faster habitat, due to high prey abundance, lower water velocities, and higher temperatures compared to the adjacent river channel (Sommer et al. 2001b; Benigno and Sommer 2008; Jeffres et al. 2008). Access to floodplain habitat also provides increased space required for growth, development, and survival. Furthermore, faster growth has been linked to higher marine survival in other west coast Chinook salmon populations (Beckman et al. 1999). Landform modifications and improvements to Tisdale Weir and other infrastructure in the three flood basins (Sutter Bypass, Butte Sink, and Colusa Basin) are expected to reduce stranding and migratory delays of all life stages of anadromous fishes. In addition, flooding of rice fields in the Sutter Bypass, Butte Sink, and Colusa Basin (20,000 acres) would be used for fish food production, though this is for food production only and is not available for fish habitat.

The VAs offer a greater proportion of MFE occurrence for the Feather (Figure 6-5), Mokelumne (Figure 6-6), and Yuba (Figure 6-7) Rivers. On the Feather River, the VA scenario provides MFE twice as frequently as the baseline scenario at 25% of the doubling goal (the target for the VAs); at 50% and 75% of the doubling goal, VA MFEs occur 43% and 13% of years, respectively (Figure 6-5). For the Mokelumne River, the VA and baseline scenarios allow for similar MFE occurrence at 25% of the doubling goal (the target for the VAs), whereas the VAs provide higher MFE occurrence at 50–100% of the doubling goal (Figure 6-6). On the Yuba River, the baseline MFEs meet 5% of the doubling goal in 2% of the years but never meet 25% of the doubling goal, while the VAs meet 5% and 25% of the doubling goal nearly 100% of the years (Figure 6-7).

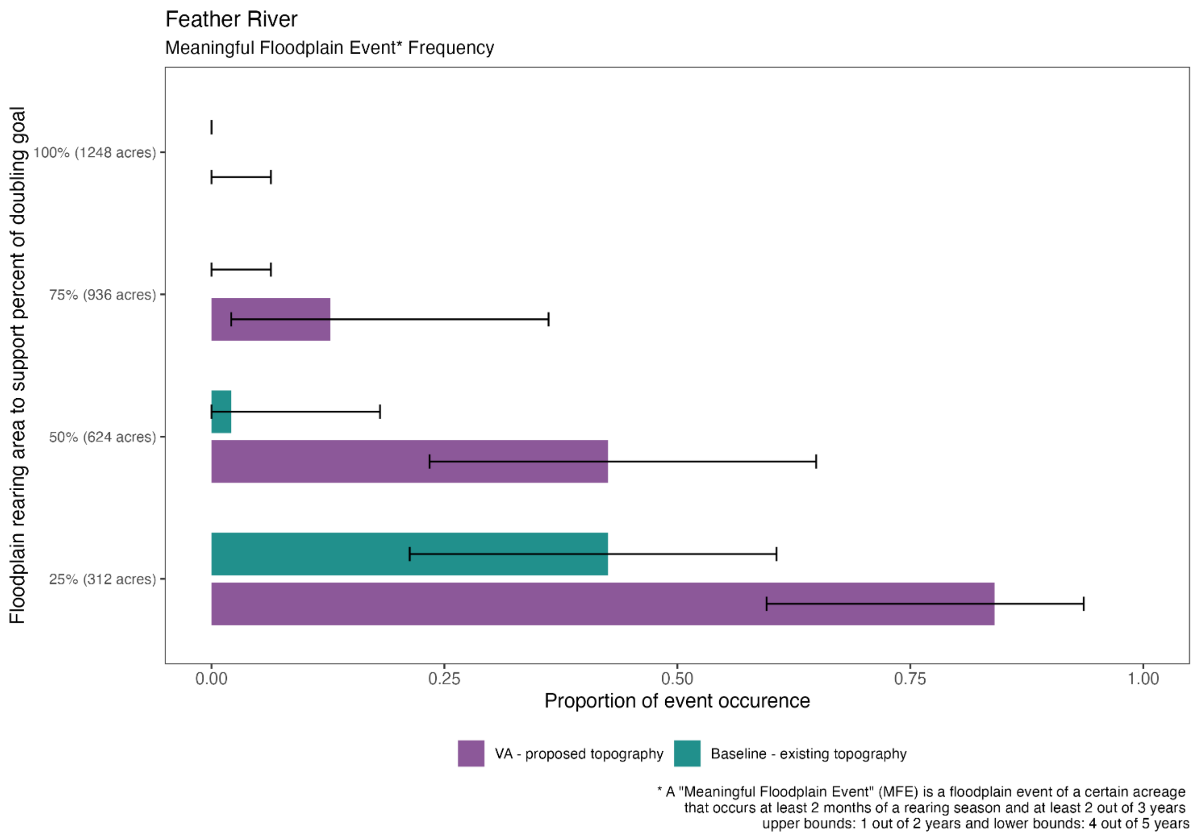

Figure 6-5. Proportion of Meaningful Floodplain Event Occurrence for the Baseline and VA Scenarios on the Feather River
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. The x-axis represents proportion of event occurrence, and the y-axis represents floodplain rearing area needed to support percent of doubling goal. Colored bars for each percent (25%, 50%, 75%, and 100%) show baseline (green) and VA (purple) scenarios. The lower bounds of the error bars represent the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of 5 years. The upper bounds of the error bars represent the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of 2 years.

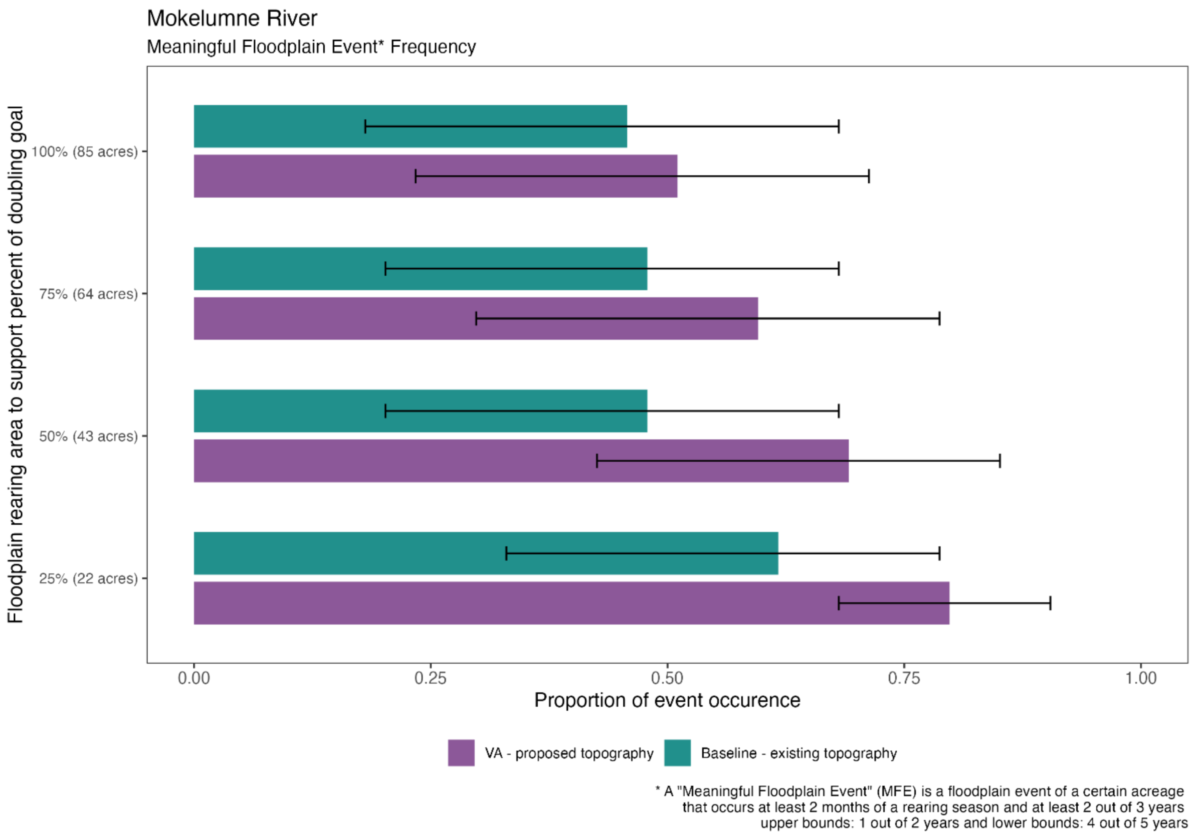

Figure 6-6. Proportion of Meaningful Floodplain Event Occurrence for the Baseline and VA Scenarios on the Mokelumne River

An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. The x-axis represents proportion of event occurrence, and the y-axis represents floodplain rearing area needed to support percent of doubling goal. Colored bars for each percent (25%, 50%, 75%, and 100%) show baseline (green) and VA (purple) scenarios. The lower bounds of the error bars represent the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of 5 years. The upper bounds of the error bars represent the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of 2 years.

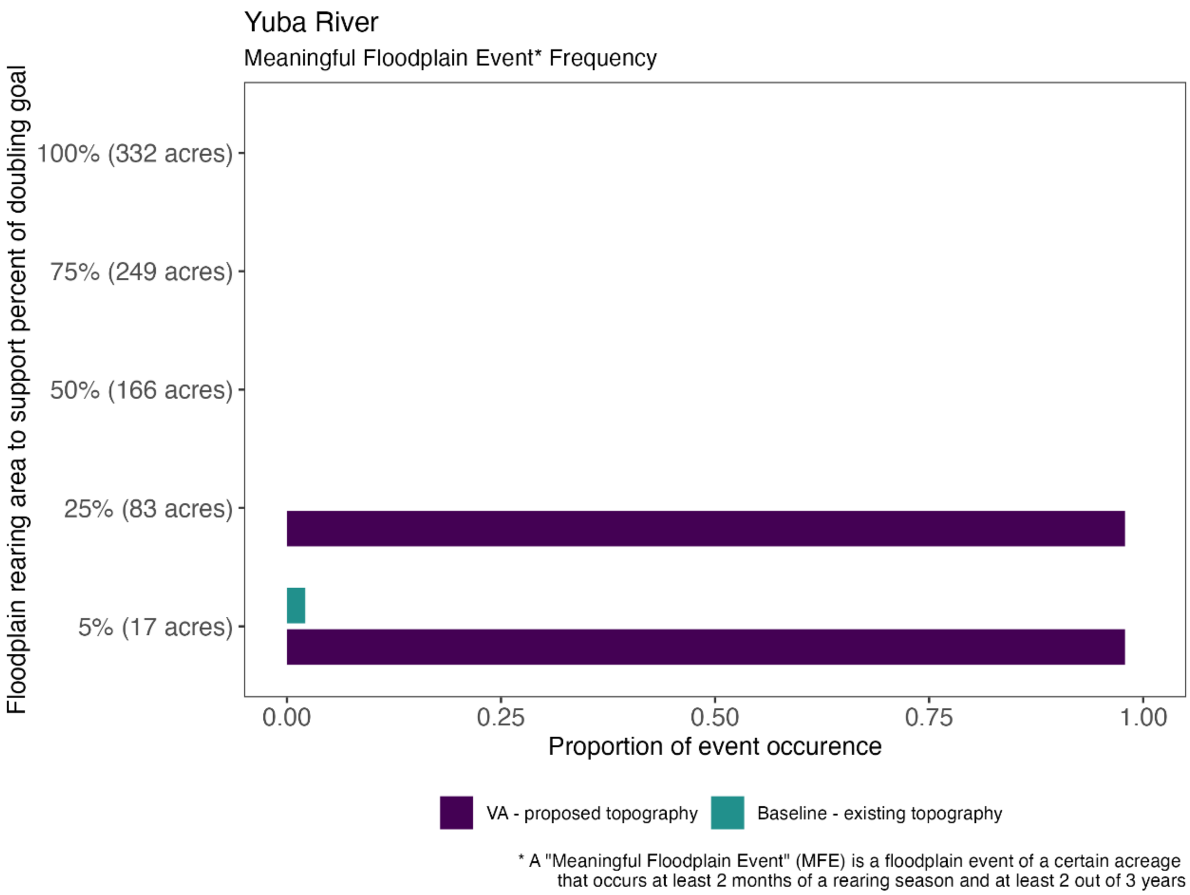

Figure 6-7. Proportion of Meaningful Floodplain Event Occurrence for the Baseline and VA Scenarios on the Yuba River
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. The x-axis represents proportion of event occurrence, and the y-axis represents floodplain rearing area needed to support percent of doubling goal. Colored bars for each percent of the doubling goal (5%, 25%, 50%, 75%, and 100%) show baseline (green) and VA (purple) scenarios. The lower bounds of the error bars represent the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of 5 years. The upper bounds of the error bars represent the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of 2 years.

Twenty thousand acres of floodplain habitat within the three flood basins are described as being generated via the Tisdale Weir and other modifications. However, modeling indicates most of that habitat will be generated via other topographic modifications, rather than changes to Tisdale Weir. In the Sutter Bypass, changes to Tisdale Weir result in increased frequency of spill over the Tisdale Weir such that monthly spills between 0 and 4,000 cfs increased by as much as 5% for the VAs compared to the existing conditions (Figure 6-8). This change in hydrologic operations of the Tisdale Weir does not create new physical habitat; rather, it improves the inundation frequency and duration of existing and VA proposed floodplain habitat in the Sutter Bypass. This will be accompanied by additional topographic modifications, land management changes, and habitat enhancements in these flood basins to generate the full 20,000 acres of floodplain habitat identified in the VAs. Based on the Sutter Bypass MFE assumptions, Figure 6-9 describes the number of acres that meet MFE criteria. These are not put in terms of a percentage of the doubling goal because doubling goal acreage has not been specifically defined for the Sutter Bypass. However, the additional floodplain habitat provided under the VAs in these flood basins could provide rearing habitat to juvenile fish from the Sacramento River and its tributaries upstream. Based on the assumptions described above, the additional floodplain habitat would exceed the rearing doubling goal for the Sacramento River (1,961 acres).

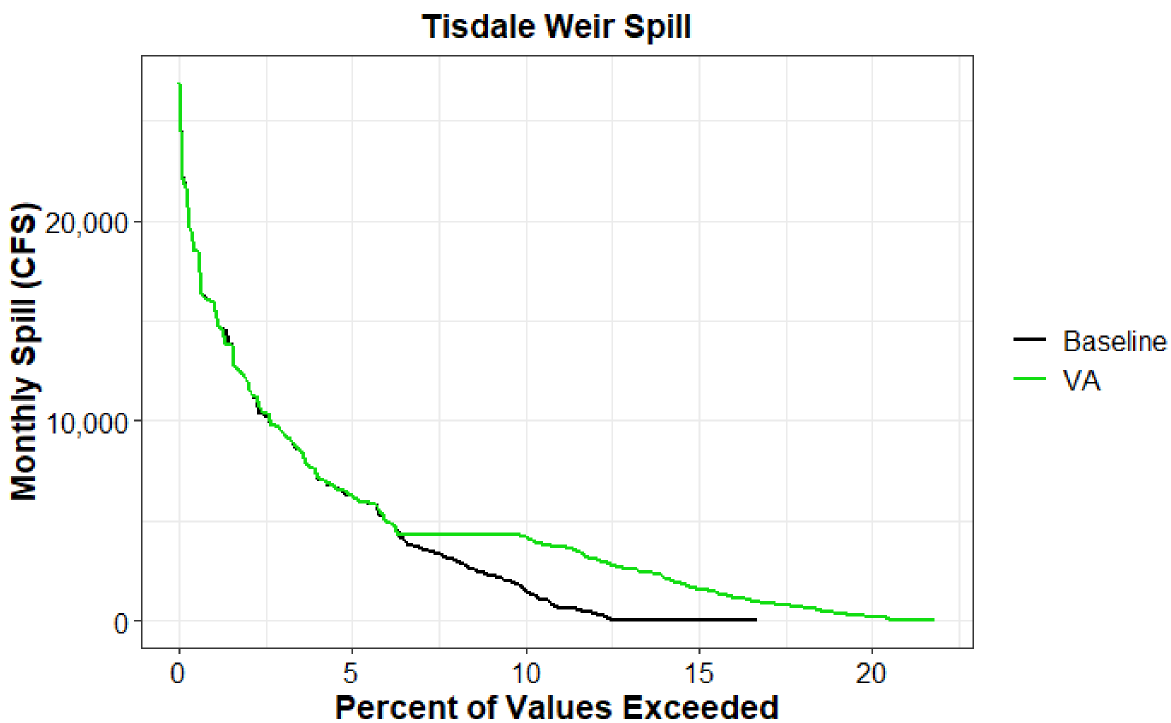

Figure 6-8. Change in Spill over the Tisdale Weir with the Notching Project Included in the VAs
The figure shows monthly spill (in cfs) on the y-axis and percent of values exceeded on the x-axis for baseline (in black) and the VAs (in green).

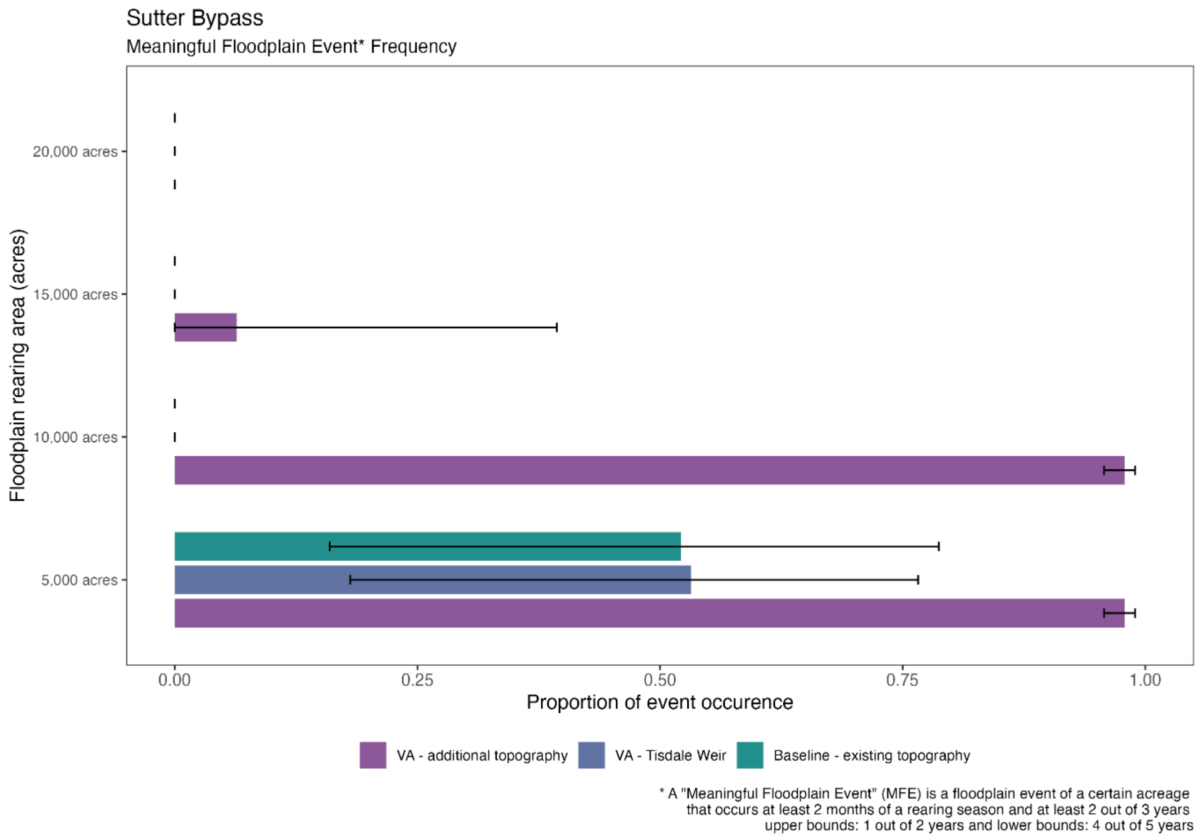

Figure 6-9. Proportion of Meaningful Floodplain Event Occurrence for the Baseline and VA Scenarios at the Sutter Bypass, Including a VA Scenario for Added 20,000 Acres of Habitat and a VA Scenario for Tisdale Weir Modifications
An MFE is defined as a floodplain event of a certain acreage that occurs at least 2 months of a rearing season and at least 2 out of 3 years. This bar chart is oriented horizontally. The x-axis represents proportion of event occurrence, and the y-axis represents floodplain rearing area in acres. Colored bars for each acreage (5,000; 10,000; 15,000; 20,000) show baseline (green), VA additional topography (purple), and VA Tisdale Weir (blue) scenarios. The lower bounds of the error bars represent the proportion of event occurrence when MFE criteria are restricted to require floodplain events 4 out of 5 years. The upper bounds of the error bars represent the proportion of event occurrence when MFE criteria are loosened to require floodplain events 1 out of 2 years.

6.1.2.3 Combined Rearing Habitat

In-channel rearing habitat and floodplain rearing habitat both provide important, but different, benefits for juvenile salmon, and including both types of habitat increases habitat diversity and resilience for the population as a whole. The combined rearing habitat in the VAs met the target of 25% of the area necessary to support the doubling goal on the Mokelumne (which also met the target in the baseline) and Yuba Rivers in all water year types (Figure 6-10, Figure 6-11). The Feather River met the target under the VAs in Above Normal and Wet (which also met the target in the baseline) years (Figure 6-10, Figure 6-11). Sacramento rearing habitat would surpass the 25% goal with the addition of 20,000 acres of floodplain restoration in the three flood basins. However, this is not shown in Figure 6-10 because assumptions about juvenile fish access to this habitat mean it is not directly comparable with other floodplain habitat. Yuba River rearing habitat would have the largest change between baseline and VAs, with increases of 149–378%. The rest of the watersheds would increase 0–63% from baseline to VAs (Table 6-3).

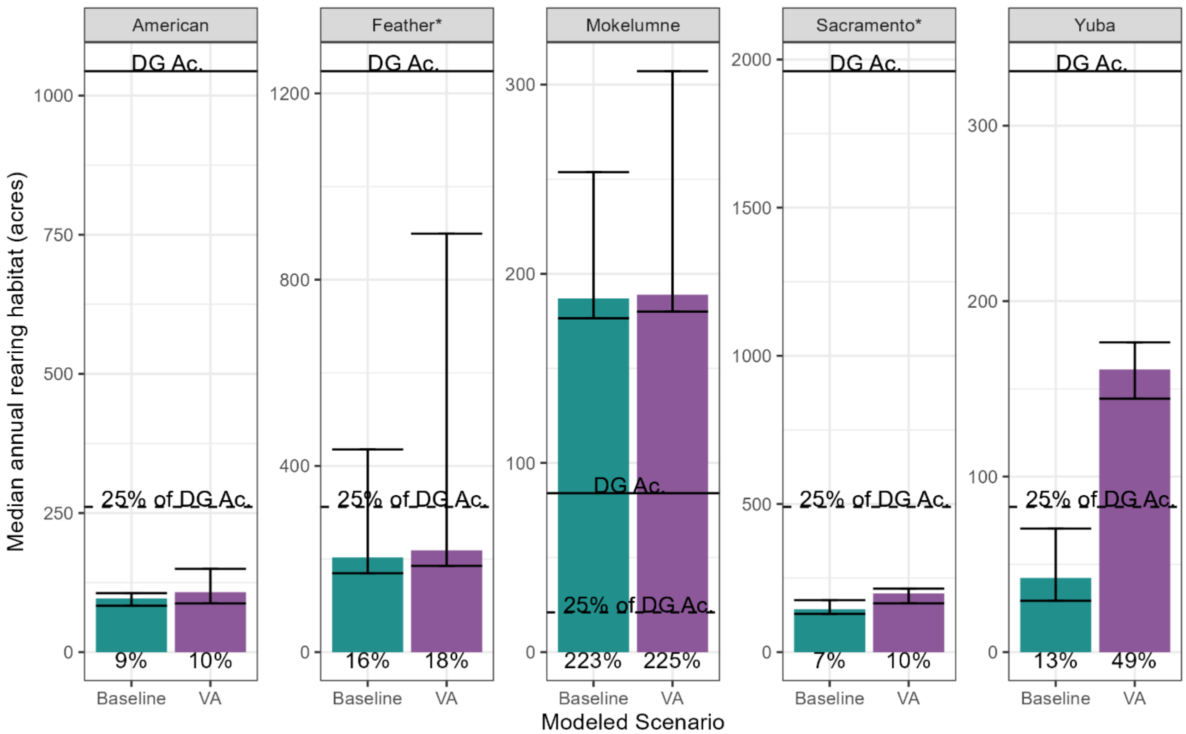

Figure 6-10. Median (Across All Years) Rearing Habitat (Acres) under Baseline (Green) and VA (Purple) Scenarios for Each Watershed, Including Both Floodplain and In-Channel Rearing Habitat ***The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25% of the doubling goal area. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. *Note that this does not include the 20,000 acres of floodplain restoration on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers.***

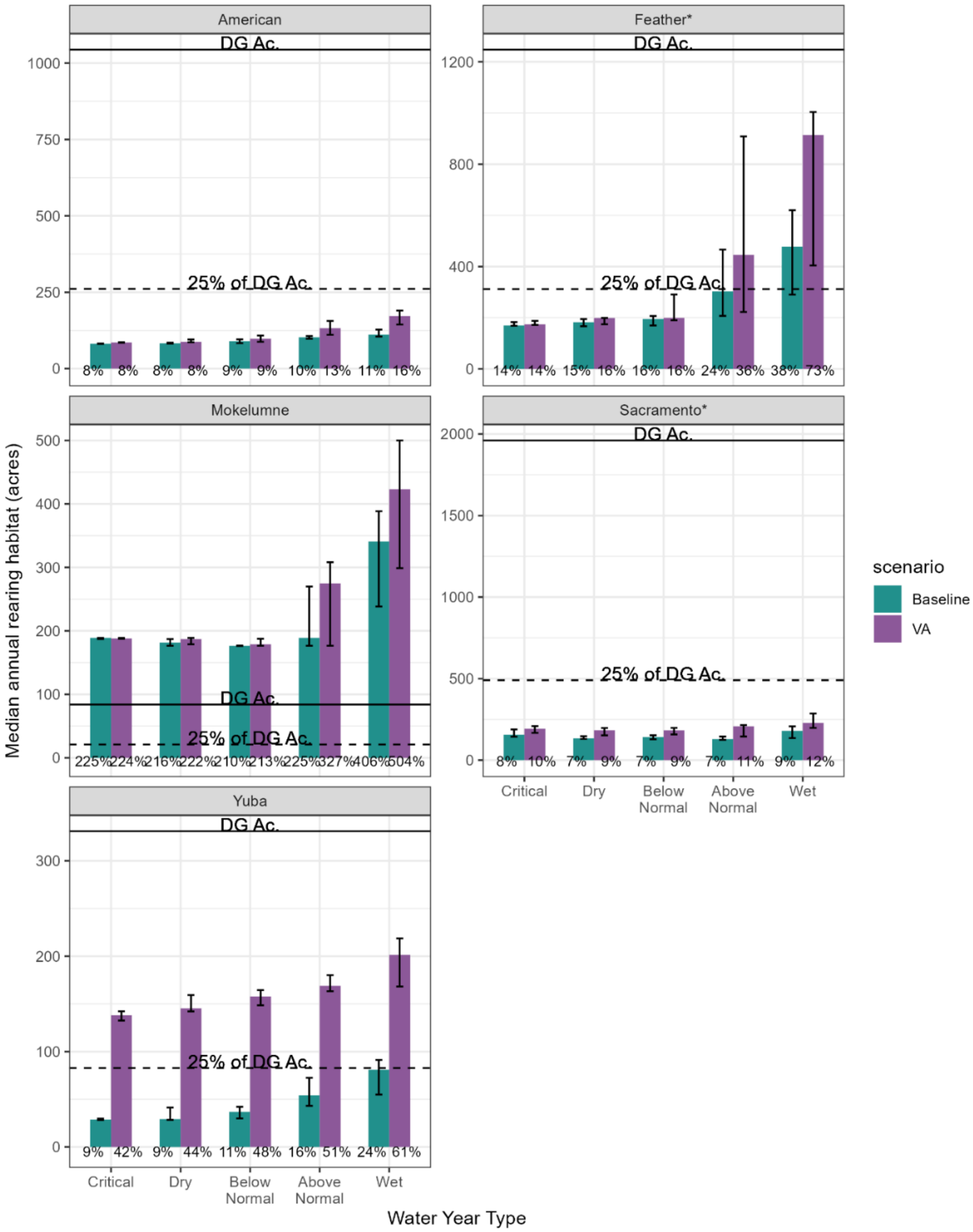

Figure 6-11. Median Annual Rearing Habitat (Acres) with Upper and Lower Quartiles by Watershed for the Baseline (Green) and VA (Purple) Scenarios, Including Both Floodplain and In-Channel Rearing Habitat

The amount of habitat as a percentage of the habitat needed to support the doubling goal (DG) is printed below each bar. Solid lines represent area of habitat required to support the doubling goal population, and dashed lines represent 25% of the doubling goal area. Medians and quantiles were calculated across all years; therefore, the quantiles represent year-to-year variability, not the full uncertainty in expected outcomes. Habitat area was estimated using CalSim and averaged by water year type across all years in the modeling period. *Note that this does not include the

20,000 acres of floodplain restoration on the Sutter Bypass that may be available as rearing habitat for fish from the Feather and Sacramento Rivers.

Table 6-3. Median Percent Change between the Baseline and VA Scenarios (Estimated Using CalSim) for Suitable Rearing Habitat (Including Both Instream and Floodplain) by Water Year Type and Watershed

Watershed	Critical	Dry	Below Normal	Above Normal	Wet
American River	5%	6%	9%	29%	38%
Feather River	3%	13%	15%	63%	61%
Mokelumne River	0%	0%	0%	16%	29%
Sacramento River	7%	13%	16%	23%	18%
Yuba River	377%	378%	317%	187%	149%

6.1.3 Benefits of Increased Flow

Floodplain habitat has ecological importance to Chinook salmon and steelhead during multiple life stages as it provides a suite of benefits for fish.

Within floodplains, rearing and foraging salmonids may find increased food resources (Sommer et al. 2001c; Bellmore et al. 2013) and habitat (Sommer et al. 2005; Cordell et al. 2011), and they may subsequently grow faster (Takata et al. 2017), theoretically conferring survival benefits (Sommer et al. 2001c; Sommer et al. 2005). Takata et al. (2017) found the duration of floodplain flooding in the Yolo Bypass positively affected total growth in coded wire tagged hatchery-origin fall-run Chinook salmon in the bypass. Floodplain habitat can provide high densities of zooplankton, aquatic insects, and benthic invertebrates, particularly when there are periods of disconnection and reconnection with the river to allow productivity to increase (Grosholz and Gallo 2006).

Flows through the mainstem Sacramento River and Yolo Bypass directly affect outmigrating Chinook salmon and steelhead travel time and survival through the Delta (Johnston et al. 2018; Pope et al. 2021). Changes in travel time can indirectly and directly influence survival probabilities for salmonids. Johnston et al. (2018) released acoustic tagged hatchery late fall-run Chinook and found no difference in cumulative survival probabilities for fish routed through the Yolo Bypass and the mainstem Sacramento River in 2012 and 2013 (2012: Yolo Bypass route 0.469; mainstem Sacramento River route 0.528). Additionally, fish released in the Yolo Bypass exhibited the longest average travel times. Their results suggest similar estimated survival probability between routes and increased travel time through the floodplain during water years with decreased flow. If increases in flow provide optimal hydrological conditions, those relationships may change. Other studies present similar results. Median survival probabilities of acoustically tagged hatchery late fall-run Chinook released in three groups during 2016 (timed to coincide with a flood pulse) did not differ between the mainstem Sacramento River route (0.704–0.845) and Yolo Bypass to Cache Slough route (0.659–0.689) (Pope et al. 2021). Mean travel times of the same release groups of juvenile Chinook were quicker for those fish migrating via the mainstem Sacramento River (2.7–3.16 days) compared with those migrating via the Yolo Bypass (4.19–5.08 days) (Pope et al. 2021).

A decrease in the proportion of time juveniles spend actively migrating in the Delta (compared with the more riverine, upper reaches of the Sacramento River) can increase their chances of survival. Juvenile salmonid survival depends on both travel distance and travel time, but the significance of each factor on survival probability is not equal and dependent on predation encounter probabilities (Anderson 2006). Steel et al. (2020) applied the mean free-path length model (XT model, which models predator/prey dynamics, Anderson et al. 2005) on hatchery late fall-run juveniles released in the winters of 2013 and 2014 and report that in high and low flow conditions both modeled travel time and travel distance had significant relationships with survival estimates. While increased flow may provide survival benefits for actively outmigrating juvenile Chinook and steelhead, it may also simultaneously benefit rearing and foraging salmon within the Estuary by increasing connectivity and activating floodplain habitat.

6.1.4 Synergy between Flow and Non-Flow Habitat

Modeling results show the benefits of increased flow in tributaries by a resulting increase in salmonid habitat. The modeled median percent changes between baseline and VA scenarios for suitable spawning habitat and instream rearing habitat are positive for most watersheds (American River, Feather River, and Sacramento River) in all water year types (Table 6-1, Table 6-2). The Mokelumne River is the only exception; modeled median percent change of suitable instream rearing habitat is 0%, but that is expected since only 1 acre of rearing habitat is included in the VAs. Suitable spawning and rearing habitat provide a suite of benefits to Chinook salmon and steelhead across all Central Valley tributaries during multiple life stages.

The earliest life history stage of salmonids (egg incubation to emergence from the gravel) is sensitive. This life stage requires suitable water temperature regimes and stable and continuous river flows to prevent redds from being dewatered or exposed to warm, deoxygenated water so incubating eggs and/or larval fish may survive. Redds constructed in shallow areas are susceptible to dewatering by flow reduction actions when operations transition from summer to winter flow regimes (Revnak et al. 2017). Augmented flows timed to decrease redd dewatering can mitigate one of the factors negatively affecting Chinook survival during early life stages.

Before juveniles begin outmigration through the tributaries to the Delta, availability of rearing habitat that provides diverse, abundant food resources in nonnatal tributaries and off-stream habitats is important. Along the upper Sacramento River, these areas that provide high value resources are hypothesized to support growth (Limm and Marchetti 2009; Phillis et al. 2018), increasing chances of survival. Larger otolith increments, translating to faster growth rates, were found in salmonids sampled in off-channel habitats compared to those sampled in main-channel habitats along the Sacramento River (Limm and Marchetti 2009). While modification of a river's hydrology can have detrimental impacts on salmonids by reducing access to rearing habitat for early life stages, modeled results show the VA flows may increase suitable rearing habitat in the tributaries.

Altered flow regimes in the Sacramento and other large Central Valley rivers have contributed to reduction of spring outmigration survival of juvenile salmon (Notch et al. 2020). Studies using acoustic tagged salmonids on the Sacramento River show that flow was the most important covariate in predicting outmigration success (Michel et al. 2015; Notch et al. 2020). Flow-survival thresholds have recently been developed using spring and summer season salmonid releases in the Sacramento River, based on Wilkins Slough river stage (Michel et al. 2021). Chinook smolt survival is estimated as greater than 50% when Wilkins Slough flows are 10,700 cfs or greater, and survival is estimated as near zero when Wilkins Slough flows are less than 4,000 cfs (Michel et al. 2021). Flow pulses can trigger outmigration cues and aid juvenile outmigration from upper reaches of tributaries towards the Delta. The combination of flow assets and barrier removal actions is expected to increase systemwide longitudinal and lateral connectivity to the benefit of both juvenile and adult life stages of native fishes.

Flows directly increase connectivity of highly productive floodplain habitat with the surrounding rivers, which has been identified as a key limiting factor in salmonid resilience (Chapter 2; Beechie et al. 2013; Herbold et al. 2018). Freshwater flows from the Sacramento River into floodplains activate habitat for Chinook salmon and steelhead, increasing primary and secondary productivity, which benefits rearing, foraging, and outmigrating juveniles. However, for flood bypasses, which differ from natural floodplains in that their activation is controlled by weirs and water control structures, putting water on the floodplain may not be enough. Flows must be sufficient to restore functional connectivity of these habitats to provide volitional ingress/egress for fishes. Several studies of the Yolo Bypass, Sutter Bypass, and Cosumnes River floodplains indicate higher concentrations of phytoplankton and invertebrates than the surrounding channel (Grosholz and Gallo 2006; Frantzich and Sommer 2015; Goertler et al. 2018a; Corline et al. 2021; Sturrock et al. 2022b), providing excellent growth conditions for juvenile fish (Sommer et al. 2001c; Jeffres et al. 2008; Takata et al. 2017; Goertler et al. 2018b).

Flows can also facilitate transport of production and food resources to areas with appropriate fish habitat. In particular, several experimental studies have been evaluating how agricultural drainage can deliver food resources to downstream regions. Frantzich et al. (2018) demonstrated from four years of weekly lower trophic data that densities of both calanoid copepod adults and cladocerans differ significantly between the Yolo Bypass and the Sacramento River, with higher densities in the perennial drainage channel in Yolo Bypass. Specifically, this increase in zooplankton densities occurred after Yolo Bypass agricultural flows with accompanying increases in chlorophyll-*a* concentrations (Frantzich et al. 2018). Studies of flooded rice fields have also found high concentrations of zooplankton that potentially can provide a benefit if exported to the surrounding rivers with agricultural drainage (Katz et al. 2017; Sommer et al. 2020b).

Foodweb hotspots benefit many native fish species, and productive habitats have the capacity to supplement the diet of species through subsidies (Farly et al. 2019). In a system similar to the Delta, Lake Saint-Pierre (a shallow fluvial lake of the St. Lawrence River), the isotopic signature in fish tissues associated with floodplain production was as high as 50% (Farly et al. 2019). In the Yolo Bypass, Sturrock et al. (2022b) reported juvenile fall-run Chinook guts were fullest in wet years (2016 and 2017), emptiest at the end of a multiyear drought (2015), and significantly differed among years. Additionally, supporting the subsidies theory, cladoceran abundance both in situ and in salmon gut contents was highest closest to a floodplain source (Sturrock et al. 2022b).

6.2 Delta and Estuary—Species and Habitat

The analysis of biological and environmental outcomes in the Delta and Estuary are based on three sources of information:

1. Quantitative modeling of stationary habitat (acreage of tidal wetlands) and the quantity of dynamic habitat (water quality and velocity).
2. Quantitative modeling of flow-abundance relationships for several native fishes.
3. A qualitative description of expected benefits to habitat restoration where no appropriate habitat-abundance models exist. Because habitat restoration in the Delta and estuary is in its

infancy and restoration sites may take many years to achieve their full benefits, the quantitative benefits of habitat restoration on population growth for fishes of concern cannot be directly modeled. Therefore, a literature review of studies showing benefits of habitat restoration to salmonids and smelt is provided.

6.2.1 Benefits of Increased Flow

As cited in the 2017 Scientific Basis Report, increased flow is expected to increase the abundance of several native species in the Delta. The mechanisms behind the flow-abundance relationships vary by species and are not fully understood, but the abundances of a number of native species residing or rearing in or migrating through the Estuary show persistent positive relationships with the volume of Delta outflow during the winter and spring (2017 Scientific Basis Report, Sections 3.2.2, 3.5.4, 3.7.4, 3.9.4, and 3.10.4). The 2017 Scientific Basis Report presented expected increases in the abundance indices of longfin smelt, starry flounder, Sacramento splittail, and California Bay shrimp based on the flow-abundance relationships for each species (2017 Scientific Basis Report, Section 5.3.3). Based on the modeled changes in Delta outflow presented above in Section 4.12, *Postprocessing of Data Outflow*, the expected percent changes for each of these four species are shown in Figure 6-12. Consistent with the approach taken in the 2017 Scientific Basis Report, these results are meant to give a general sense of the relative benefit each species may realize for a given flow scenario, and they should not be interpreted as a prediction of future population abundances. Because the median water year type in the Sacramento River watershed is Below Normal, the values estimated for Below Normal years reflect a reasonable estimate of the likely long-term effect of increased flows on the abundances of these species.

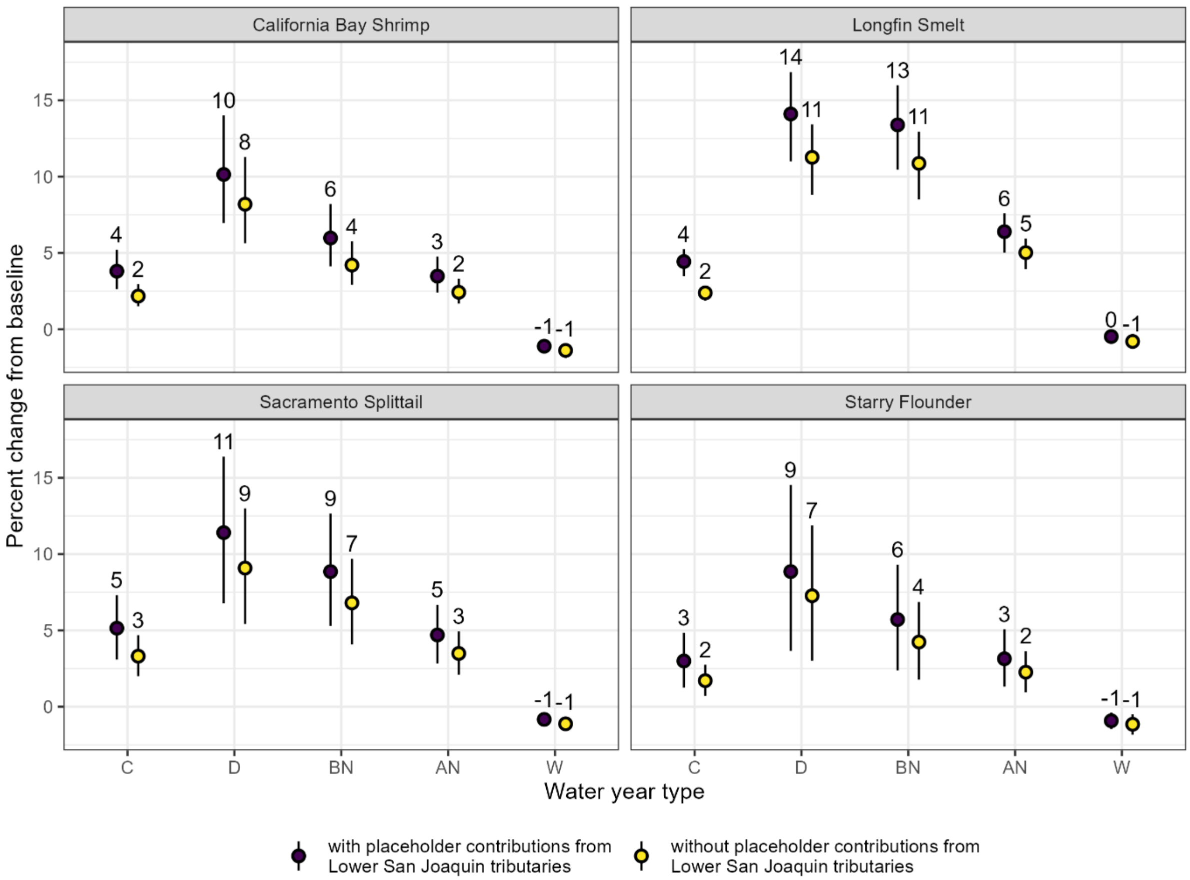

Figure 6-12. Potential Percent Change (Median Prediction ± 95% Confidence Intervals) in Abundance Indices Relative to Baseline Conditions
The median predictions (rounded to a whole number) are also printed above each point. The current August 2022 VA Term Sheet identifies placeholder San Joaquin River flow contributions. However, to date only Tuolumne River water users (as well as contributions from Friant water users) have signed on to the VA Term Sheet. To account for the range of possible VA flows from the lower San Joaquin River, this report includes an analysis of with and without placeholder lower San Joaquin River flow contributions to Delta outflow using the volumes identified in Appendix 1 of the VA Term Sheet.

Flow actions also have the potential to increase food supply in certain regions of the Estuary. For example, high abundances of the calanoid copepod *Pseudodiaptomus forbesi* occupy freshwater reaches of the Delta during the spring and summer regardless of inflow (Kimmerer et al. 2018b). During high flow years, these high densities are flushed into Suisun Marsh, which is hypothesized to be good habitat for Delta smelt, juvenile salmon, and other native fishes (Colombano et al. 2020; Sommer et al. 2020a; Aha et al. 2021). When spatial subsidies of zooplankton combine with a low salinity zone in Suisun Bay and Suisun Marsh, stationary habitat (extensive shallow water and wetlands), dynamic habitat (high turbidity, appropriate salinity, and lower temperatures), and food supply combine to create ideal conditions for pelagic fish species.

While not directly addressed by any actions within the VAs, returning to a more natural flow regime and restoring habitat for native species may limit the competitive advantage that invasive predatory fishes (centrachids, catfish, etc.) currently possess. Unfortunately, presence of invasive species may also limit the effectiveness of the actions proposed in the VAs, because invaders cannot be blocked from restoration sites and will not be excluded by flow actions.

Increased flows may decrease predation on juvenile salmonids by moving them more quickly through the system between habitat patches or to the ocean, providing a benefit for migrating juveniles. Higher flows increase survival rates of juvenile salmonids moving through the Delta, most likely due to decreased travel time and decreased exposure to predation (Perry et al. 2018). Greater Sacramento River inflow also results in a higher proportion of juvenile Chinook salmon from the Sacramento River basin remaining in the mainstem Sacramento River, as opposed to the entering the low-survival interior Delta via Georgiana Slough, for example (Perry et al. 2018; Hance et al. 2022). Perry et al. (2018) estimated the probability of survival of acoustic tagged late fall-run Chinook salmon from Freeport to Chipps Island to increase from just over 0.30 at ~7,000 cfs of Sacramento River inflow to 0.70 at over 75,000 cfs, with a particularly steep rate of increase up to ~35,000 cfs. Both Perry et al. (2018) and Hance et al. (2022) illustrated that flow-survival relationships are particularly strong in Delta reaches that transition between mostly riverine and mostly tidal, e.g., in the Sacramento River between Sutter/Steamboat Slough and Rio Vista. This is because the magnitude of Sacramento River inflow affects the amount of time flow is unidirectional (i.e., more riverine) versus bidirectional (i.e., more tidal), which affects factors such as travel time and the proportion of flow entering the interior Delta (Cavallo et al. 2015; Perry et al. 2016). Increased flows would decrease the amount of bidirectional flow in such reaches, thereby increasing the probability of juvenile Chinook salmon survival.

6.2.2 Delta and Estuary Habitat Analysis Results

The final habitat analysis results are reported as seasonally averaged acres of habitat in each region. Habitat calculations are described in Section 5.5.5, *Habitat Area Calculations*. Figure 6-13 through Figure 6-16 provide a summary of the seasonal results for each region for all scenarios. The overall seasonal averages (i.e., the average of the seasonal averages from all years) are compared for each species, with individual charts for each region. For Delta smelt and salmonid rearing—where mean, least restrictive, and most restrictive values were calculated—all three values are included in these charts. Dashed red lines indicate the total region wetted area (VA geometry) on the Delta and Suisun Region charts.

Overall seasonal average habitat area increases resulting from the VA scenario are generally small, relative to the total region wetted area, ranging from no change up to an increase of 4,000 acres, with a maximum increase of 14% over baseline for salmonid rearing in the Suisun region.

In the Delta region, the additional restoration area in the VA geometry configuration accounts for much of the increase over baseline habitat area for longfin smelt, salmonid rearing, and spring Delta smelt habitat. The same is true for salmonid rearing in the Suisun region; however, habitat areas for the other species are more affected by the flow changes. In the Bay region, flow impacts on EC drive habitat area differences for longfin smelt and spring Delta smelt. High EC in this region in the summer–fall seasons limits Delta smelt habitat, and VA scenario flow changes are not large enough to change this. Salmonid habitat in the Bay region is unaffected by flow changes.

Detailed seasonal results are tabulated in the following sections, and the habitat parameters for each species and season are provided in Section 5.5.6, *Species* (see Appendix A, *RMA Modeling Methods*).

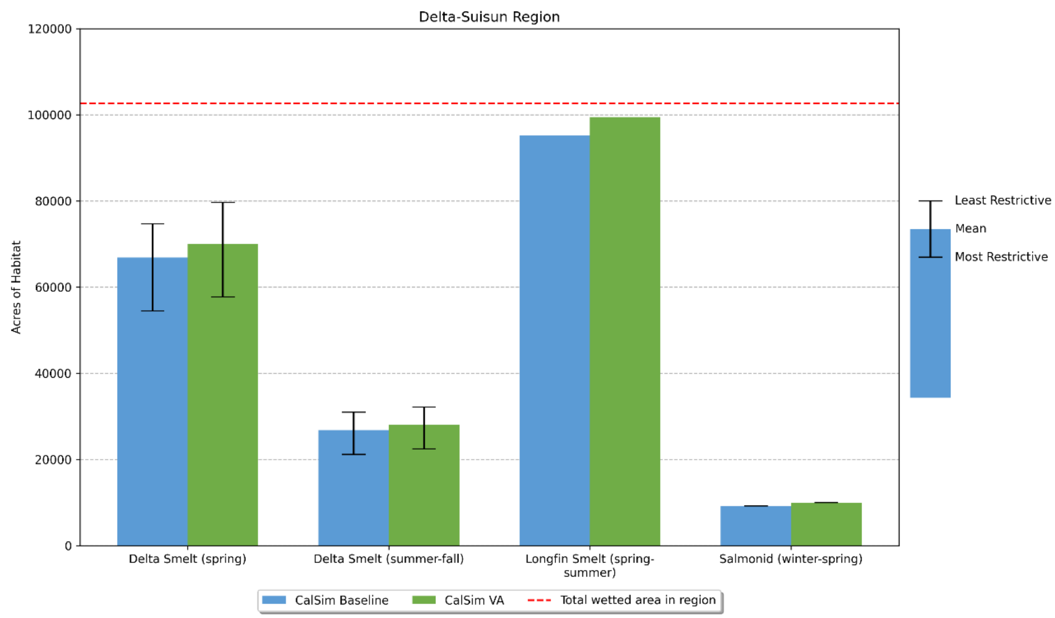

Figure 6-13. Overall Seasonal Average Habitat Areas by Species, for Each Scenario, in the Delta and Suisun Region

The x-axis represents species and season, and the y-axis represents acres of habitat. Paired bar graphs show acres of habitat by scenario for each of the species and season categories: light blue (CalSim baseline), green (CalSim VA). A dashed red line represents "total wetted area in region."

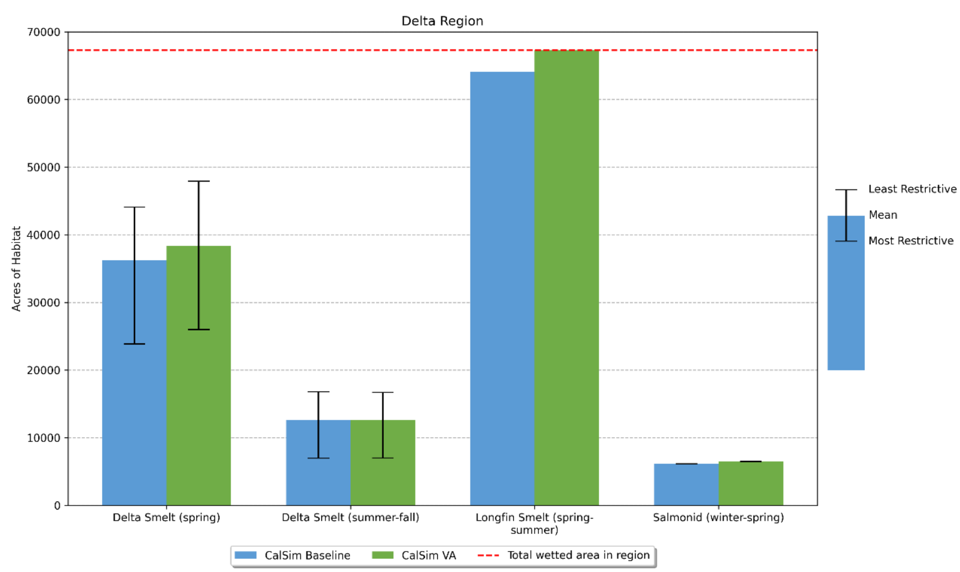

Figure 6-14. Overall Seasonal Average Habitat Areas by Species, for Each Scenario, in the Delta Region

The x-axis represents species and season, and the y-axis represents acres of habitat. Paired bar graphs show acres of habitat by scenario for each of the species and season categories: light blue (CalSim baseline), green (CalSim VA). A dashed red line represents "total wetted area in region."

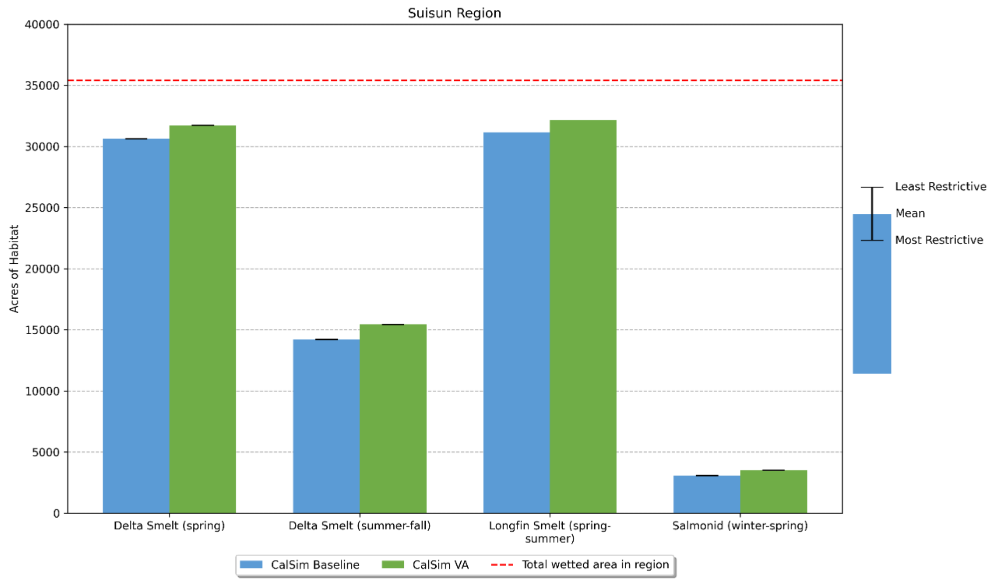

Figure 6-15. Overall Seasonal Average Habitat Areas by Species, for Each Scenario, in the Suisun Region
The x-axis represents species and season, and the y-axis represents acres of habitat. Paired bar graphs show acres of habitat by scenario for each of the species and season categories: light blue (CalSim baseline), green (CalSim VA). A dashed red line represents "total wetted area in region."

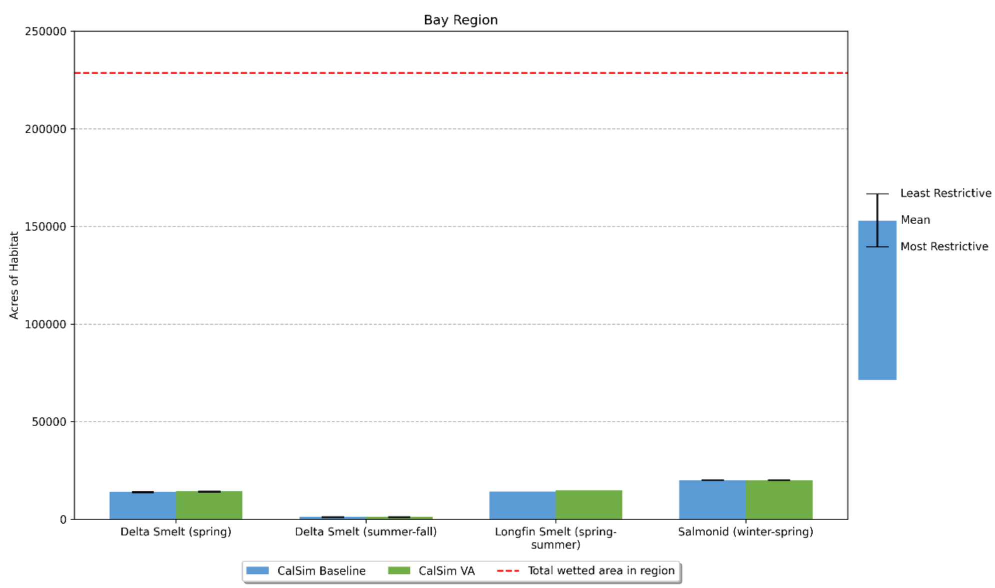

Figure 6-16. Overall Seasonal Average Habitat Areas by Species, for Each Scenario, in the Bay Region
The x-axis represents species and season, and the y-axis represents acres of habitat. Paired bar graphs show acres of habitat by scenario for each of the species and season categories: light blue (CalSim baseline), green (CalSim VA). A dashed red line represents "total wetted area in region."

6.2.2.1 Delta Smelt Habitat

Seasonal Delta smelt habitat results are reported for simulations using CalSim II operations model inputs (see Appendix B, *RMA Modeling Results*, Table 5 through Table 8). For each scenario, most restrictive, mean, and least restrictive seasonally averaged habitat acreages and percent change from baseline are tabulated. The seasons of interest for Delta smelt habitat are spring and summer–fall.

In the Delta region (see Appendix B, Table 5), the VA scenario increased spring Delta smelt habitat areas by 6–9% on average over baseline and changed the summer–fall habitat areas by less than 1%.

In the Suisun region (see Appendix B, Table 6), the VA scenario increased spring habitat on average by about 3.5%, and summer–fall habitat by 5–9%. There is little variation based on mean, least restrictive, and most restrictive, indicating that EC is the controlling factor for Delta smelt habitat in this region.

In the Bay region (see Appendix B, Table 8), the impacts of the VAs have a wide range, depending on water year type. For example, extremely dry years provide no Delta smelt habitat in this region, due to high salinity values, and the scenario flow changes are not sufficient to improve the habitat. Habitat in extremely wet years is not limited by salinity; therefore, flow changes are not very impactful. In between those extremes, the flow scenarios have impacts ranging from 2% to 1,300%.

6.2.2.2 Longfin Smelt Habitat

Seasonal longfin smelt habitat results are reported for simulations using CalSim II operations model inputs (see Appendix B, Table 13 through Table 16). For each scenario, seasonally averaged habitat acreages and percent change from baseline are tabulated. The season of interest for longfin smelt habitat is spring–summer.

In the Delta region (see Appendix B, Table 13), the VA scenario increased Longfin smelt habitat areas by 5% over baseline, indicating that the VA increase was due to geometry changes.

In the Suisun region (see Appendix B, Table 14), the VA scenario increased habitat by 1–3%.

In the Bay region (see Appendix B, Table 16), the VA scenario increased habitat area by around 3.5% on average.

6.2.2.3 Salmonid Rearing Habitat

Seasonal salmonid rearing habitat results are reported for simulations using CalSim II operations model inputs (see Appendix B, Table 21 through Table 24). For each scenario, most restrictive, mean and, least restrictive seasonally averaged habitat acreages and percent change from baseline are tabulated. The season of interest for salmonid rearing habitat is winter-spring.

VA scenario salmonid rearing habitat areas increase by approximately 6% over baseline in the Delta region and 12% in the Suisun region, with no change in the Bay region.

6.2.3 Benefits of Habitat Restoration

While there is a clear relationship between flow and abundance for many native fish species, other factors in addition to flow contribute to population viability. For example, the R-squared value for the relationship between juvenile salmon catch at Chipps Island and flow at Rio Vista provided in the 2017 Scientific Basis Report (p.3–44) is 0.44, meaning that 56% of the variability in salmon catch is explained by factors other than Rio Vista flow. Such non-flow factors could include area of available habitat, with habitat restoration potentially providing benefits related to many of the limiting factors discussed in Chapter 2, *Limiting Factors for Native Fish Species*, as discussed further below.

Restoration of tidal wetlands within the Delta is hypothesized to increase ecosystem productivity and provide increased food supply. This hypothesis is based both on analyses of primary production from tidal wetlands in the Estuary and on similar estuaries where large-scale restoration has resulted in significant improvement to fish populations. The Delta is currently composed mostly of deep, open-water habitats with low productivity due to lack of light penetration (Jassby et al. 2002; Dahm et al. 2016). The tidal wetlands that surround open-water areas carry resources and food into the open-water channels on the outgoing tide where they are available for pelagic species (Sherman et al. 2017), though these may or may not provide net export to open waters, see Yelton et al. (2022). Wetlands have high production of organic carbon produced by the large stands of emergent vegetation (in the Delta this is chiefly cattails [*Typha* spp.] and tules [*Schoenoplectus* spp.]). Carbon from vegetation forms the base of the foodweb in wetlands in the Delta (Howe and Simenstad 2011; Cohen et al. 2014; Schroeter et al. 2015; Young et al. 2021). While phytoplankton is also a critical part of the open-water foodweb (Sobczak et al. 2005), carbon from wetland plants was probably a much larger part of the open-water foodweb historically (Cloern et al. 2016).

The shallow water in wetlands also allows for greater phytoplankton production because light can penetrate to the bottom of the water column. This has been demonstrated both theoretically (Cloern 2007; Lucas et al. 2009) and empirically (Muller-Solger et al. 2002; Lopez et al. 2006; Lehman et al. 2015). Furthermore, water will remain within dead-end channels and wetland ponds longer than in river habitat, allowing for accumulation of greater phytoplankton biomass (Downing et al. 2016; Montgomery 2017). Longer water residence times can result in higher chlorophyll-*a* levels (Stumpner et al. 2020). For example, tidal slough in the North Delta adjacent to wetlands have relatively high levels of phytoplankton (Sommer et al. 2003; Lehman et al. 2010; Frantzich et al. 2018).

The VAs propose restoration of 5,227 acres of tidal wetlands within the Delta and Suisun Marsh. This is about 1% of the historical extent of tidal wetlands in the Delta. Cloern et al. (2021) conducted a literature review to determine median values for productivity on tidal wetlands in the Delta from major groups of primary producers (Table 6-4). Given 5,227 acres of additional tidal wetland restoration in the Delta, and assuming restoration of agricultural land or other areas not hydrologically connected, this could result in additional algal production of 80,000–280,000 kg/yr and additional vascular plant production of over 1,000,000 kg/yr, or an increase in aquatic primary production of 1.5% over current levels of productivity.

Table 6-4. Potential Primary Production Rates in Freshwater Tidal Wetlands in the Delta as Derived by Cloern et al. (2021) and Scaled Up to the Potential Production from 5,000 Acres of Tidal Wetland Restoration Included in the VAs

Primary Producer group	Median and Interquartile Range (from Cloern et al. 2021)	Potential Production from VA Restoration Sites
Phytoplankton	44.9 (25.2–68.62) $g/m^2/yr$	90,855 (50,992–138,852) kg/yr
Epiphytic algae	44 (14–71) $g/m^2/yr$	89,034 (28,329–143,669) kg/yr
Marsh plants	576 (388–917) $g/m^2/yr$	1,165,536 (785,118–1,855,550) kg/yr

The high concentrations of organic carbon and phytoplankton in wetlands provide food for the zooplankton and other invertebrates that fish eat. Recent research has found higher zooplankton and invertebrate abundance in freshwater tidal wetland complexes than in other parts of the Delta (Montgomery 2017; Frantzich et al. 2018), particularly in the Cache Slough Complex (Kimmerer et al. 2018a). As with phytoplankton, small, dead-end channels and wetlands can also support higher biomass of zooplankton than larger channels or rivers (Frantzich et al. 2018; Corline et al. 2021). Wetlands also provide high biomass of epiphytic and epibenthic invertebrates, such as amphipods, isopods, and insect larvae, that are often more nutritious than zooplankton (Howe et al. 2014; Whitley and Bollens 2014; Hartman et al. 2019). Terrestrial arthropods are also more abundant in wetland habitats than in open water, which is particularly important for juvenile salmon rearing (David et al. 2016). Accessing these resources may be particularly important for native fishes, given recent declines in zooplankton biomass (Winder and Jassby 2011; Brown et al. 2016a).

Benefits of increased food supply directly translate to increased fish foraging efficiency, growth, and survival. Many native and nonnative fishes forage in tidal wetlands in the Estuary, where they feed on epiphytic and epibenthic invertebrates as well as zooplankton (Colombano et al. 2021). Hammock et al (2019) found an increase in stomach fullness in fish captured near areas of extended tidal wetlands—even when nearby zooplankton sampling indicated zooplankton biomass was low. The conclusion was that fish may be foraging in tidal wetlands and accessing resources not available to the channel-based zooplankton tows. Juvenile salmon growth rates in complex off-channel remnant floodplain habitats were higher when compared to main-channel habitats (Limm and Marchetti 2009; Sturrock et al. 2022b). In sites restored in the Salmon River Estuary, Oregon, juvenile salmon foraged primarily on amphipods in older marshes and on chironomids in newer marshes, but all sites supported large numbers of juvenile salmon (Gray et al. 2002). Riparian and marsh vegetation was associated with higher feeding rates in juvenile salmon in the Fraser River Estuary (Levings et al. 1991; Levings and Nishimura 1997) and the Nisqually River Delta (Woo et al. 2019).

The 20,000 acres of managed flood plains in the Sutter Bypass, Butte Sink, and Colusa Basin that are to be managed for fish food production are also expected to help increase food availability. Salmon reared near outfalls from managed wetlands or rice fields also have higher growth and condition factors than those reared further from sources of wetland production (Jeffres et al. 2020; Aha et al. 2021). These habitats with higher water residence times produce higher chlorophyll-*a*, zooplankton biomass, and ultimately higher salmon growth rates (Cordoleani et al. 2022). Zooplankton prey biomass is elevated in these habitats, which may be contributing to the increased growth rates (Corline et al. 2017; Aha et al. 2021). Zooplankton subsidies from floodplains can also benefit fish further downstream (Sturrock et al. 2022b).

Besides providing productivity, wetlands provide physical habitat as a chance for fish to feed and grow. Salmonids frequently use estuaries as habitat to feed and reside in along their migratory journey (Moore et al. 2016). Magnussen and Hilborn (2003) found that salmonids that rear in west coast estuaries have higher survival than those that rear in other habitats, but overall survival of Pacific salmon is correlated to the percentage of the Estuary that is in pristine condition. Therefore, increasing the area of habitat in the Delta that is appropriate for salmon rearing should increase the survival of juvenile salmonids in their emigration to the ocean (Herbold et al. 2018). It was estimated that approximately 23,475 acres of additional marsh habitat in the Estuary would create well-distributed, suitable habitat for outmigrating salmon (SFEI 2020), so the VAs would contribute approximately 25% of this amount. In other systems, tidal marshes have been shown to increase juvenile salmon survival and provide important refuges to allow salmonid growth, maximizing their size at ocean entry (Chalifour et al. 2019; Davis et al. 2019b). Estuaries can benefit and support different salmonid life histories, thereby increasing population resilience (Craig et al. 2014).

While the VA restoration commitment includes 5,227 acres of stationary habitat, this restoration must overlap with appropriate water quality conditions in order to provide fish habitat. Not all of this habitat will be appropriate for salmonid rearing. In the Delta and Suisun Region, the modeled VA scenario increased salmonid winter–spring rearing habitat areas by 789 acres (on average). The VA scenario did not increase salmonid winter–spring rearing habitat in the Bay region (CalSim II operations model, "all years" simulation season, most restrictive, Appendix B, Table 23 and Table 24). There was no variability among individually modeled years (Appendix B, Table 24). While not all the tidal wetland restoration can be directly used for winter–spring rearing every year, wetland restoration may provide increased resiliency through a broadened portfolio of potential habitat that may be appropriate in different water year types. Furthermore, the habitat will provide increased primary productivity that may be transported to regions of the Estuary with better habitat.

There are relatively few areas within the Delta that are close enough to large tidal marshes (i.e., >500 hectares, a size associated with the presence of dendritic channel networks) to allow juvenile salmonids to reach them within one day of swimming (fry: 2 km; smolts: 15 km; SFEI 2020:33–34). Tidal habitat restoration under the VAs could therefore increase habitat connectivity for juvenile salmonids.

Water quality factors will also improve with habitat restoration. For example, temperatures in wetlands may be reduced when compared to unvegetated shallow water habitat due to shading from vegetation and cooling of water at night on the marsh plain (Enright et al. 2013). Restoration projects in regions that already have lower temperatures may increase their effectiveness at providing refugia in a changing climate (Mahardja et al. 2022). While none of the VA actions are designed specifically to address contaminant stressors, restoration of wetlands may help remove pesticides from the water (Budd et al. 2009), and converting managed wetlands to tidal wetlands may reduce mercury methylation (Lee and Manning 2020). Converting managed wetlands or agricultural fields to tidal wetlands may also reduce issues with low dissolved oxygen exported from the site (Stringfellow et al. 2008; Siegel et al. 2011).

6.2.4 Synergy between Flow and Non-flow Habitat

While both flow and non-flow habitat are important in and of themselves, optimal conditions for native species only occur when both flow and non-flow habitat function in conjunction with each other. In the Estuary, the dynamic components of habitat (temperature, turbidity, salinity, etc.) are influenced heavily by freshwater flow, whereas the static components of habitat targeted by restoration projects are not (Feyrer et al. 2021). If restoration projects increase the amount of stationary habitat but flow conditions do not provide optimal dynamic habitat, the expected benefit of habitat restoration will not be realized. Similarly, if high flows provide optimal water quality but the area with optimal water quality occurs in a channelized, rip-rapped physical region of the Estuary, the expected benefit of the dynamic habitat will not be realized.

This situation is demonstrated best by the concept of low salinity zone habitat for Delta smelt (Figure 6-17). As explained in the 2017 Scientific Basis Report, increased Delta outflow will move X2 further downstream so that the low salinity zone (the 'dynamic habitat,' specifically the area where salinity is between 0.5–6 ppt) is centered in Suisun Bay. This area has more tidal wetlands, extended shallows, and hydrodynamic complexity (good stationary habitat) than upstream regions (Feyrer et al. 2011; IEP-MAST et al. 2015; Feyrer et al. 2021; FLOAT-MAST 2021).

In the Delta and Suisun Region, the modeled VA scenario increased longfin smelt spring–summer average habitat by 4,238 acres on average. The modeled VA scenario increased habitat in the Bay region by 490 acres (CalSim II operations model, "all years" simulation season, Appendix A, Table 15 and Table 16). However, there was variability among individually modeled years (Appendix A, Table 16). The modeled VA scenario similarly increased Delta smelt spring and summer–fall average habitat in the Delta and Suisun Region by 9,805 acres and increased average habitat in the Bay region by 9 acres (CalSim II operations model, "all years" simulation season, most restrictive Appendix A, Table 7). However, there was variability among individually modeled years (Appendix A, Table 7). This analysis shows that while stationary habitat restoration only provides an increase of 5,227.5 acres, flow and non-flow habitat restoration together increase available habitat by over 9,000 acres.

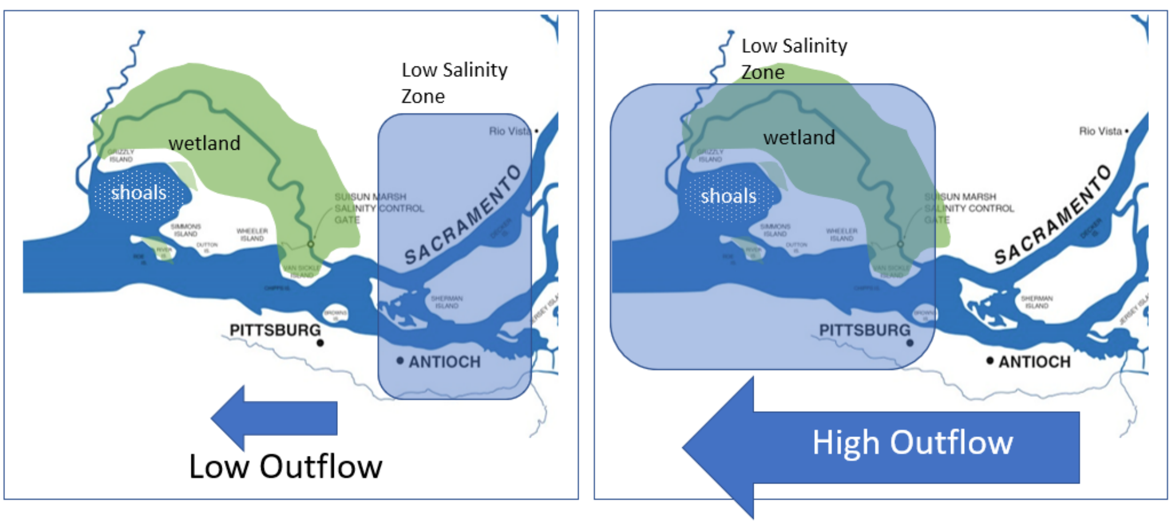

Figure 6-17. Delta Smelt Preferred Dynamic Habitat Shifts Eastward with Decreased Outflows and Westwards with Increased Outflows
***At low* outflow (left panel), the low salinity zone is upstream in the narrow, rip-rapped channels of the Sacramento and San Joaquin Rivers where the total habitat size (quantity) is low, and the stationary habitat quality is also low. At high outflows, the low salinity zone overlaps with Suisun Marsh where there is better quality of stationary habitat and larger quantity of appropriate dynamic habitat.**

Similarly, the synergy of flow and non-flow habitat may explain the mechanisms behind some of the observed flow-abundance relationships. Longfin smelt have one of the strongest flow-abundance relationships of any fish in the Estuary (Kimmerer 2002). One hypothesized mechanism is that higher flows allow spawning longfin smelt access to the productive, lower-temperature wetlands on the edge of Suisun Bay and San Pablo Bay by lowering salinity of these areas. Large numbers of longfin smelt are found rearing in these regions during wet years, but not during dry years, suggesting that spawning in the region is flow-dependent (Parker et al. 2017; Lewis et al. 2019). However, another analysis found that, east of Carquinez Straight, longfin smelt larval abundance was poorly related to outflow, indicating that rearing habitat, rather than spawning habitat, was behind the strong relationship between flow and abundance (Kimmerer and Gross 2022). Regardless, increases in Delta outflow will only be effective if habitat is available, and restoration in the mesohaline regions of Suisun Bay and San Pablo Bay will increase the benefits of increases to flow.

Flow can increase connectivity between off-channel habitats for salmonids (Ellings et al. 2016; Perry et al. 2018), and between natal streams and rearing habitat lower in the system. Flows and habitat structure also influence optimal water quality conditions in the tributaries, including temperature, dissolved oxygen, and channel velocities that benefit spawning salmonids (Merz 2004; Merz et al. 2019) and survival of early life stages of Chinook salmon (Del Rio et al. 2019). River flows can interact with tides in the Delta to affect travel time and survival (Perry et al. 2018). This is discussed in more depth in Section 6.2.2, *Delta and Estuary Habitat Analysis Results*, and Section 6.2.3, *Benefits of Habitat Restoration*.

6.3 Systemwide

High flows are critical for many of California's native species. However, flow may not be able to recover at-risk fish species when the frequency of floods and droughts increases with climate change. Reliance on one management tool, such as flow, is less likely to result in a desired outcome, given the level of uncertainty with future conditions. While flow actions rely on a certain amount of precipitation falling each year, many habitat restoration sites may be available to fishes in all water years. Restoring aspects of a natural flow regime is more effective when paired with physical habitat restoration in order to achieve optimal system resiliency, as reviewed by Chilton et al (Chilton et al. 2021), and suggested for the Estuary by Robinson et al. (2016). With estuarine fish populations at all-time lows, and resilience of many fishes to drought-managed flows decreasing over time (Mahardja et al. 2021), the system may no longer have the flexibility to recover from major ecological disturbances. Both habitat restoration and changes to flows have been proposed in the Delta Smelt Resiliency Strategy (California Natural Resources Agency 2016) and the Sacramento Valley Salmon Resiliency Strategy (California Natural Resources Agency 2017); the VAs expand on these initial goals.

Improvements in multiple types of rearing habitat over upstream regions, off-channel habitat, and estuarine habitat can increase population resiliency through a "portfolio effect," which may assist with population persistence even in low flow years (Robinson et al. 2016; Herbold et al. 2018; Woo et al. 2019). The portfolio effect is an ecological principle addressing how multiple life history strategies, habitat types, or species will increase a community's resiliency (Schindler et al. 2015). The construction of dams, water management, and the subsequent reliance on hatcheries for salmon in the Central Valley has weakened the portfolio effect in the population as a whole (Satterthwaite et al. 2015; Satterthwaite et al. 2017). Future strategies should bolster a greater diversity of life history strategies with diverse rearing habitats and unique spawning habitats in order to restore lost resilience (Yamane et al. 2018).

Chapter 7
Conclusions and Uncertainties

Native aquatic species have been declining in tributaries, off-stream habitats, and the Bay-Delta due to anthropogenic stressors. These stressors include inadequate flows, barriers to habitat connectivity, impaired water quality, direct entrainment, limited high-quality habitat, reduced food supply, invasive species, and climate change. The VAs propose a combination of flow and restoration assets to improve conditions for native species under the hypothesis that habitat restoration in combination with higher flows will provide enhanced benefits (Voluntary Agreements Parties 2022). As previously described, for the purposes of this Draft Supplement Report, the VA flow and non-flow habitat assets are analyzed consistent with the 2017 Scientific Basis Report regulatory baseline (e.g., D-1641 and the 2008/2009 BiOps).

The expectation from the VAs is that the proposed combination of flow and non-flow restoration assets improve conditions for native species to achieve two objectives: (1) the existing narrative objective in the Bay-Delta Plan to double salmon populations by the year 2050 relative to the reference population of 1967–1991 and (2) a new narrative objective to “maintain water quality conditions, including flow conditions in and from tributaries and into the Delta, together with other measures in the watershed, sufficient to support and maintain the natural production of viable native fish populations” (Voluntary Agreements Parties 2022).

To evaluate the scientific support for the expectation of achieving the dual objectives, this report analyzed the contributions of the proposed flow and restoration assets toward habitat and population increases for salmonids and estuarine fishes. This was achieved through quantitative modeling coupling hydrodynamic and operations models to flow-dependent habitat and abundance models. A qualitative literature review was used where no quantitative models exist (e.g., linking habitat improvements to expected population-level outcomes).

The quantitative analyses indicate expected increases in suitable spawning and rearing habitat for salmonids and increases in suitable habitat and population abundance indices for estuarine species. Salmonid spawning (Figure 6-1, Figure 6-2, Table 6-1), rearing (Figure 6-3, Figure 6-4, Figure 6-10, Figure 6-11, Table 6-2, Table 6-3), and floodplain (Figure 6-5, Figure 6-6, Figure 6-7, Figure 6-8, Figure 6-9) habitats are expected to contribute toward the narrative objectives described above. However, the magnitude of increase varies with water year type and tributary such that not all habitat categories will have increases in all water year types. The VAs are projected to surpass the spawning habitat needed to support 25% of the doubling goal (the target for the VAs) in all tributaries (Figure 6-1). The combination of instream rearing and floodplain habitat needed to support 25% of the doubling goal population is projected to be met in the Mokelumne (which currently meets the target) and Yuba Rivers, but not in the American, Feather, and Sacramento Rivers (Figure 6-10). Sacramento River rearing habitat would surpass the habitat needed to support 25% of the doubling goal population with the addition of 20,000 acres of floodplain restoration on the Sutter Bypass, provided that juvenile fish passage considerations can be addressed. Floodplain habitat is expected to be provided to support 25% of the doubling goal population in 80–98% of years in the Feather (84%; Figure 6-5), Mokelumne (80%; Figure 6-6), and Yuba (Figure 6-7; 98%) Rivers. Habitat areas for estuarine species are also expected to increase in the Bay-Delta (Figure 6-13, Figure 6-14, Figure 6-15, Figure 6-16) contributing toward the narrative objective for viable native fish populations proposed in the VAs. However, increases are small relative to total region size. Abundance indices based on increases in flows under the VAs of four species (California Bay shrimp, Sacramento splittail, longfin smelt, and starry flounder) are expected to increase in all water year types except wet years (in which they are expected to decrease) (Figure 6-12). Qualitatively, the synergy of flow and non-flow habitat restoration assets proposed in the VAs is expected to improve conditions for salmonids and estuarine species toward achieving the proposed new narrative viable native fish population objective and existing salmon protection objective.

While the modeling and qualitative analyses described above indicate expected benefits from the VAs, the actual outcomes of the VAs are not certain at this time. As with all modeling analyses, the results have uncertainty arising from assumptions and simplifications.

1. The VAs have some flexibility for when assets could be provided and the outcome could deviate from modeled results in this report if not provided on the proposed schedule.
2. Analysis of habitat restoration benefits is based on the assumption that restored sites will replicate natural ecosystem functions, and that restoration sites will be maintained over time such that species benefits do not diminish over time.
3. Specific locations for VA habitat restoration projects are not yet available, so the modeling relied upon possible locations selected with regional expert opinion. Different locations for these restoration projects could affect the actual outcomes.
4. While baseline suitable spawning and rearing habitat area was determined with a quantitative method (weighted usable area; Section 5.2.1, *Existing Habitat Quantification*), based on needs of fall-run Chinook salmon, VA proposed spawning and rearing habitat was all assumed to be suitable from expert opinion and commitments from the VA Parties, and it was not informed by water temperature. If the habitat is not all suitable, that would reduce the VA habitat contributions.
5. The MFE method was designed conservatively so suitable habitat would be guaranteed. This likely underestimated the amount of floodplain habitat that would be available.
6. Current and future hydrologic conditions will likely be more extreme than the modeling periods used, which were limited by computational demands. While the modeling periods did include past extreme events (e.g., the DSM2 modeling period of 1975–1991 included an extreme drought and wet year), they may not be fully reflective of the current conditions (e.g., extended dry periods) and those expected in the future (e.g., climate whiplash [Swain et al. 2018]).
7. The quantitative connection between restored non-flow habitat and species abundance was not modeled, only evaluated qualitatively, so benefits are expected but unquantified with respect to species abundance. However, the flow-abundance relationship was quantified.
8. Analyses were focused on a few at-risk species with the expectation that the benefits for those species would apply more generally to all native aquatic species, natural ecosystem functions, and other natural processes fundamental to all beneficial uses of water resources. For salmonids in particular, modeling was conducted based on needs of fall-run Chinook salmon, but needs of other species and runs will vary.

The VAs, if adopted, would include a set of implementation criteria and habitat suitability and utilization criteria, along with a monitoring program, to ascertain the actual benefits realized and overall program success. As described in more detail in Chapter 1, *Introduction*, the VA governance, strategic planning, and science programs are under development and are proposed to work to address uncertainties described above with oversight by the State Water Board.

Chapter 8
References

Aha, N.M., Moyle, P.B., Fangue, N.A., Rypel, A.L. and Durand, J.R. 2021. Managed Wetlands Can Benefit Juvenile Chinook Salmon in a Tidal Marsh. *Estuaries and Coasts*, 44: 1440-1453.

Ahearn, D.S., Viers, J.H., Mount, J.F. and Dahlgren, R.A. 2006. Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. *Freshwater Biology*, 51: 1417-1433.

Anchor QEA, LLC. 2019. *Conservation Planning Foundation for Restoring Chinook Salmon (Oncorhynchus Tshawytscha) and O. mykissin the Stanislaus River.* Available: https://www.scienceforconservation.org/assets/downloads/SEP_Report_April_2019.pdf. Accessed: December 28, 2022.

Anderson, J. 2006. Review of the 2005 Environmental Water Account Workshop. p. 14.

Anderson, J. J., E. Gurarie, and R. W. Zabel. 2005. Mean free-path length theory of predator-prey interactions: Application to juvenile salmon migration. Ecological Modelling 186:196-211. https://doi.org/10.1016/j.ecolmodel.2005.01.014

Anzalone, S.E., Fuller, N.W., Hartz, K.E.H., Fulton, C.A., Whitledge, G.W., Magnuson, J.T. et al. 2022. Pesticide residues in juvenile Chinook salmon and prey items of the Sacramento River watershed, California–A comparison of riverine and floodplain habitats. *Environmental Pollution*, 303: 119102.

Avila, M. and Hartman, R. 2020. San Francisco Estuary mysid abundance in the fall, and the potential for competitive advantage of *Hyperacanthomysis longirostris* over *Neomysis mercedis*. *California Fish and Wildlife*, 106(1): 19-38.

Baker, P. and Morhardt, J. 2001. Survival of Chinook Salmon Smolts in the Sacramento-San Joaquin Delta and Pacific Ocean. *Fishery Bulletin 179, Volume 2. Contributions to the Biology of Central Valley Salmonids*: 163-182.

Baldwin, A.H., Egnotovich, M.S. and Clarke, E. 2001. Hydrologic change and vegetation of tidal freshwater marshes: Field, greenhouse, and seed-bank experiments. *Wetlands*, 21(4): 519-531.

Barros, A., Hobbs, J.A., Willmes, M., Parker, C.M., Bisson, M., Fangue, N.A. et al. 2022. Spatial Heterogeneity in Prey Availability, Feeding Success, and Dietary Selectivity for the Threatened Longfin Smelt. *Estuaries and Coasts*, 45: 1766-1779.

Bashevkin, S.M. and Mahardja, B. 2022. Seasonally variable relationships between surface water temperature and inflow in the upper San Francisco Estuary. *Limnology and Oceanography*, 67: 684-702.

Bashevkin, S.M., Mahardja, B. and Brown, L.R. 2022. Warming in the upper San Francisco Estuary: Patterns of water temperature change from 5 decades of data. *Limnology and Oceanography*, 67(5): 1065-1080.

Baumsteiger, J., Schroeter, R.E., O'Rear, T.A., Cook, J.D. and Moyle, P.B. 2017. Long-Term Surveys Show Invasive Overbite Clams (*Potamocorbula amurensis*) are Spatially Limited in Suisun Marsh, California. *San Francisco Estuary and Watershed Science*, 15(2).

Baxter, R.D. 1999. Osmeridae. In: *Report on the 1980-1995 fish, shrimp and crab sampling in the San Francisco Estuary* (ed. Orsi, J). Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 63, pp. 179-216.

Bayley, P. B. 1991. The flood pulse advantage and the restoration of river-floodplain systems. Regulated Rivers: Research and Management 6:75-86. https://doi.org/10.1002/rrr.3450060203

Beckman, B.R., Dickhoff, W.W., Zaugg, W.S., Sharpe, C., Hirtzel, S., Schrock, R. et al. 1999. Growth, Smoltification, and Smolt-to-Adult Return of Spring Chinook Salmon from Hatcheries on the Deschutes River, Oregon. *Transactions of the American Fisheries Society*, 128(6): 1125-1150.

Beechie, T., Imaki, H., Greene, J., Wade, A., Wu, H., Pess, G. et al. 2013. Restoring salmon habitat for a changing climate. *River Research and Applications*, 29(8): 939-960.

Bellmore, J.R., Baxter, C.V., Martens, K. and Connolly, P.J. 2013. The floodplain food web mosaic: a study of its importance to salmon and steelhead with implications for their recovery. *Ecological Applications*, 23(1): 189-207.

Benigno, G.M. and Sommer, T.R. 2008. Just add water: sources of chironomid drift in a large river floodplain. *Hydrobiologia*, 600(1): 297-305.

Bever, A.J., MacWilliams, M.L. and Fullerton, D.K. 2018. Influence of an Observed Decadal Decline in Wind Speed on Turbidity in the San Francisco Estuary. *Estuaries and Coasts*, 41(7): 1943-1967.

Bever, A.J., MacWilliams, M.L., Herbold, B., Brown, L.R. and Feyrer, F.V. 2016. Linking hydrodynamic complexity to Delta Smelt (*Hypomesus transpacificus*) distribution in the San Francisco Estuary, USA. *San Francisco Estuary and Watershed Science*, 14(1).

Boughton, D.A. and Pike, A.S. 2013. Floodplain Rehabilitation as a Hedge against Hydroclimatic Uncertainty in a Migration Corridor of Threatened Steelhead. *Conservation Biology*, 27: 1158-1168.

Brandes, P. L., and J. S. McLain. 2001. Abundance and survival of juvenile Chinook salmon in the Sacramento-San Joaquin estuary. Fish Bulletin. 131 pages.

Brenneis, V.E., Sih, A. and de Rivera, C.E. 2011. Integration of an invasive consumer into an estuarine food web: direct and indirect effects of the New Zealand mud snail. *Oecologia*, 167(1): 169-179.

Bridges, B.B., Wu, B.J., Reyes, R.C., Bowen, M.D. and Bark, R.C. 2019. Effects of Striped Bass Predation on Salvage of Adult Delta Smelt and Juvenile Chinook Salmon at the Tracy Fish Collection Facility. Volume 45. In: *Tracy Series* Byron, CA, p. 77 pp.

Brown, L.R. 2003. Will tidal wetland restoration enhance populations of native fishes? *San Francisco Estuary and Watershed Science*, 1(1): 43 pages.

Brown, L.R., Kimmerer, W., Conrad, J.L., Lesmeister, S. and Mueller–Solger, A. 2016a. Food webs of the Delta, Suisun Bay, and Suisun Marsh: an update on current understanding and possibilities for management. *San Francisco Estuary and Watershed Science*, 14(3).

Brown, L.R., Komoroske, L.M., Wagner, R.W., Morgan-King, T., May, J.T., Connon, R.E. et al. 2016b. Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish. *PLOS ONE*, 11(1): e0146724.

Budd, R., O'Geen, A., Goh, K.S., Bondarenko, S. and Gan, J. 2009. Efficacy of constructed wetlands in pesticide removal from tailwaters in the Central Valley, California. *Environmental science and technology*, 43(8): 2925-2930.

California Department of Fish and Game (CDFG). 2001. Evaluation of Effects of Flow Fluctuations on the Anadromous Fish Populations in the Lower American River. Stream Evaluation Program. California Department of Fish and Game.

California Department of Fish and Wildlife (CDFW). 2012. Sutter Bypass - Weir I - Fish Ladder Passage Issue/Fish Die-off. California Department of Fish and Wildlife, North Central Region.

California Department of Fish and Wildlife (CDFW). 2016a. Summary of fish rescues conducted within the Yolo and Sutter bypasses. Beccio, M California Department of Fish and Wildlife, North Central Region.

California Department of Fish and Wildlife (CDFW). 2016b. Fall midwater trawl monthly abundance indices. Available: http://www.dfg.ca.gov/delta/data/fmwt/indices.asp. Accessed: April 15, 2016.

California Department of Fish and Wildlife (CDFW). 2017. Summary of Fish Rescues Conducted at the Fremont Weir and Northern Yolo Bypass Winter 2016 through Spring 2017. California Department of Fish and Wildlife, North Central Region.

California Department of Fish and Wildlife (CDFW). 2021. Butte Creek Spring-run Chinook Salmon Adult Monitoring Annual Report 2021. Wildlife, CDoFa. California Department of Fish and Wildlife, North Central Region.

California Department of Fish and Wildlife (CDFW). 2022. Wallace Weir Fish Trapping and Relocation Efforts 2019–2020. California Department of Fish and Wildlife, North Central Region.

California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation). 2012. Yolo Bypass salmonid habitat restoration and fish passage implementation plan. Department of Water Resources Fish Passage Improvement Program, FloodSAFE Environmental Stewardship and Statewide Resources Office (DWR FESSRO), Sacramento, CA; U.S. Bureau of Reclamation, Mid-Pacific Region (Reclamation), Sacramento, CA. Available: http://www.water.ca.gov/fishpassage/docs/yolo2.pdf. Accessed: 6/3/16.

California Department of Water Resources (DWR). 2004. *Phase 2 Report Evaluation of Project Effects on Instream Flows and Fish Habitat SP F-16*. Available: https://s3-us-west-2.amazonaws.com/cvpiahabitat-r-package/cvpia-sit-model-inputs/Feather_FERC_IFIM_Phase_2.pdf. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2005. *Addendum to Phase 2 Report Evaluation of Project Effects on Instream Flows and Fish Habitat SP-F16. Oroville Facilities Relicensing FERC Project No. 2100*. Available: https://cvpiahabitat-r-package.s3-us-west-2.amazonaws.com/F16_phase_2_addendum.pdf. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2012. *San Francisco Bay and Sacramento-San Joaquin Delta DEM version 3 (Superseded).* Available: https://data.cnra.ca.gov/dataset/san-francisco-bay-and-sacramento-san-joaquin-delta-dem-v3. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2017. Dayflow Data through Water Year 2016. Available: https://data.cnra.ca.gov/dataset/dayflow.

California Department of Water Resources (DWR). 2018. *San Francisco Bay and Sacramento-San Joaquin Delta DEM version 4.1 (Superseded).* Available: https://data.cnra.ca.gov/dataset/san-francisco-bay-and-sacramento-san-joaquin-delta-dem-for-modeling-version-4-1. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2019. Yolo Bypass released Hatchery-origin Chinook salmon 2018-2019 Season (PROVISIONAL DATA).

California Department of Water Resources (DWR). 2019a. Investigating Yolo Bypass as a Fall Food Web Subsidy for the Delta. California Natural Resources Agency California Department of Water Resources, West Sacramento, CA.

California Department of Water Resources (DWR). 2019b. Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project, Environmental Impact Statement, Environmental Impact Report. Resources, BoRaCDoW.

California Department of Water Resources (DWR). 2020. Tisdale Weir Rehabilitation and Fish Passage Project (EIR/EIS). California Department of Water Resources, Sacramento, CA.

California Department of Water Resources (DWR). 2022a. *Delta Bathymetry Catalog.* Available: https://gis.water.ca.gov/app/bathymetry/. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2022b. *Cross Section Development Program NAVD88 Update.* Available: https://data.ca.gov/dataset/cross-section-development-program-navd88-update. Accessed: December 28, 2022.

California Department of Water Resources (DWR). 2022c. *Elevation/SacDelta_LiDAR_DEM_2007 (Image Serve).* Available: https://gis.water.ca.gov/arcgisimg/rest/services/elevation/SacDelta_LiDAR_DEM_2007/ImageServer. Accessed: December 28, 2022

California Natural Resources Agency. 2016. Delta Smelt Resiliency Strategy. California Natural Resources Agency Sacramento, CA, p. 13pp.

California Natural Resources Agency. 2017. Sacramento Valley Salmon Resiliency Strategy. California Natural Resources Agency Sacramento, CA, p. 13pp.

Carlson, S.M. and Satterthwaite, W.H. 2011. Weakened portfolio effect in a collapsed salmon population complex. *Canadian Journal of Fisheries and Aquatic Sciences*, 68(9): 1579-1589.

Caudill, J., Madsen, J. and Pratt, W. 2021. Operational aquatic weed management in the California Sacramento-San Joaquin River Delta. *J. Aquat. Plant Manage*, 59: 112-122.

Cavallo, B., Gaskill, P., Melgo, J. and Zeug, S.C. 2015. Predicting juvenile Chinook Salmon routing in riverine and tidal channels of a freshwater estuary. *Environmental Biology of Fishes*, 98(6): 1571-1582.

Central Valley Flood Protection Board. 2016. *Appendix H. Central Valley Chinook Salmon Rearing Habitat Required to Satisfy the Anadromous Fish Restoration Program Doubling Goal*. Available: http://cvfpb.ca.gov/wp-content/uploads/2017/08/ConservStrat-App-H-Chinook-Salmon-Rearing-Habitat.pdf. Accessed: December 28, 2022.

Chalifour, L., Scott, D.C., MacDuffee, M., Iacarella, J.C., Martin, T.G. and Baum, J.K. 2019. Habitat use by juvenile salmon, other migratory fish, and resident fish species underscores the importance of estuarine habitat mosaics. *Marine Ecology Progress Series*, 625: 145-162.

Chilton, D., Hamilton, D.P., Nagelkerken, I., Cook, P., Hipsey, M.R., Reid, R. et al. 2021. Environmental Flow Requirements of Estuaries: Providing Resilience to Current and Future Climate and Direct Anthropogenic Changes. *Frontiers in Environmental Science*, 9(534).

Cloern, J.E. and Jassby, A.D. 2010. Patterns and Scales of Phytoplankton Variability in Estuarine–Coastal Ecosystems. *Estuaries and Coasts*, 33(2): 230-241.

Cloern, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series*, 210: 223-253.

Cloern, J.E. 2007. Habitat connectivity and ecosystem productivity: implications from a simple model. *The American Naturalist*, 169(1): E21-E33.

Cloern, J.E., Robinson, A., Richey, A., Grenier, L., Grossinger, R., Boyer, K.E. et al. 2016. Primary production in the Delta: then and now. *San Francisco Estuary and Watershed Science*, 14(3).

Cloern, J.E., Safran, S.M., Smith Vaughn, L., Robinson, A., Whipple, A.A., Boyer, K.E. et al. 2021. On the human appropriation of wetland primary production. *Science of The Total Environment*, 785: 147097.

Cohen, R.A., Wilkerson, F.P., Parker, A.E. and Carpenter, E.J. 2014. Ecosystem-scale rates of primary production within wetland habitats of the Northern San Francisco Estuary. *Wetlands*, 34(4): 759-774.

Colombano, D.D., Manfree, A.D., O'Rear, T.A., Durand, J.R. and Moyle, P.B. 2020. Estuarine-terrestrial habitat gradients enhance nursery function for resident and transient fishes in the San Francisco Estuary. *Marine Ecology Progress Series*, 637: 141-157.

Colombano, D.D., Handley, T.B., O'Rear, T.A., Durand, J.R. and Moyle, P.B. 2021. Complex Tidal Marsh Dynamics Structure Fish Foraging Patterns in the San Francisco Estuary. *Estuaries and Coasts*.

Connon, R.E., Hasenbein, S., Brander, S.M., Poynton, H.C., Holland, E.B., Schlenk, D. et al. 2019. Review of and Recommendations for Monitoring Contaminants and their Effects in the San Francisco Bay−Delta. *San Francisco Estuary and Watershed Science*, 17(4).

Conrad, J.L., Bibian, A.J., Weinersmith, K.L., De Carion, D., Young, M.J., Crain, P. et al. 2016. Novel species interactions in a highly modified estuary: Association of Largemouth Bass with Brazilian waterweed *Egeria densa*. *Transactions American Fisheries Society*, 145: 249-263.

Contreras, D., Hartman, R. and Sherman, S. 2018. Sampling fish and invertebrate resources in tidal wetlands of the Sacramento-San Joaquin Delta: Report on Phase III Pilot Monitoring, 2017. California Department of Fish and Wildlife Stockton, CA.

Cordell, J.R., Toft, J.D., Gray, A., Ruggerone, G.T. and Cooksey, M. 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary. *Ecological Engineering*, 37(2): 343-353.

Cordoleani, F., Holmes, E., Bell-Tilcock, M., Johnson, R.C. and Jeffres, C. 2022. Variability in foodscapes and fish growth across a habitat mosaic: Implications for management and ecosystem restoration. *Ecological Indicators*, 136: 108681.

Corline, N.J., Peek, R.A., Montgomery, J., Katz, J.V.E. and Jeffres, C.A. 2021. Understanding community assembly rules in managed floodplain food webs. *Ecosphere*, 12(2): e03330.

Corline, N.J., Sommer, T., Jeffres, C.A. and Katz, J. 2017. Zooplankton ecology and trophic resources for rearing native fish on an agricultural floodplain in the Yolo Bypass California, USA. *Wetlands Ecology and Management*: 1-13.

Craig, B.E., Simenstad, C.A. and Bottom, D.L. 2014. Rearing in natural and recovering tidal wetlands enhances growth and life-history diversity of Columbia Estuary tributary coho salmon Oncorhynchus kisutch population. *Journal of Fish Biology*, 85(1): 31-51.

Crauder, J.S., Thompson, J.K., Parchaso, F., Anduaga, R.I., Pearson, S.A., Gehrts, K. et al. 2016. Bivalve effects on the food web supporting Delta Smelt—A long-term study of bivalve recruitment, biomass, and grazing rate patterns with varying freshwater outflow. Open-File Report 2016–1005. U.S. Geological Survey Reston, VA, p. 216 p.

Crepeau, K.L. and Miller, R.L. 2014. Water temperature differences by plant community and location in re-established wetlands in the Sacramento-San Joaquin Delta, California, July 2005 to February 2008. In: *Data Series* Reston, VA, p. 30.

CVPIA Science Integration Team. No Date. Homepage for the CVPIA Science Integration Team. Last revised: December 16, 2022. Available: https://cvpia.scienceintegrationteam.com/cvpia-sit/. Accessed: December 28, 2022.

Dahm, C.N., Parker, A.E., Adelson, A.E., Christman, M.A. and Bergamaschi, B.A. 2016. Nutrient Dynamics of the Delta: Effects on Primary Producers. *San Francisco Estuary and Watershed Science*, 14(4).

David, A.T., Goertler, P.A.L., Munsch, S.H., Jones, B.R., Simenstad, C.A., Toft, J.D. et al. 2016. Influences of Natural and Anthropogenic Factors and Tidal Restoration on Terrestrial Arthropod Assemblages in West Coast North American Estuarine Wetlands. *Estuaries and Coasts*, 39(5): 1491-1504.

Davis, B.E., Cocherell, D.E., Fangue, N.A., Todgham, A.E., Sommer, T., Baxter, R.D. et al. 2019a. Sensitivities of an endemic, endangered California smelt and two non-native fishes to serial increases in temperature and salinity: implications for shifting community structure with climate change. *Conservation Physiology*, 7(1).

Davis, M.J., Woo, I., Ellings, C.S., Hodgson, S., Beauchamp, D.A., Nakai, G. et al. 2019b. Freshwater Tidal Forests and Estuarine Wetlands May Confer Early Life Growth Advantages for Delta-Reared Chinook Salmon. *Transactions of the American Fisheries Society*, 148(2): 289-307.

Del Rio, A.M., Davis, B.E., Fangue, N.A. and Todgham, A.E. 2019. Combined effects of warming and hypoxia on early life stage Chinook salmon physiology and development. *Conservation physiology*, 7(1): coy078.

del Rosario, R.B., Redler, Y.J., Newman, K., Brandes, P.L., Sommer, T., Reece, K. et al. 2013. Migration patterns of juvenile winter-run-sized Chinook Salmon (*Oncorhynchus tshawytscha*) through the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 11(1).

Delta Independent Science Board (Delta ISB). 2017. *Review of SWRCB's "Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations*." Sacramento, CA.

Diefenderfer, H.L., Johnson, G.E., Thom, R.M., Buenau, K.E., Weitkamp, L.A., Woodley, C.M. et al. 2016. Evidence-based evaluation of the cumulative effects of ecosystem restoration. *Ecosphere*, 7(3): e01242.

Downing, B.D., Bergamaschi, B.A., Kendall, C., Kraus, T.E.C., Dennis, K.J., Carter, J.A. et al. 2016. Using Continuous Underway Isotope Measurements To Map Water Residence Time in Hydrodynamically Complex Tidal Environments. *Environmental Science and Technology*, 50(24): 13387-13396.

Eastern Bay Municipal Utility District (EBMUD). 1988. Lower Mokelumne River Project. Joint Settlement Agreement. FERC Project No. 2916-004.

EDAW. 2005. Lower Putah Creek Watershed Management Action Plan. Phase I – Resource Assessments. Prepared for the Lower Putah Creek Coordinating Committee. Sacramento, CA, p. 351 pp.

Ellings, C.S., Davis, M.J., Grossman, E.E., Woo, I., Hodgson, S., Turner, K.L. et al. 2016. Changes in habitat availability for outmigrating juvenile salmon (*Oncorhynchus* spp.) following estuary restoration. *Restoration Ecology*.

Enright, C., Culberson, S. and Burau, J. 2013. Broad timescale forcing and geomorphic mediation of tidal marsh flow and temperature dynamics. *Estuaries and Coasts*, 36(6): 1319-1339.

Farly, L., Hudon, C., Cattaneo, A. and Cabana, G. 2019. Seasonality of a Floodplain Subsidy to the Fish Community of a Large Temperate River. *Ecosystems*, 22.

Ferrari, M.C.O., Ranaker, L., Weinersmith, K.L., Young, M.J., Sih, A. and Conrad, J.L. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. *Environmental Biology of Fishes*, 97: 79-90.

Feyrer, F., Newman, K., Nobriga, M. and Sommer, T. 2011. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. *Estuaries and Coasts*, 34(1): 120-128.

Feyrer, F., Sommer, T. and Harrell, W. 2006a. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: evidence from two adjacent engineered floodplains on the Sacramento River, California. *North American Journal of Fisheries Management*, 26(2): 408-417.

Feyrer, F., Sommer, T. and Harrell, W. 2006b. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. *Hydrobiologia*, 573(1): 213-226.

Feyrer, F., Young, M.J., Huntsman, B.M. and Brown, L.R. 2021. Disentangling Stationary and Dynamic Estuarine Fish Habitat to Inform Conservation: Species-Specific Responses to Physical Habitat and Water Quality in San Francisco Estuary. *Marine and Coastal Fisheries*, 13(5): 559-574.

Fisher, F.W. 1994. Past and Present Status of Central Valley Chinook Salmon. *Conservation Biology*, 8(3): 870-873.

FLOAT-MAST (Flow Alteration - Management Analysis and Synthesis Team). 2021. Synthesis of data and studies relating to Delta Smelt biology in the San Francisco Estuary, emphasizing water year 2017. Interagency Ecological Program Sacramento, CA.

Fong, S., Louie, S., Werner, I., Davis, J. and Connon, R.E. 2016. Contaminant Effects on California Bay-Delta Species and Human Health. *San Francisco Estuary and Watershed Science*, 14(4).

Foott, J., Harmon, R. and Stone, R. 2004. Effect of water temperature on non-specific immune function and ceratomyxosis in juvenile Chinook salmon and steelhead from the Klamath River. *California Fish and Game*, 90(2): 71-84.

Foott, J.S. 2014. Sacramento and Feather River Juvenile Chinook Pathogen Survey. Anderson, Ca.

Foott, J.S. 2016a. *Ceratonova shasta* and *Parvicapsula minibicornis* (Phylum Cnidaria: Myxosporea) infectivity for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Upper Sacramento River: July–November 2016. Anderson, Ca.

Foott, J.S. 2016b. Parasite infection of juvenile late fall and winter-run Chinook in the Sacramento

Fox, J. and Weisberg, S. 2019. *An {R} Companion to Applied Regression, Third Edition*. Sage, Thousand Oaks, CA.

Frantzich, J. and Sommer, T. 2015. Yolo Bypass as a fall food web subsidy for the Lower Estuary. *IEP Newsletter*, 28(1): 3-13.

Frantzich, J., Davis, B.E., MacWilliams, M., Bever, A. and Sommer, T. 2021. Use of a Managed Flow Pulse as Food Web Support for Estuarine Habitat. *San Francisco Estuary and Watershed Science*, 19(3): art3.

Frantzich, J., Sommer, T. and Schreier, B. 2018. Physical and biological responses to flow in a tidal freshwater slough complex. *San Francisco Estuary and Watershed Science*, 16(1).

Fregoso, T.A., Stevens, A.W., Wang, R-F., Handley, T., Dartnell, P., Lacy, J.R., Ateljevich, E., and Dailey, E.T., 2020, Bathymetry, topography, and acoustic backscatter data, and a digital elevation model (DEM) of the Cache Slough Complex and Sacramento River Deep Water Ship Channel, Sacramento-San Joaquin Delta, California: U.S. Geological Survey data release, https://doi.org/10.5066/P9AQSRVH.

Gahan, K., Healey, M., Mckibbin, C., Kubo, H. and Purdy, C. 2016. Colusa Basin Drain and Wallace Weir Fish Trapping and Relocation Efforts November 2013–June 2014. California Department of Fish and Wildlife, North Central Region.

Gearty, A.J., Ignoffo, T.R., Slaughter, A.M. and Kimmerer, W.J. 2021. Growth and reproductive rates of the dominant copepod *Pseudodiaptomus forbesi* in response to environmental factors and habitat type in the northern San Francisco Estuary. *Aquatic Ecology*.

Ghalambor, C.K., Gross, E.S., Grosholtz, E.D., Jeffries, K.M., Largier, J.K., McCormick, S.D. et al. 2021. Ecological Effects of Climate-Driven Salinity Variation in the San Francisco Estuary: Can We Anticipate and Manage the Coming Changes? *San Francisco Estuary and Watershed Science*, 19(2).

Gill, Sadie and Tompkins, Mark. No Date [a]. *Habitat Data.* Available: https://cvpia-osc.github.io/DSMhabitat/reference/habitat_data.html. Accessed: December 28, 2022.

Gill, Sadie and Tompkins, Mark. No Date [b]. *Modeled Habitat Areas.* Available: https://cvpia-osc.github.io/DSMhabitat/index.html. Accessed: December 28, 2022.

Gill, Sadie and Thompkins, Mark. 2020a. *Sacramento River.* July. Available: http://cvpia-habitat-docs-markdown.s3-website-us-west-2.amazonaws.com/watershed/sacramento_river.html. Accessed: December 28, 2022.

Gill, Sadie and Thompkins, Mark. 2020b. *Feather River.* Last revised: July. Available: http://cvpia-habitat-docs-markdown.s3-website-us-west-2.amazonaws.com/watershed/feather_river.html. Accessed: December 28, 2022.

Gill, Sadie and Thompkins, Mark. 2020c. *American River.* Last revised: *July*. Available: http://cvpia-habitat-docs-markdown.s3-website-us-west-2.amazonaws.com/watershed/american_river.html. Accessed: December 28, 2022.

Gill, Sadie and Thompkins, Mark. 2020d. *Bypasses.* Last revised: July. Available: http://cvpia-habitat-docs-markdown.s3-website-us-west-2.amazonaws.com/watershed/bypasses.html >. Accessed: December 28, 2022.

Gill, Sadie and Thompkins, Mark. 2020e. *Mokelumne River.* Last revised: July. Available: http://cvpia-habitat-docs-markdown.s3-website-us-west-2.amazonaws.com/watershed/mokelumne_river.html. Accessed: December 28, 2022.

Goertler, P., Jones, K., Kirsch, J., Conrad, J.L. and Sommer, T. 2017. Chinook Salmon. In: *Effects of Tidal Wetland Restoration on Fish: A Suite of Conceptual Models, Interagency Ecological Program Technical Report 91* (eds. Sherman, S, Hartman, R and Contreras, D). Department of Water Resources Sacramento, CA.

Goertler, P., Jones, K., Cordell, J., Schreier, B. and Sommer, T. 2018a. Effects of Extreme Hydrologic Regimes on Juvenile Chinook Salmon Prey Resources and Diet Composition in a Large River Floodplain. *Transactions of the American Fisheries Society*, 147(2): 287-299.

Goertler, P.A.L., Sommer, T.R., Satterthwaite, W.H. and Schreier, B.M. 2018b. Seasonal floodplain-tidal slough complex supports size variation for juvenile Chinook salmon (*Oncorhynchus tshawytscha*). *Ecology of Freshwater Fish*, 27(2): 580-593.

Grant, J.W.A. and Kramer, D.L. 1990. Territory Size as a Predictor of the Upper Limit to Population Density of Juvenile Salmonids in Streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 47(9): 1724-1737.

Grantham, T.E., Carlisle, D.M., Howard, J., Lane, B., Lusardi, R., Obester, A. et al. 2022. Modeling Functional Flows in California's Rivers. *Frontiers in Environmental Science*: 103.

Gray, A., Simenstad, C.A., Bottom, D.L. and Cornwell, T.J. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, U.S.A. *Restoration Ecology*, 10(3): 514-526.

Greene, V.E., Sullivan, L.J., Thompson, J.K. and Kimmerer, W.J. 2011. Grazing impact of the invasive clam *Corbula amurensis* on the microplankton assemblage of the northern San Francisco Estuary. *Marine Ecology Progress Series*, 431: 183-193.

Gregory, R.S. and Levings, C.D. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. *Transactions of the American Fisheries Society*, 127: 275-285.

Grimaldo, L., Feyrer, F., Burns, J. and Maniscalco, D. 2017. Sampling Uncharted Waters: Examining Rearing Habitat of Larval Longfin Smelt (*Spirinchus thaleichthys*) in the Upper San Francisco Estuary. *Estuaries and Coasts*, 40: 1771-1748.

Grosholz, E. and Gallo, E. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. *Hydrobiologia*, 568(1): 91-109.

Gross, E., W. Kimmerer, J. Korman, L. Lewis, S. Burdick, and L. Grimaldo. 2022. Hatching distribution, abundance, and losses to freshwater diversions of longfin smelt inferred using hydrodynamic and particle-tracking models. Marine Ecology Progress Series 700:179-196, https://www.int-res.com/abstracts/meps/v700/p179-196/

Halverson, G.H., Lee, C.M., Hestir, E.L., Hulley, G.C., Cawse-Nicholson, K., Hook, S.J. et al. 2022. Decline in Thermal Habitat Conditions for the Endangered Delta Smelt as Seen from Landsat Satellites (1985–2019). *Environmental Science and Technology*, 56(1): 185-193.

Hammock, B.G., Hartman, R., Slater, S.B., Hennessy, A. and Teh, S.J. 2019. Tidal Wetlands Associated with Foraging Success of Delta Smelt. *Estuaries and Coasts*.

Hammock, B.G., Hobbs, J.A., Slater, S.B., Acuña, S. and Teh, S.J. 2015. Contaminant and food limitation stress in an endangered estuarine fish. *Science of the Total Environment*, 532(0): 316-326.

Hance, D.J., Perry, R.W., Pope, A.C., Ammann, A.J., Hassrick, J.L. and Hansen, G. 2022. From drought to deluge: spatiotemporal variation in migration routing, survival, travel time and floodplain use of an endangered migratory fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 0(0): 1-19.

Hartman, R., Avila, M., Barros, A., Bowles, C., Ellis, D., Tempel, T. et al. 2022a. I'm Not that Shallow—Different Zooplankton Abundance but Similar Community Composition Between Habitats in the San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 20(3).

Hartman, R., Rasmussen, N., Bosworth, D., Berg, M., Ateljevich, E., Flynn, T. et al. 2022b. Temporary Urgency Change Petition of 2021 and Emergency Drought Salinity Barrier; Impact on Harmful Algal Blooms and Aquatic Weeds in the Delta. Report to the State Water Resources Control Board. Sacramento, CA, p. 239 pg.

Hartman, R., Sherman, S., Contreras, D., Furler, A. and Kok, R. 2019. Characterizing macroinvertebrate community composition and abundance in freshwater tidal wetlands of the Sacramento-San Joaquin Delta. *PLOS ONE*, 14(11): e0215421.

Hasenbein, M., Komoroske, L.M., Connon, R., Geist, J. and Fangue, N.A. 2013. Turbidity and Salinity Affect Feeding Performance and Physiological Stress in the Endangered Delta Smelt. *Integr. Comp. Biol.*, 53(4): 620-634.

Hasenbein, S., Poynton, H. and Connon, R.E. 2018. Contaminant exposure effects in a changing climate: how multiple stressors can multiply exposure effects in the amphipod Hyalella azteca. *Ecotoxicology*, 27(7): 845-859.

Hellmair, M., Peterson, M., Mulvey, B., Young, K., Montgomery, J. and Fuller, A. 2018. Physical Characteristics Influencing Nearshore Habitat Use by Juvenile Chinook Salmon in the Sacramento River, California. *North American Journal of Fisheries Management*, 38(4): 959-970.

Henery, R.E., Sommer, T.R. and Goldman, C.R. 2010. Growth and methylmercury accumulation in juvenile Chinook salmon in the Sacramento River and its floodplain, the Yolo Bypass. *Transactions of the American Fisheries Society*, 139(2): 550-563.

Herbold, B., Bush, E., Castillo, G., Colombano, D., Hartman, R., Lehman, P. et al. 2022. Climate Change Impacts on San Francisco Estuary Aquatic Ecosystems: A Review. *San Francisco Estuary and Watershed Science*, 20(2).

Herbold, B., Carlson, S.M., Henery, R., Johnson, R., Mantua, N., McClure, M. et al. 2018. Managing for Salmon Resilience in California's Variable and Changing Climate. *San Francisco Estuary and Watershed Science*, 16(2).

Hestir, E.L., Schoellhamer, D.H., Greenberg, J., Morgan-King, T. and Ustin, S.L. 2016. The effect of submerged aquatic vegetation expansion on a declining turbidity trend in the Sacramento-San Joaquin River Delta. *Estuaries and Coasts*, 39(4): 1100-1112.

Hieb, K. 2017. 1980–2015 Bay Study Indices.

Hinkelman, Travis M., M. Johnston, J.E. Merz, and J. Zimmerman. 2018. Sacramento River Basin ESHE. Created for The Nature Conservancy, San Francisco CA. June. Available: https://fishsciences.shinyapps.io/sacramento-eshe/.

Howe, E.R. and Simenstad, C.A. 2011. Isotopic determination of food web origins in restoring and ancient estuarine wetlands of the San Francisco Bay and Delta. *Estuaries and Coasts*, 34(3): 597-617.

Howe, E.R., Simenstad, C.A., Toft, J.D., Cordell, J.R. and Bollens, S.M. 2014. Macroinvertebrate prey availability and fish diet selectivity in relation to environmental variables in natural and restoring North San Francisco Bay tidal marsh channels. *San Francisco Estuary and Watershed Science*, 12(1).

Hutton, P.H., Meko, D.M. and Roy, S.B. 2021. Supporting Restoration Decisions through Integration of Tree-Ring and Modeling Data: Reconstructing Flow and Salinity in the San Francisco Estuary over the Past Millennium. *Water*, 13(15): 2139.

IEP Tidal Wetland Monitoring Project Work Team (PWT) 2017. Tidal wetland monitoring framework for the upper San Francisco Estuary: Monitoring plan guidance. Available at: https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Environmental-Services/Interagency-Ecological-Program/Files/Tidal-Wetland-Monitoring-Framework-for-the-Upper-San-Francisco-Estuary.pdf?la=en&hash=5668D6D21C50D0A666919680FB5EE825FC9C57BE.

IEP-MAST, Baxter, R., Brown, L.R., Castillo, G., Conrad, L., Culberson, S. et al. 2015. An updated conceptual model for Delta Smelt: our evolving understanding of an estuarine fish. In: *Draft MAST report (Management, Analysis, Synthesis Team)*. Interagency Ecological Program Sacramento, CA.

Jassby, A.D., Cloern, J.E. and Cole, B.E. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. *Limnology and Oceanography*, 47(3): 698-712.

Jeffres, C.A., Holmes, E.J., Sommer, T.R. and Katz, J.V.E. 2020. Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. *PLOS ONE*, 15(9): e0216019.

Jeffres, C.A., Opperman, J.J. and Moyle, P.B. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. *Environmental Biology of Fishes*, 83(4): 449-458.

Johnson, M.R. and Merrick, K. 2012. Juvenile salmonid monitoring using rotary screw traps in Deer Creek and Mill Creek, Tehama County, California summary report: 1994-2010. California Department of Fish and Wildlife, Fisheries Office, Redbluff, CA, pp. 1-105.

Johnson, R. C. et al. 2012. "Managed metapopulations: do salmon hatchery 'sources' lead to in-river 'sinks' in conservation?" *PLOS ONE* 7(2): e28880.

Johnston, M., Frantzich, J., Espe, M.B., Goertler, P., Singer, G., Sommer, T. et al. 2020. Contrasting the migratory behavior and stranding risk of White Sturgeon and Chinook Salmon in a modified floodplain of California. *Environmental Biology of Fishes*.

Johnston, M.E., Steel, A.E., Espe, M., Sommer, T., Klimley, A.P., Sandstrom, P. et al. 2018. Survival of Juvenile Chinook Salmon in the Yolo Bypass and the Lower Sacramento River, California. *San Francisco Estuary and Watershed Science*, 16(2).

Jones & Stokes Associates. 1996. Measured and Simulated Temperatures in Putah Creek, Yolo and Solano Counties, California. Prepared for University of California, Davis, CA. Sacramento, CA.

Jungbluth, M.J., Burns, J., Grimaldo, L., Slaughter, A., Katla, A. and Kimmerer, W. 2021. Feeding habits and novel prey of larval fishes in the northern San Francisco Estuary. *Environmental DNA*: 1-22.

Junk, W.J., Bayley, P.B. and Sparks, R.E. 1989. The flood pulse concept in river-floodplain systems. *Canadian special publication of fisheries and aquatic sciences*, 106(1): 110-127.

Katz, J.V.E., Jeffres, C., Conrad, J.L., Sommer, T.R., Martinez, J., Brumbaugh, S. et al. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. *PLOS ONE*, 12(6): e0177409.

Keeley, A.T.H., Fremier, A.K., Goertler, P.A.L., Huber, P.R., Sturrock, A.M., Bashevkin, S.M. et al. 2022. Governing Ecological Connectivity in Cross-Scale Dependent Systems. *BioScience*.

Khanna, S., Ustin, S.L., Hestir, E.L., Santos, M.J. and Andrew, M. 2022. The Sacramento-San Joaquin Delta genus and community level classification maps derived from airborne spectroscopy data. *Knowledge Network for Biocomplexity*.

Kimmerer, W. 2002. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. *Estuaries*, 25(6B): 1275-1290.

Kimmerer, W.J., Ferm, N., Nicolini, M.H. and Penalva, C. 2005. Chronic food limitation of egg production in populations of copepods of the genus *Acartia* in the San Francisco Estuary. *Estuaries*, 28(4): 541-550.

Kimmerer, W.J., Gartside, E. and Orsi, J. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. *Marine Ecology Progress Series*, 113: 81-93.

Kimmerer, W. and Gross, E. 2022. Population Abundance and Diversion Losses in a Threatened Estuarine Pelagic Fish. *Estuaries and Coasts*.

Kimmerer, W., Ignoffo, T.R., Bemowski, B., Modéran, J., Holmes, A. and Bergamaschi, B. 2018a. Zooplankton Dynamics in the Cache Slough Complex of the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 16(3).

Kimmerer, W.J., Ignoffo, T.R., Kayfetz, K.R. and Slaughter, A.M. 2018b. Effects of freshwater flow and phytoplankton biomass on growth, reproduction, and spatial subsidies of the estuarine copepod *Pseudodiaptomus forbesi*. *Hydrobiologia*, 807(1): 113-130.

Kimmerer, W.J. and Lougee, L. 2015. Bivalve grazing causes substantial mortality to an estuarine copepod population. *Journal of Experimental Marine Biology and Ecology*, 473: 53-63.

Kimmerer, W.J. and Rose, K.A. 2018. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey. *Transactions of the American Fisheries Society*, 147(1): 223-243.

Kimmerer, W., Wilkerson, F., Downing, B., Dugdale, R., Gross, E.S., Kayfetz, K. et al. 2019. Effects of Drought and the Emergency Drought Barrier on the Ecosystem of the California Delta. *San Francisco Estuary and Watershed Science*, 17(3).

Kjelson, M.A. and Brandes, P.L. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. *Canadian special publication of fisheries and aquatic sciences/Publication speciale canadienne des sciences halieutiques et aquatiques. 1989.*

Komoroske, L.M., Jeffries, K.M., Connon, R.E., Dexter, J., Hasenbein, M., Verhille, C. et al. 2016. Sublethal salinity stress contributes to habitat limitation in an endangered estuarine fish. *Evolutionary Applications*, 9(8): 963-981.

Larrieu, K.G. and Pasternack, G.B. 2021. Automated analysis of lateral river connectivity and fish stranding risks. Part 2: Juvenile Chinook salmon stranding at a river rehabilitation site. *Ecohydrology*, 14(6): e2303.

Lee, P. and Manning, J. 2020. Mercury Imports and Exports of Four Tidal Wetlands in the Sacramento-San Joaquin Delta, Yolo Bypass, and Suisun Marsh for Delta Mercury Control Program Compliance. California Department of Water Resources West Sacramento, CA.

Lehman, B.M., Gary, M.P., Demetras, N. and Michel, C.J. 2019. Where Predators and Prey Meet: Anthropogenic Contact Points Between Fishes in a Freshwater Estuary. *San Francisco Estuary and Watershed Science*, 17(4).

Lehman, B., Johnson, R.C., Adkison, M., Burgess, O.T., Connon, R.E., Fangue, N.A. et al. 2020a. Disease in Central Valley Salmon: Status and Lessons from Other Systems. *San Francisco Estuary and Watershed Science*, 18(3).

Lehman, P.W., Kurobe, T. and Teh, S.J. 2022. Impact of extreme wet and dry years on the persistence of *Microcystis* harmful algal blooms in San Francisco Estuary. *Quaternary International*, 621: 16-25.

Lehman, P.W., Kurobe, T., Huynh, K., Lesmeister, S. and Teh, S.J. 2021. Covariance of Phytoplankton, Bacteria, and Zooplankton Communities Within *Microcystis* Blooms in San Francisco Estuary. *Frontiers in Microbiology*, 12(1184).

Lehman, P.W., Mayr, S., Liu, L. and Tang, A. 2015. Tidal day organic and inorganic material flux of ponds in the Liberty Island freshwater tidal wetland. *Springer Plus*, 4: 273.

Lehman, P.W., Mayr, S., Mecum, L. and Enright, C. 2010. The freshwater tidal wetland Liberty Island, CA was both a source and sink of inorganic and organic material to the San Francisco Estuary. *Aquatic Ecology*, 44(2): 359-372.

Lehman, P.W., Sommer, T. and Rivard, L. 2008. The influence of floodplain habitat on the quantity and quality of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. *Aquatic Ecology*, 42(3): 363-378.

Levings, C.D., Conlin, K. and Raymond, B. 1991. Intertidal habitats used by juvenile chinook salmon (Oncorhynchus tshawytscha) rearing in the North Arm of the Fraser River estuary. *Marine Pollution Bulletin*, 22(1): 20-26.

Levings, C.D. and Nishimura, D.J.H. 1997. Created and restored marshes in the lower Fraser River, British Columbia: summary of their functioning as fish habitat. *Water Quality Research Journal Canada*, 32(3): 599-618.

Lewis, L., Barros, A., Willmes, M., Denney, C., Parker, C., Bisson, M. et al. 2019. Interdisciplinary Studies on Longfin Smelt in the San Francisco Estuary. 2018-19 Annual Report for DWR Contract # 4600011196. University of California, Davis, Davis, CA.

Limm, M.P. and Marchetti, M.P. 2003. Contrasting patterns of juvenile chinook salmon (*Oncorhynchus tshawytscha*) growth, diet, and prey densities in off-channel and main stem habitats on the Sacramento River. California State University, Chico.

Limm, M.P. and Marchetti, M.P. 2009. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. *Environmental Biology of Fishes*, 85(2): 141-151.

Lindley, S. T., C. B. Grimes, M. S. Mohr, W. Peterson, J. Stein, J. T. Anderson, L. W. Botsford, D. L. Bottom, C. A. Busack, T. K. Collier, J. Ferguson, J. C. Garza, A. M. Grover, D. G. Hankin, R. G. Kope, P. W. Lawson, A. Low, R. B. MacFarlane, K. Moore, M. Palmer-Zwahlen, F. B. Schwing, J. Smith, C. Tracy, R. Webb, B. K. Wells, and T. H. Williams. 2009. What caused the Sacramento River fall Chinook stock collapse? NOAA Technical Memorandum NMFS-SWFSC-447, 125 pp.

Livsey, D.N., Downing-Kunz, M.A., Schoellhamer, D.H. and Manning, A. 2021. Suspended-sediment flux in the San Francisco Estuary; Part II: the Impact of the 2013–2016 California Drought and Controls on Sediment Flux. *Estuaries and Coasts*, 44(4): 972-990.

Lopez, C.B., Cloern, J.E., Schraga, T.S., Little, A.J., Lucas, L.V., Thompson, J.K. et al. 2006. Ecological values of shallow-water habitats: Implications for the restoration of disturbed ecosystems. *Ecosystems*, 9(3): 422-440.

Lucas, L.V., Koseff, J.R., Monismith, S.G. and Thompson, J.K. 2009. Shallow water processes govern system-wide phytoplankton bloom dynamics: A modeling study. *Journal of Marine Systems*, 75(1–2): 70-86.

Lucas, L.V., Cloern, J.E., Thompson, J.K., Stacey, M.T. and Koseff, J.R. 2016. Bivalve grazing can shape phytoplankton communities. *Frontiers in Marine Science*, 3: 14.

Mac Nally, R., Thomson, J.R., Kimmerer, W.J., Feyrer, F., Newman, K.B., Sih, A. et al. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). *Ecological Applications*, 20(5): 1417-1430.

Magnusson, A., and R. Hilborn. 2003. Estuarine influence on survival rates of coho (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) released from hatcheries on the U.S. Pacific coast. Estuaries 26:1094-1103. 10.1007/BF02803366

Mahardja, B. and Sommer, T. 2017. Evaluating Potential Impact of Fish Removal at the Salvage Facility as part of the Delta Smelt Resiliency Strategy. *IEP Newsletter*, 30(1): 21-23.

Mahardja, B., Bashevkin, S.M., Pien, C., Nelson, M., Davis, B.E. and Hartman, R. 2022. Escape from the heat: thermal stratification in a well-mixed estuary and implications for fish species facing a changing climate. *Hydrobiologia*.

Mahardja, B., Goodman, A., Goodbla, A., Schreier, A.D., Johnston, C., Fuller, R.C. et al. 2020. Introduction of Bluefin Killifish *Lucania goodei* into the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 18(2).

Mahardja, B., Tobias, V., Khanna, S., Mitchell, L., Lehman, P., Sommer, T. et al. 2021. Resistance and resilience of pelagic and littoral fishes to drought in the San Francisco Estuary. *Ecological Applications*, 31(2): e02243, 02216 p.

Marine, K.R. and Cech Jr, J.J. 2004. Effects of High Water Temperature on Growth, Smoltification, and Predator Avoidance in Juvenile Sacramento River Chinook Salmon. *North American Journal of Fisheries Management*, 24(1): 198-210.

Maslin, P., Lennox, M., Kindopp, J. and McKinney, W. 1997. Intermittent streams as rearing habitat for Sacramento River chinook salmon (*Oncorhynchus tshawytscha*). California State University, Chico, Chico, California.

McKibbin, C.J. 2022. Summary Report for the Central Valley fall Chinook Salmon (*Oncorhynchus tshawytscha*) Migration Study in the Sacramento-San Joaquin River Delta. California Department of Fish and Wildlife.

McManamay, R.A., Orth, D.J., Dolloff, C.A. and Cantrell, M.A. 2010. Gravel Addition as a Habitat Restoration Technique for Tailwaters. *North American Journal of Fisheries Management*, 30(5): 1238-1257.

Merz JE, S.J. 2004. Evaluation of a spawning habitat enhancement site for chinook salmon in a regulated California river. *North American Journal of Fisheries Management*, 24(2): 397-407.

Merz, J., Caldwell, L., Beakes, M., Hammersmark, C. and Sellheim, K. 2019. Balancing competing life-stage requirements in salmon habitat rehabilitation: between a rock and a hard place. *Restoration Ecology*, 27(3): 661-671.

Merz, J.E., Bergman, P.S., Melgo, J.F. and Hamilton, S. 2013. Longfin smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California. *California Fish and Game*, 99(3): 122-148.

Michel, C.J. 2019. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences*, 76(8): 1398-1410.

Michel, C.J., Ammann, A.J., Lindley, S.T., Sandstrom, P.T., Chapman, E.D., Thomas, M.J. et al. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. *Canadian Journal of Fisheries and Aquatic Sciences*, 72(11): 1749-1759.

Michel, C.J., Henderson, M.J., Loomis, C.M., Smith, J.M., Demetras, N.J., Iglesias, I.S. et al. 2020a. Fish predation on a landscape scale. *Ecosphere*, 11(6): e03168.

Michel, C.J., Smith, J.M., Lehman, B.M., Demetras, N.J., Huff, D.D., Brandes, P.L. et al. 2020b. Limitations of Active Removal to Manage Predatory Fish Populations. *North American Journal of Fisheries Management*.

Michel, C.J., Notch, J.J., Cordoleani, F., Ammann, A.J. and Danner, E.M. 2021. Nonlinear survival of imperiled fish informs managed flows in a highly modified river. *Ecosphere*, 12(5): e03498.

Miller, J.A., Gray, A. and Merz, J. 2010. Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon *Oncorhynchus tshawytscha*. *Marine Ecology Progress Series*, 408: 227-240.

Montgomery, J.R. 2017. Foodweb Dynamics in Shallow Tidal Sloughs of the San Francisco Estuary. University of California, Davis.

Moore, J.W., Gordon, J., Carr-Harris, C., Gottesfeld, A., Wilson, S. and Russell, J.H. 2016. Assessing estuaries as stopover habitats for juvenile Pacific salmon. *Marine Ecology Progress Series*, 559.

Morzaria-Luna, L., Callaway, J.C., Sullivan, G. and Zedler, J.B. 2004. Relationship between topographic heterogeneity and vegetation patterns in a Californian salt marsh. *Journal of Vegetation Science*, 15(4): 523-530.

Moyle, P.B. 2002. *Inland Fishes of California*. 2nd edn. University of California Press, Berkeley, California.

Moyle, P., Baxter, R., Sommer, T., Foin, T. and Matern, S. 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary. pp. 1-47.

Moyle, P.B., Crain, P.K. and Whitener, K. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. *San Francisco Estuary and Watershed Science*, 5(3).

Moyle, P.B., Kiernan, J.D., Crain, P.K. and Quinones, R.M. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. *PLOS ONE*, 8(5): e63883.

Moyle, P.B. and White, D. 2002. Effects of screening diversions on fish populations in the Central Valley: What do we know? Citeseer.

Muller-Solger, A.B., Jassby, A.D. and Muller-Navarra, D.C. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). *Limnology and Oceanography*, 47(5): 1468-1476.

Munsch, S. H., C. M. Greene, R. C. Johnson, W. H. Satterthwaite, H. Imaki, P. L. Brandes, and M. R. O'Farrell. 2020. Science for integrative management of a diadromous fish stock:

interdependencies of fisheries, flow, and habitat restoration. *Canadian Journal of Fisheries and Aquatic Sciences* 77:1487-1504. 10.1139/cjfas-2020-0075-

Mussen, T.D., Cocherell, D., Hockett, Z., Ercan, A., Bandeh, H., Kavvas, M.L. et al. 2013. Assessing juvenile Chinook salmon behavior and entrainment risk near unscreened water diversions: large flume simulations. *Transactions of the American Fisheries Society*, 142(1): 130-142.

National Marine Fisheries Service (NMFS). 2009. Biological Opinion and Conference Opinion on the long-term operations of the Central Valley Project and the State Water Project. National Marine Fisheries Service, Long Beach, CA.

National Marine Fisheries Service (NMFS). 2014. Recovery plan for the Evolutionarily Significant Units of Sacramento River winter-run Chinook Salmon and Central Valley spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley steelhead. National Marine Fisheries Service, California Central Valley Area Office, Sacramento, CA.

National Marine Fisheries Service (NMFS). 2016. Endangered Species Act Section 7(a)(2) Biological Opinion, and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response and Fish and Wildlife Coordination Act Recommendations for Relicensing the Oroville Facilities Hydroelectric Project, Butte County California (FERC Project No. 2100-134).

National Marine Fisheries Service (NMFS). 2019. Biological Opinion on the Long-Term Operation of the Central Valley Project and the State Water Project. West Coast Region.

Newman, K. B., and P. L. Brandes. 2010. Hierarchical modeling of juvenile Chinook salmon survival as a function of Sacramento-San Joaquin Delta water exports. North American Journal of Fisheries Management 30:157-169,

Nobriga, M.L., Michel, C.J., Johnson, R.C. and Wikert, J.D. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. *Ecology and Evolution*, 11(15): 10381-10395.

Notch, J.J., McHuron, A.S., Michel, C.J., Cordoleani, F., Johnson, M., Henderson, M.J. et al. 2020. Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions. *Environmental Biology of Fishes*.

Opperman, J.J. 2012. A Conceptual Model for Floodplains in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 10(3).

Orlando, J.L., De Parsia, M., Sanders, C., Hladik, M. and Frantzich, J. 2020. Pesticide concentrations associated with augmented flow pulses in the Yolo Bypass and Cache Slough Complex, California. U.S. Geological Survey.

Orsi, J.J. and Mecum, W.L. 1996. Food limitation as the probable cause of a long-term decline in the abundance of *Neomysis mercedis* the opossum shrimp in the Sacramento-San Joaquin Estuary. In: *San Francisco Bay the Ecosystem* (ed. Hollibaugh, JT). Pacific Division of the American Association for the Advancement of Science San Francisco, California, pp. 375-401.

Parker, C., Hobbs, J., Bisson, M. and Barros, A. 2017. Do Longfin Smelt Spawn in San Francisco Bay Tributaries? *IEP Newsletter*, 30(1): 29-36.

Perry, R.W., Brandes, P.L., Burau, J.R., Sandstrom, P.T. and Skalski, J.R. 2015a. Effect of tides, river flow, and gate operations on entrainment of juvenile salmon into the interior Sacramento-San Joaquin River Delta. *Transactions of the American Fisheries Society*, 144(3): 445-455.

Perry, R.W., Plumb, J.M. and W. Huntington, C. 2015b. Using a laboratory-based growth model to estimate mass-and temperature-dependent growth parameters across populations of juvenile Chinook salmon. *Transactions of the American Fisheries Society*, 144(2): 331-336.

Perry, R.W., Buchanan, R.A., Brandes, P.L., Burau, J.R. and Israel, J.A. 2016. Anadromous Salmonids in the Delta: New Science 2006–2016. *San Francisco Estuary and Watershed Science*, 14(2).

Perry, R.W., Pope, A.C., Romine, J.G., Brandes, P.L., Burau, J.R., Blake, A.R. et al. 2018. Flow-mediated effects on travel time, routing, and survival of juvenile Chinook salmon in a spatially complex, tidally forced river delta. *Canadian Journal of Fisheries and Aquatic Sciences*: 1-16.

Person-Le Ruyet, J., Mahe, K., Le Bayon, N. and Le Delliou, H. 2004. Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass, *Dicentrarchus labrax*. In: *Aquaculture*, pp. 269-280.

Peterson, M.S. 2003. A Conceptual View of Environment-Habitat-Production Linkages in Tidal River Estuaries. *Reviews in Fisheries Science*, 11(4): 291-313.

Phillis, C.C., Sturrock, A.M., Johnson, R.C. and Weber, P.K. 2018. Endangered winter-run Chinook salmon rely on diverse rearing habitats in a highly altered landscape. *Biological Conservation*, 217: 358-362.

Poletto, J.B., Cocherell, D.E., Mussen, T.D., Ercan, A., Bandeh, H., Kavvas, M.L. et al. 2015. Fish-protection devices at unscreened water diversions can reduce entrainment: evidence from behavioural laboratory investigations. *Conservation Physiology*, 3(1).

Pope, A.C., Perry, R.W., Harvey, B.N., Hance, D.J. and Hansel, H.C. 2021. Juvenile Chinook Salmon Survival, Travel Time, and Floodplain Use Relative to Riverine Channels in the Sacramento-San Joaquin River Delta. *Transactions American Fisheries Society*.

QEDA Consulting, LLC, Cheva Consulting, Institute of Marine Sciences, National Marine Fisheries Services Southwest Center, and National Marine Fisheries Services Northwest Center. 2017. *Model Description for the Sacramento River Winter-Run Chinook Salmon Life Cycle Model.* Available: https://cvpiahabitat-r-package.s3-us-west-2.amazonaws.com/2017Hendrix.pdf. January 6. Accessed: December 28, 2022.

R Core Team. 2022. *R: A Language and Environment for Statistical Computing*. 4.2.2 edn, Vienna, Austria.

Rabidoux, A., M. Stevenson, P. B. Moyle, M. C. Miner, L. G. Hitt, D. E. Cocherell, N. A. Fangue, and A. L. Rypel. 2022. The Putah Creek Fish Kill: Learning from a Local Disaster. California Water Blog, Davis, CA, https://californiawaterblog.com/2022/04/24/the-putah-creek-fish-kill-learning-from-a-local-disaster/

Revnak, R., Memeo, M. and Killam, D. 2017. Redd Dewatering and Juvenile Stranding in the Upper Sacramento River Year 2016-2017.

Richter, A. and Kolmes, S.A. 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. In: *Reviews in Fisheries Science*, pp. 23-49.

RMA. 2012. Appendix D: Prospect Island Tidal Restoration Project Calibration and Verification of Hydrodynamic Model Used for Phase 1 Preliminary Alternatives Screening. Technical Memorandum, June 2012. In: *Prospect Island Tidal Restoration: Synthesis of Phase 1 Screening-Level Modeling Evaluation of Conceptual Restoration Alternatives, Final Report* (ed. Stillwater Sciences and Wetlands and Water Resources, I).

RMA. 2015a. Initial Modeling of Local and Regional Impacts of the Proposed Winter Island Tidal Marsh Restoration. Technical Memorandum, July 2015. Prepared for the California Department of Water Resources.

RMA. 2015b. Salinity Modeling Analysis of the Proposed Tule Red Tidal Marsh Restoration, Grizzly Island, California. Technical Memorandum, November 2015. Prepared for the California Department of Water Resources.

Robinson, A., Safran, S., Beagle, J., Grenier, J., Grossinger, R., Spotswood, E. et al. 2016. A Delta Renewed: A Guide to Science-Based Ecological Restoration in the Sacramento-San Joaquin Delta. In: *Delta Landscapes Project*. San Francisco Estuary Institute - Aquatic Science Center Richmond, CA.

Robinson, A., Safran, S., Beagle, J., Grossinger, R. and Grenier, L. 2014. A Delta Transformed: Ecological Functions, Spatial Metrics, and Landscape Change in the Sacramento-San Joaquin Delta. In: *San Francisco Estuary Institute-Aquatic Science Center (SFEI-ASC), Prepared for the California Department of Fish and Wildlife and Ecosystem Restoration Program. A Report of SFEI-ASC's Resilient Landscapes Program*. San Francisco Estuary Institute-Aquatic Science Center Richmond, CA, p. 134.

Rolls, R. and Bond, N. 2017. Environmental and Ecological Effects of Flow Alteration in Surface Water Ecosystems. pp. 65-83.

Roni, P., Hanson, K. and Beechie, T.J. 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North American Journal of Fisheries Management*, 28(3): 856-890.

Roni, P. 2019. Does River Restoration Increase Fish Abundance and Survival or Concentrate Fish? The Effects of Project Scale, Location, and Fish Life History. *Fisheries*, 44(1): 7-19.

Roni, P., Pess, G., Beechie, T. and Morley, S. 2010. Estimating Changes in Coho Salmon and Steelhead Abundance from Watershed Restoration: How Much Restoration is Needed to Measurably Increase Smolt Production? *North American Journal of Fisheries Management*, 30(6): 1469-1484.

Roni, P., Pess, G.R., Beechie, T.J. and Hanson, K.M. 2014. Fish-habitat relationships and the effectiveness of habitat restoration. U.S. Dept. Commer.

Rosenfield, J.A. and Baxter, R.D. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. *Transactions American Fisheries Society*, 136: 1577-1592.

Satterthwaite, W.H., Carlson, S.M. and Bradbury, I. 2015. Weakening portfolio effect strength in a hatchery-supplemented Chinook salmon population complex. *Canadian Journal of Fisheries and Aquatic Sciences*, 72(12): 1860-1875.

Satterthwaite, W.H., Carlson, S.M. and Criss, A. 2017. Ocean Size and Corresponding Life History Diversity among the Four Run Timings of California Central Valley Chinook Salmon. *Transactions of the American Fisheries Society*, 146(4): 594-610.

Schindler, D.E., Armstrong, J.B. and Reed, T.E. 2015. The portfolio concept in ecology and evolution. *Frontiers in Ecology and the Environment*, 13(5): 257-263.

Schoellhamer, D.H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. *Estuaries and Coasts*, 34(5): 885-899.

Schroeter, R.E., O'Rear, T.A., Young, M.J. and Moyle, P.B. 2015. The aquatic trophic ecology of Suisun Marsh, San Francisco Estuary, California, during autumn in a wet year. *San Francisco Estuary and Watershed Science*, 13(3).

Setka, J. and Bishop, J. 2003. Fall-run Chinook salmon and steelhead trout spawning survey, September 2002 through March 2003 Mokelumne River, California. 26 pp.

SFEI. 2020. Identifying Suitable Rearing Habitat for Chinook Salmon in the Sacramento-San Joaquin Delta. San Francisco Estuary Institute, Richmond, CA. Version 1.0

Sherman, S., Hartman, R. and Contreras, D. 2017. Effects of Tidal Wetland Restoration on Fish: A Suite of Conceptual Models. Interagency Ecological Program Technical Report 91. California Department of Water Resources, Sacramento, CA.

Siegel, S., Bachand, P., Gillenwater, D., Chappell, S., Wickland, B., Rocha, O. et al. 2011. Final Evaluation Memorandum, Strategies for Resolving Low Dissolved Oxygen and Methylmercury Events in Northern Suisun Marsh. Prepared for the State Water Resources Control Board Sacramento, CA.

Simenstad, C.A. and Cordell, J.R. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. *Ecological Engineering*, 15(3–4): 283-302.

Singer, G.P., Chapman, E.D., Ammann, A.J., Klimley, A.P., Rypel, A.L. and Fangue, N.A. 2020. Historic drought influences outmigration dynamics of juvenile fall and spring-run Chinook Salmon. *Environmental Biology of Fishes*, 103(5): 543-559.

Slater, S.B., Schultz, A., Hammock, B.G., Hennessy, A. and Burdi, C. 2019. Patterns of Zooplankton Consumption by Juvenile and Adult Delta Smelt (*Hypomesus transpacificus*). In: *Directed Outflow Project: Technical Report 1.* (ed. Schultz, AA). U.S. Bureau of Reclamation, Bay-Delta Office, Mid-Pacific Region Sacramento, CA., pp. 9-54.

Sloey, T.M., Willis, J.M. and Hester, M.W. 2015. Hydrologic and edaphic constraints on *Schoenoplectus acutus*, *Schoenoplectus californicus*, and *Typha latifolia* in tidal marsh restoration. *Restoration Ecology*, 23(4): 430-438.

Slotton, D.G., Ayers, S.M., Reuter, J.E. and Goldman, C.R. 1997. Gold mining impacts on food chain mercury in northwestern Sierra Nevada streams (1997 revision), Appendix B in Larry Walker Associates, 1997, Sacramento River watershed mercury control planning project—report for the Sacramento Regional County Sanitation District. 74 p.

Slotton, D.G., Ayers, S.M., Reuter, J.E. and Goldman, C.R. 1999. Lower Putah Creek 1997–1998 Mercury Biological Distribution Study. Dept of Environmental Science and Policy. Prepared for the Department of Environmental Health and Safety, University of California, Davis. Davis, CA.

Small, K.M., Crain, P.K. and Moyle, P.B. 2004. Chinook Salmon in Putah Creek, Spring, 2004 Report to Lower Putah Creek Coordinating Committee 10 pp.

Smalling, K.L., Orlando, J.L. and Kuivila, K.M. 2007. Occurrence of pesticides in water, sediment, and soil from the Yolo Bypass, California. *San Francisco Estuary and Watershed Science*, 5(1).

Smith, S.G., Muir, W.D., Williams, J.G. and Skalski, J.R. 2002. Factors Associated with Travel Time and Survival of Migrant Yearling Chinook Salmon and Steelhead in the Lower Snake River. In: *North American Journal of Fisheries Management*, pp. 385-405.

Snider, B., Titus, R. and Vyberberg, K. 2001. Evaluation of effects of flow fluctuations on the anadromous fish populations in the lower American River. *California Department of Fish and Game, Habitat Conservation Division. Stream Evaluation Program. Tech. Reports*(1): 1-3.

Sobczak, W.V., Cloern, J.E., Jassby, A.D., Cole, B.E., Schraga, T.S. and Arnsberg, A. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. *Estuaries*, 28(1): 122-135.

Solutions, E.D. 2012. Prospect Island Tidal Wetland Restoration Project Condition Bathymetric Survey: Cache Slough, Sutter Slough and the Sacramento River at Rio Vista. California Department of Water Resources, Sacramento, CA.

Sommer, T., Armor, C., Baxter, R., Breuer, R., Brown, L., Chotkowski, M. et al. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. *Fisheries*, 32(6): 270-277.

Sommer, T., Harrell, B., Nobriga, M., Brown, R., Moyle, P., Kimmerer, W. et al. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries*, 26(8): 6-16.

Sommer, T., Harrell, W., Nobriga, M. and Kurth, R. 2001b. Floodplain as habitat for native fish: lessons from California's Yolo Bypass. *California Riparian Systems: Processes and Floodplain Management, Ecology, and Restoration*: 81-87.

Sommer, T., Hartman, R., Koller, M., Koohafkan, M., Conrad, J.L., MacWilliams, M. et al. 2020a. Evaluation of a large-scale flow manipulation to the upper San Francisco Estuary: Response of habitat conditions for an endangered native fish. *Plos ONE*, 15(10).

Sommer, T. and Mejia, F. 2013. A place to call home: a synthesis of Delta Smelt habitat in the upper San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 11(2): 25 pages.

Sommer, T., Schreier, B., Conrad, J.L., Takata, L., Serup, B., Titus, R. et al. 2020b. Farm to Fish: Lessons from a Multi-Year Study on Agricultural Floodplain Habitat. *San Francisco Estuary and Watershed Science*, 18(3).

Sommer, T.R., Conrad, L., O'Leary, G., Feyrer, F. and Harrell, W.C. 2002. Spawning and Rearing of Splittail in a Model Floodplain Wetland. *Transactions of the American Fisheries Society*, 131(5): 966-974.

Sommer, T.R., Harrell, W.C. and Nobriga, M.L. 2005. Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain. *North American Journal of Fisheries Management*, 25: 1493-1504.

Sommer, T.R., Harrell, W.C., Nobriga, M.L. and Kurth, R. 2003. Floodplain as habitat for native fish: Lessons from California's Yolo Bypass. In: *California riparian systems: Processes and floodplain management, ecology, and restoration. 2001 Riparian Habitat and Floodplains Conference Proceedings* (ed. Faber, PM). Riparian Habitat Joint Venture Sacramento, pp. 81-87.

Sommer, T.R., Nobriga, M.L., Harrell, W.C., Batham, W. and Kimmerer, W.J. 2001c. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(2): 325-333.

State Water Resources Control Board (State Water Board). 2017. *Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows*. State Water Resources Control Board, CEPA Sacramento, CA.

State Water Resources Control Board (State Water Board). 2018. July 2018 Framework for the Sacramento/Delta Update to the Bay-Delta Plan. https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/sed/sac_delta_framework_070618%20.pdf

State Water Resources Control Board (State Water Board) and California Environmental Protection Agency. 2018. *Analyses of Benefits to Native Fish Populations from Increased Flow between February 1 and June 30.* Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2018_sed/docs/ch_19_fish.pdf. Accessed: December 28, 2022.

Steel, A.E., Anderson, J.J., Mulvey, B. and Smith, D.L. 2020. Applying the mean free-path length model to juvenile Chinook salmon migrating in the Sacramento River, California. *Environmental Biology of Fishes*, 103(12): 1603-1617.

Stern, M., Flint, L., Minear, J., Flint, A. and Wright, S. 2016. Characterizing Changes in Streamflow and Sediment Supply in the Sacramento River Basin, California, Using Hydrological Simulation Program—FORTRAN (HSPF). *Water*, 8(10): 432.

Stern, M.A., Flint, L.E., Flint, A.L., Knowles, N. and Wright, S.A. 2020. The Future of Sediment Transport and Streamflow Under a Changing Climate and the Implications for Long-Term Resilience of the San Francisco Bay-Delta. *Water Resources Research*, 56(9): e2019WR026245.

Stocking, R.W., Holt, R.A., Foott, J.S. and Bartholomew, J.L. 2006. Spatial and temporal occurrence of the salmonid parasite *Ceratomyxa shasta* in the Oregon–California Klamath River basin. *Journal of Aquatic Animal Health*, 18(3): 194-202.

Stokes, I.J. 2009. Lower Yuba River Redd Dewatering and Fry Stranding Study 2008 Annual Report. Sacramento, CA.

StreamWise. 2021. Los Rios Check Dam Fish Passage Enhancement Project. Prepared for: Solano County Water Agency and California Department of Fish and Wildlife.

Stringfellow, W.T., Hanlon, J.S., Borglin, S.E. and Quinn, N.W.T. 2008. Comparison of wetland and agriculture drainage as sources of biochemical oxygen demand to the San Joaquin River, California. *Agricultural Water Management*, 95(5): 527-538.

Stumpner, E.B., Bergamaschi, B.A., Kraus, T.E.C., Parker, A.E., Wilkerson, F.P., Downing, B.D. et al. 2020. Spatial variability of phytoplankton in a shallow tidal freshwater system reveals complex controls on abundance and community structure. *Science of The Total Environment*, 700: 134392.

Sturrock, A.M., Carlson, S.M., Wikert, J.D., Heyne, T., Nusslé, S., Merz, J.E. et al. 2019a. Unnatural selection of salmon life histories in a modified riverscape. *Global Change Biology*.

Sturrock, A.M., Satterthaite, W.H., Cervantes-Yoshida, K.M., Huber, E.R., Sturrock, H.J.W., Nusslé, S. et al. 2019b. Eight decades of hatchery salmon releases in the California Central Valley: Factors influencing straying and resilience. *Fisheries*, 44(9): 433-444.

Sturrock, A.M., Ogaz, M., Neal, K., Corline, N.J., Peek, R., Myers, D. et al. 2022. Floodplain trophic subsidies in a modified river network: managed foodscapes of the future? *Landscape Ecology*: 37:2991-3009. https://doi.org/10.1007/s10980-022-01526-5.

Sturrock, A.M., Wikert, J.D., Heyne, T., Mesick, C., Hubbard, A.E., Hinkelman, T.M. et al. 2015. Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes. *PLOS ONE*, 10(5): e0122380.

Swain, D.L., Langenbrunner, B., Neelin, J.D. and Hall, A. 2018. Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change*, 8(5): 427-433.

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

Takata, L., Sommer, T.R., Louise Conrad, J. and Schreier, B.M. 2017. Rearing and migration of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a large river floodplain. *Environmental Biology of Fishes*, 100(9): 1105-1120.

Teh, S.J., Acuña, S., Garcia, P.A.T., Duarte, W.R., Young, T., Vallopi, L. et al. 2019. Evaluation of Delta Smelt Health with Respect to Regional Delta Contaminant Levels. In: *Directed Outflow Project: Technical Report 1.* (ed. Schultz, AA). U.S. Bureau of Reclamation, Bay-Delta Office, Mid-Pacific Region Sacramento, CA., pp. 161-200.

Tillotson, M.D., Hassrick, J., Collins, A.L. and Phillis, C. 2022. Machine Learning Forecasts to Reduce Risk of Entrainment Loss of Endangered Salmonids at Large-Scale Water Diversions in the Sacramento-San Joaquin Delta, California. *San Francisco Estuary and Watershed Science*, 20(2).

U.S. Bureau of Reclamation (Reclamation). 2021. American River Group Summary of Activities for Water Year 2021. Folsom, CA.

U.S. Bureau of Reclamation (Reclamation) and U.S. Fish and Wildlife Service (USFWS). 2020. Near-term Restoration Strategy for the Central Valley Project Improvement Act Fish Resource Area FY2021–FY2025. Prepared for the Bureau of Reclamation and U.S. Fish and Wildlife Service Sacramento, CA, p. 100.

U.S. Fish and Wildlife Service (USFWS). 1995. *Working Paper on Restoration Needs. Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Volume 3.* Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/2006wqcp/exhibits/append2/doi/doi-16e.pdf. Accessed: December 28, 2022.

U.S. Fish and Wildlife Service (USFWS). 2003. *Flow-Habitat Relationships for Steelhead and Fall, Late-Fall, and Winter-Run Chinook Salmon Spawning in the Sacramento River between Keswick Dam and Battle Creek.* Available: https://dsm-docs.s3.us-west-2.amazonaws.com/Sacramento_River_Spawning_Final_Report_Feb_4_2003.pdf. Accessed: December 28, 2022.

U.S. Fish and Wildlife Service (USFWS). 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). United States Fish and Wildlife Service Sacramento, California.

U.S. Fish and Wildlife Service (USFWS). 2014. Identification of the Instream Flow Requirements for Anadromous Fish in the Streams Within the Central Valley of California and Fisheries Investigations. Annual Progress Report Fiscal Year 2014. Sacramento, CA.

Vogel, D. A. 2011. Insights into the problems, progress, and potential solutions for Sacramento River Basin anadromous fish restoration. Prepared for the Northern California Water Association and Sacramento Valley Water Users, 161 pp.

Voluntary Agreements Parties. 2022. Memorandum of Understanding Advancing a Term Sheet for the Voluntary Agreements to Update and Implement the Bay-Delta Water Quality Control Plan, and Other Related Actions. California Natural Resource Agency, California Environmental Protection Agency, State Water Contractors, et. al.

Ward, D.M. and Sepulveda, A. 2014. A race against time: Establishing baseline data on redwood ecosystem food webs before New Zealand mud snails invade. *Report. Save The Redwoods League*.

Ward, P.D. and McReynolds, T.R. 2004. Butte and Big Chico Creeks Spring-Run Chinook Salmon Life History Investigation, 1998-2000. California Department of Fish and Game, Rancho Cordova, CA.

Weitkamp, L.A., Teel, D.J., Liermann, M., Hinton, S.A., Van Doornik, D.M. and Bentley, P.J. 2015. Stock-specific size and timing at ocean entry of Columbia river juvenile chinook salmon and steelhead: Implications for early ocean growth. In: *Marine and Coastal Fisheries*, pp. 370-392.

Weston, D.P., Chen, D. and Lydy, M.J. 2015. Stormwater-related transport of the insecticides bifenthrin, fipronil, imidacloprid, and chlorpyrifos into a tidal wetland, San Francisco Bay, California. *Science of the Total Environment*, 527(Supplement C): 18-25.

Whipple, A., Grossinger, R., Rankin, D., Stanford, B. and Askevold, R. 2012. Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process. San Francisco Estuary Institute Richmond.

Whitley, S.N. and Bollens, S.M. 2014. Fish assemblages across a vegetation gradient in a restoring tidal freshwater wetland: diets and potential for resource competition. *Environmental Biology of Fishes*, 97(6): 659-674.

Wildlife Survey and Photo Service. 2015. 2014 Putah Salmon Run. Prepared for Rich Marovich and Chris Lee. p. 6 pp.

Williams, J.G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science*, 4(3).

Williams, P.B., Andrews, E., Opperman, J.J., Bozkurt, S. and Moyle, P.B. 2009. Quantifying activated floodplains on a lowland regulated river: its application to floodplain restoration in the Sacramento Valley. *San Francisco Estuary and Watershed Science*, 7(1).

Winder, M. and Jassby, A.D. 2011. Shifts in zooplankton community structure: implications for food web processes in the upper San Francisco Estuary. *Estuaries and Coasts*, 34(4): 675-690.

Windham-Myers, L., Fleck, J.A., Ackerman, J.T., Marvin-DiPasquale, M., Stricker, C.A., Heim, W.A. et al. 2014. Mercury cycling in agricultural and managed wetlands: a synthesis of methylmercury production, hydrologic export, and bioaccumulation from an integrated field study. *The Science of the total environment*, 484: 221-231.

Woo, I., Davis, M.J., Ellings, C.S., Hodgson, S., Takekawa, J.Y., Nakai, G. et al. 2019. A Mosaic of Estuarine Habitat Types with Prey Resources from Multiple Environmental Strata Supports a Diversified Foraging Portfolio for Juvenile Chinook Salmon. *Estuaries and Coasts*, 42(7): 1938-1954.

Wood Rogers. 2014. *Central Valley Floodplain Evaluation and Delineation. Task Order No. 25. Subtask 5 Combined Sacramento River System Model Technical Memorandum.* Available: https://s3-us-west-2.amazonaws.com/cvpiahabitat-r-package/cvpia-sit-model-inputs/CombinedTM_IQAR_Final-FULL-REPORT_20140206.pdf. Accessed: December 28, 2022.

Work, P.A., Downing-Kunz, M. and Drexler, J.Z. 2020. Trapping of Suspended Sediment by Submerged Aquatic Vegetation in a Tidal Freshwater Region: Field Observations and Long-Term Trends. *Estuaries and Coasts*.

Wyrick, J. and Pasternack, G. 2012. Landforms of the lower Yuba River. *University of California, Davis*.

Yamane, L., Botsford, L.W. and Kilduff, D.P. 2018. Tracking restoration of population diversity via the portfolio effect. *Journal of Applied Ecology*, 55(2): 472-481.

Yanagitsuru, Y.R., Davis, B.E., Baerwald, M.R., Sommer, T.R. and Fangue, N.A. 2022. Using physiology to recover imperiled smelt species. In: *Fish Physiology*. Academic Press.

Yarnell, S.M., Stein, E.D., Webb, J.A., Grantham, T., Lusardi, R.A., Zimmerman, J. et al. 2020. A functional flows approach to selecting ecologically relevant flow metrics for environmental flow applications. *River Research and Applications*, 36(2): 318-324.

Yelton, R., Slaughter, A.M. and Kimmerer, W.J. 2022. Diel Behaviors of Zooplankton Interact with Tidal Patterns to Drive Spatial Subsidies in the Northern San Francisco Estuary. *Estuaries and Coasts*.

Young, M., Howe, E., O'Rear, T., Berridge, K. and Moyle, P. 2021. Food Web Fuel Differs Across Habitats and Seasons of a Tidal Freshwater Estuary. *Estuaries and Coasts*, 44(1): 286-301.

Young, M.J., Feyrer, F.V., Colombano, D.D., Conrad, J.L. and Sih, A. 2018. Fish-Habitat Relationships Along the Estuarine Gradient of the Sacramento-San Joaquin Delta, California: Implications for Habitat Restoration. *Estuaries and Coasts*.

Yuba Basin Foundation and California Department of Fish and Wildlife (CDFW). 2016. Initial Study and Mitigated Negative Declaration for the Lower Putah Creek Restoration Project.

Zabel, R.W., Anderson, J.J. and Shaw, P.A. 1998. A multiple-reach model describing the migratory behavior of Snake River yearling chinook salmon (*Oncorhynchus tshawytscha*). In: *Canadian Journal of Fisheries and Aquatic Sciences*, pp. 658-667.

Appendix A
RMA Modeling Methods

Appendix A
Delta and Estuary Hydrodynamic Analyses, Analytical Approach to Evaluating Assets

A.1 Observed Data Processing

Observed data were used to produce habitat data layers for temperature and turbidity. Data were downloaded for the 2010–2019 period, outliers were removed, and small data gaps were filled by interpolation.

All data were monthly averaged and then processed to produce overall monthly statistics (e.g., statistics for all Junes in the dataset). Statistics include mean, 25 percent quantiles, and 75 percent quantiles. Monthly averages and overall monthly statistics are plotted for each temperate and turbidity station in the sections below.

A.2 Temperature

Observed temperature data were downloaded from the California Department of Water Resources' California Data Exchange Center[1] at the locations shown in Figure 1.

For each station, bar and whisker plots and monthly average temperature time series plots are provided in Figure 2 through Figure 140. The bar and whisker plots show, for each month of the year, the overall data range (maximum and minimum values) as the "whiskers" and the mean, 25 percent, and 75 percent quantile values as the "bars." In the time series plots, annual temperature time series are plotted for each year that data are available during the 2010–2019 period. The 25° Celsius maximum limit for Delta smelt habitat is included on all plots for reference. While each of the two types of plots provides information about the data ranges, the time series plots give more information about the data availability. At some locations, data are only available for a few years out of the 10-year period.

[1] California Department of Water Resources, California Data Exchange Center. 2022. Historical Data Selector. Available: https://cdec.water.ca.gov/dynamicapp/selectQuery.

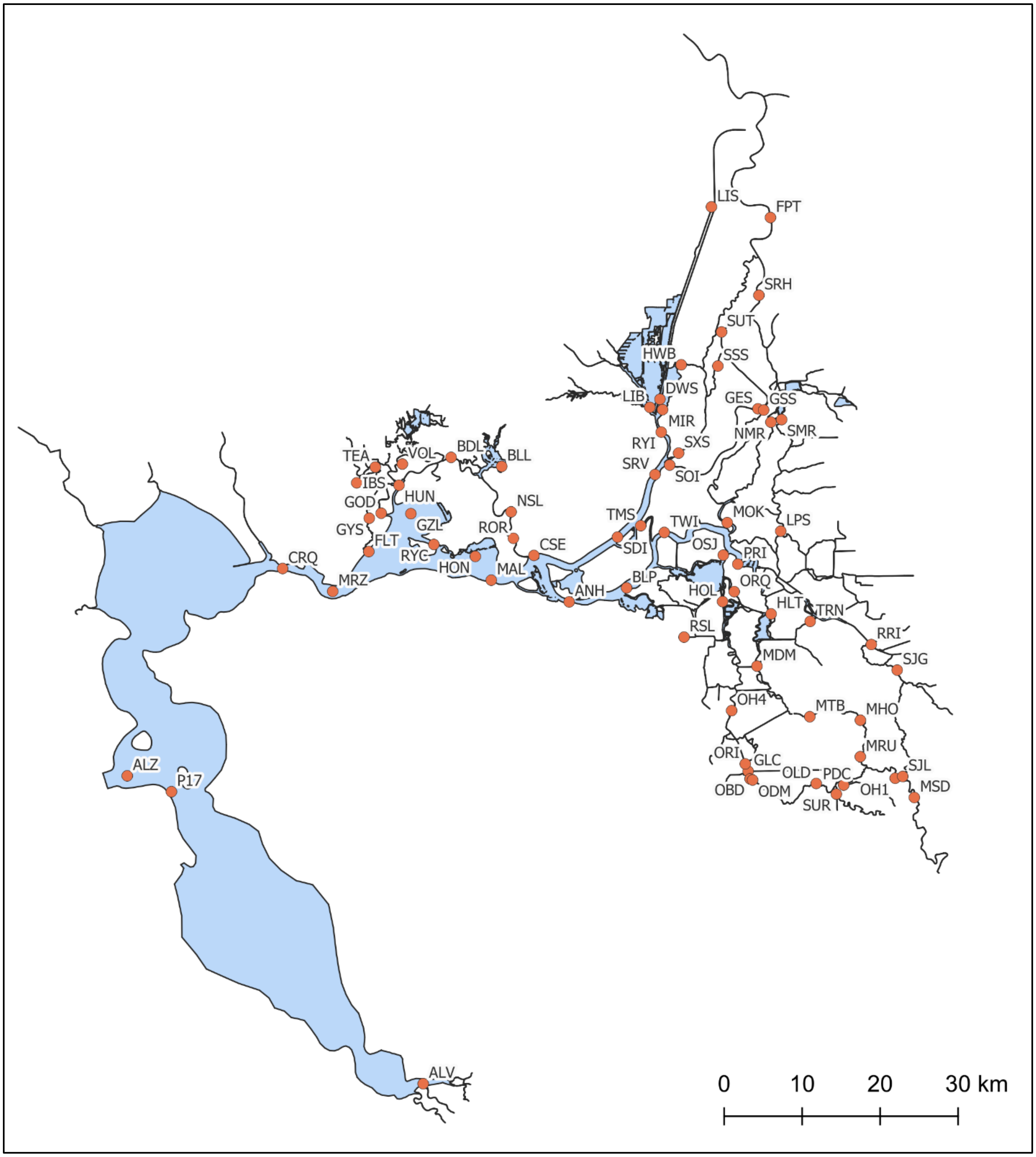

Figure 1. Locations of Observed Temperature Stations Used to Calculate the Temperature Data Layers for the Habitat Calculations

Figure is a map of the San Francisco Bay Estuary showing red points denoted by three-letter station codes representing sampling stations.

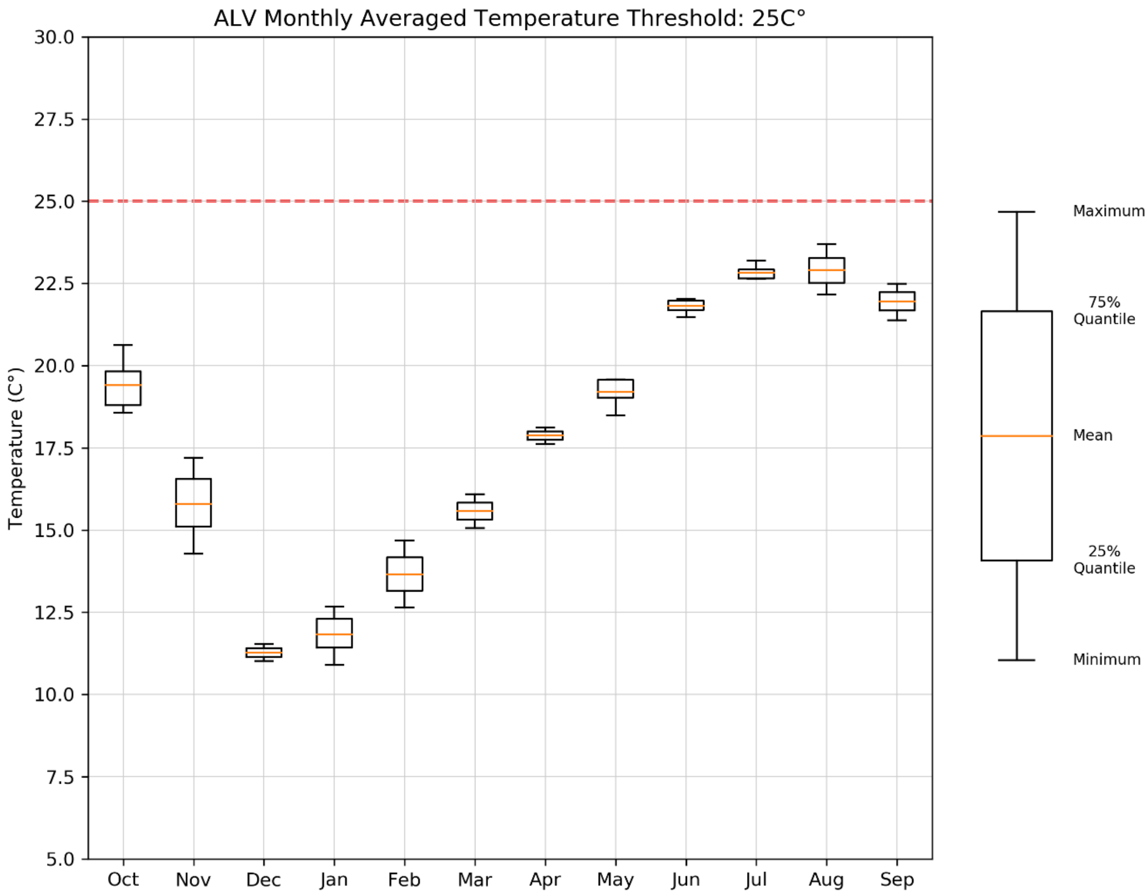

Figure 2. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ALV – Alviso Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; top and bottom portions of the whisker are maximum and minimum, respectively.

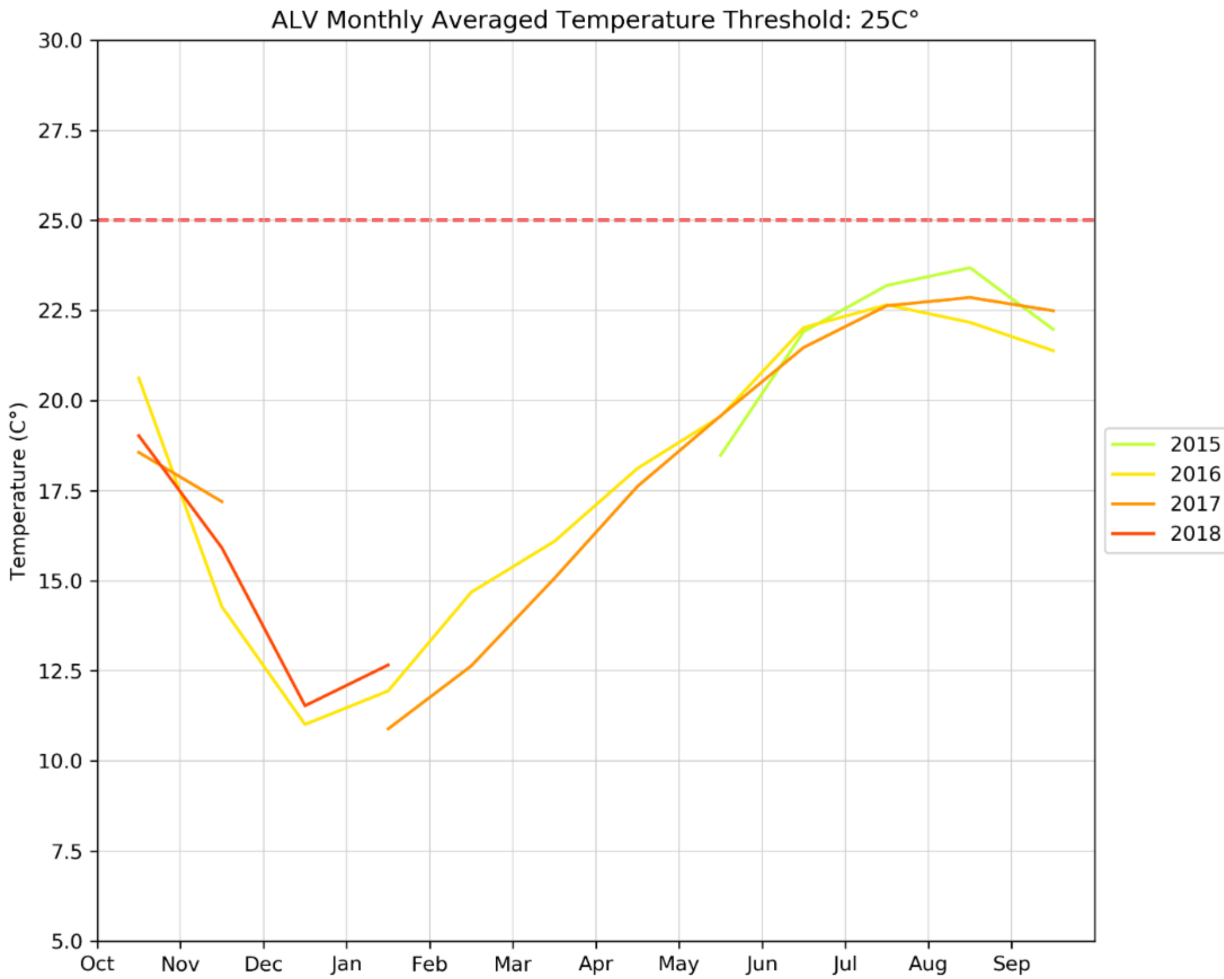

Figure 3. Monthly Average Temperature for the Period of Record at Station ALV – Alviso Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

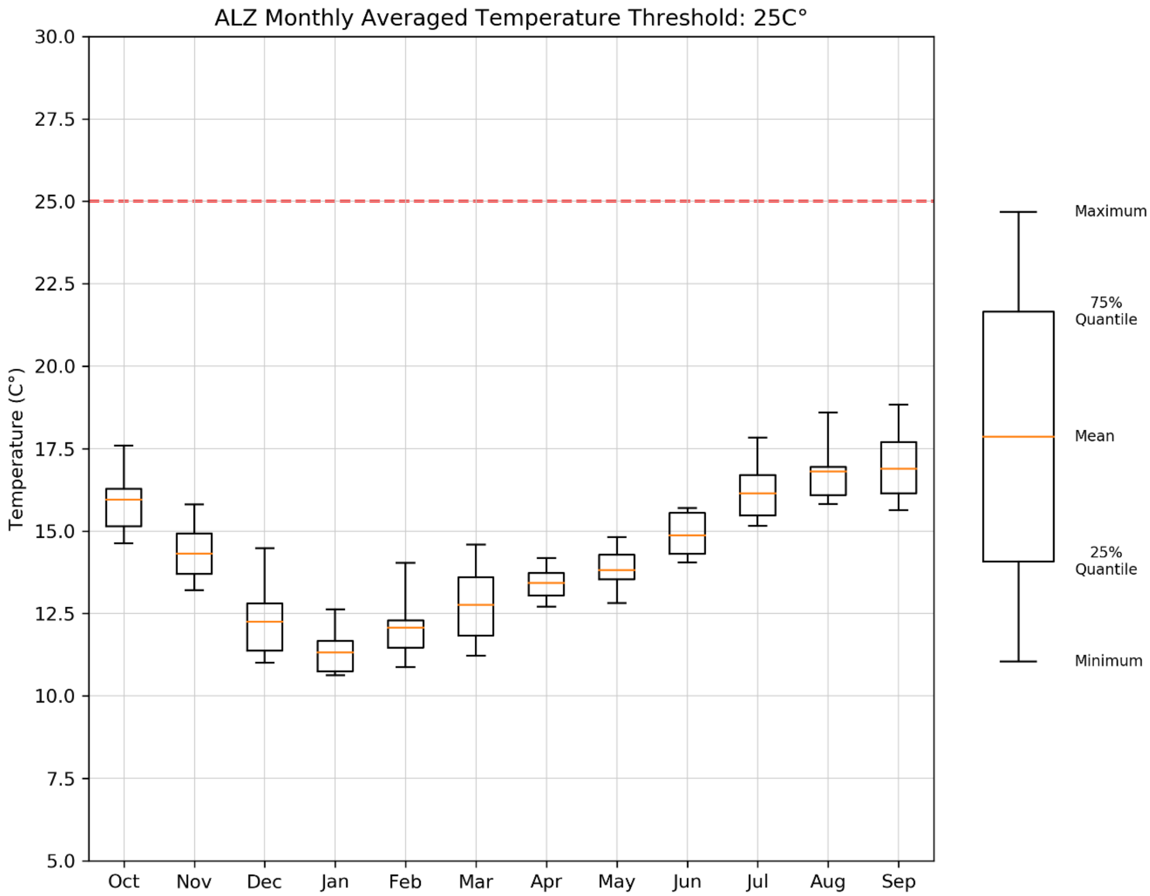

Figure 4. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ALZ – Alcatraz Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; top and bottom portions of the whisker are maximum and minimum, respectively.

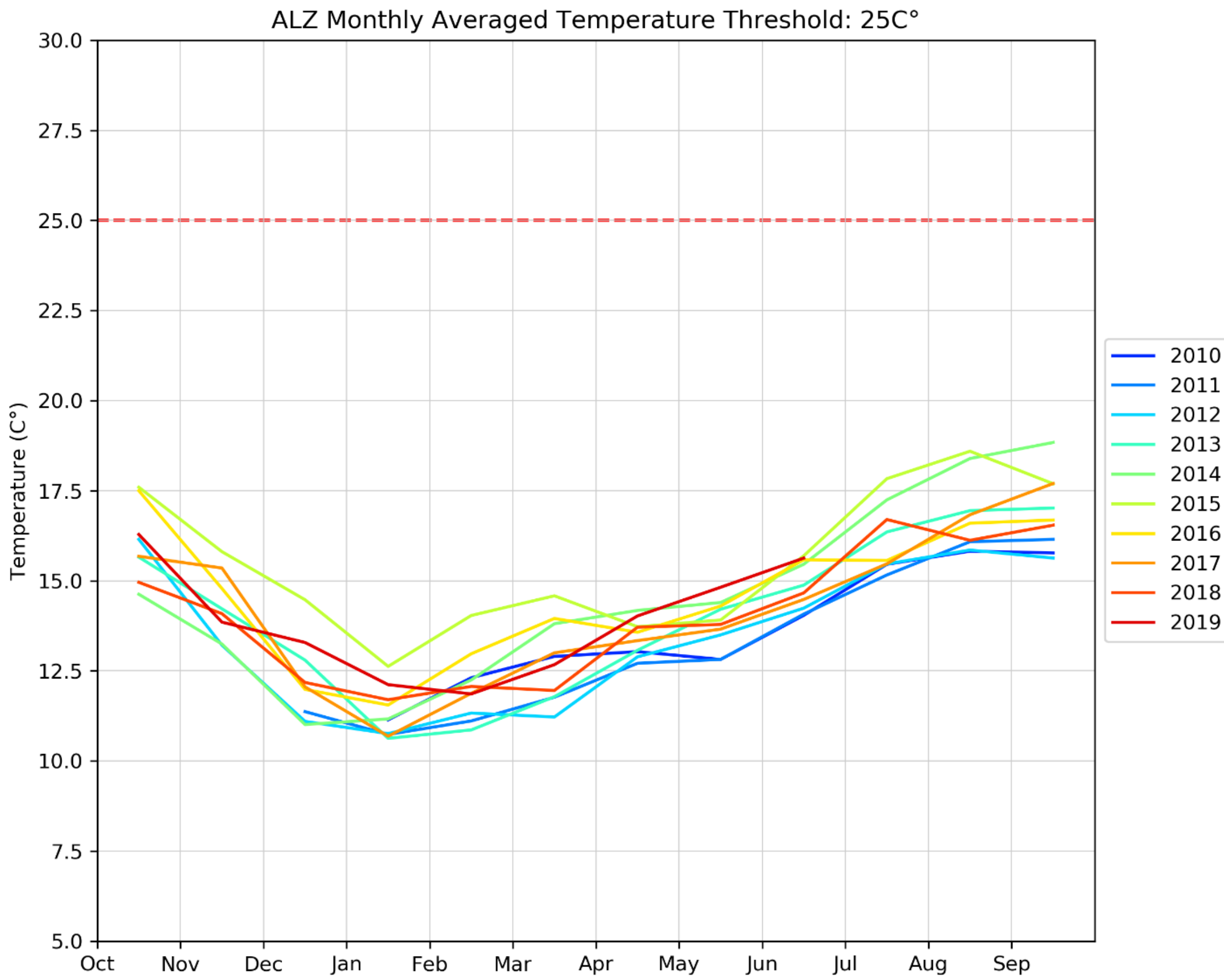

Figure 5. Monthly Average Temperature for the Period of Record at Station ALZ – Alcatraz Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

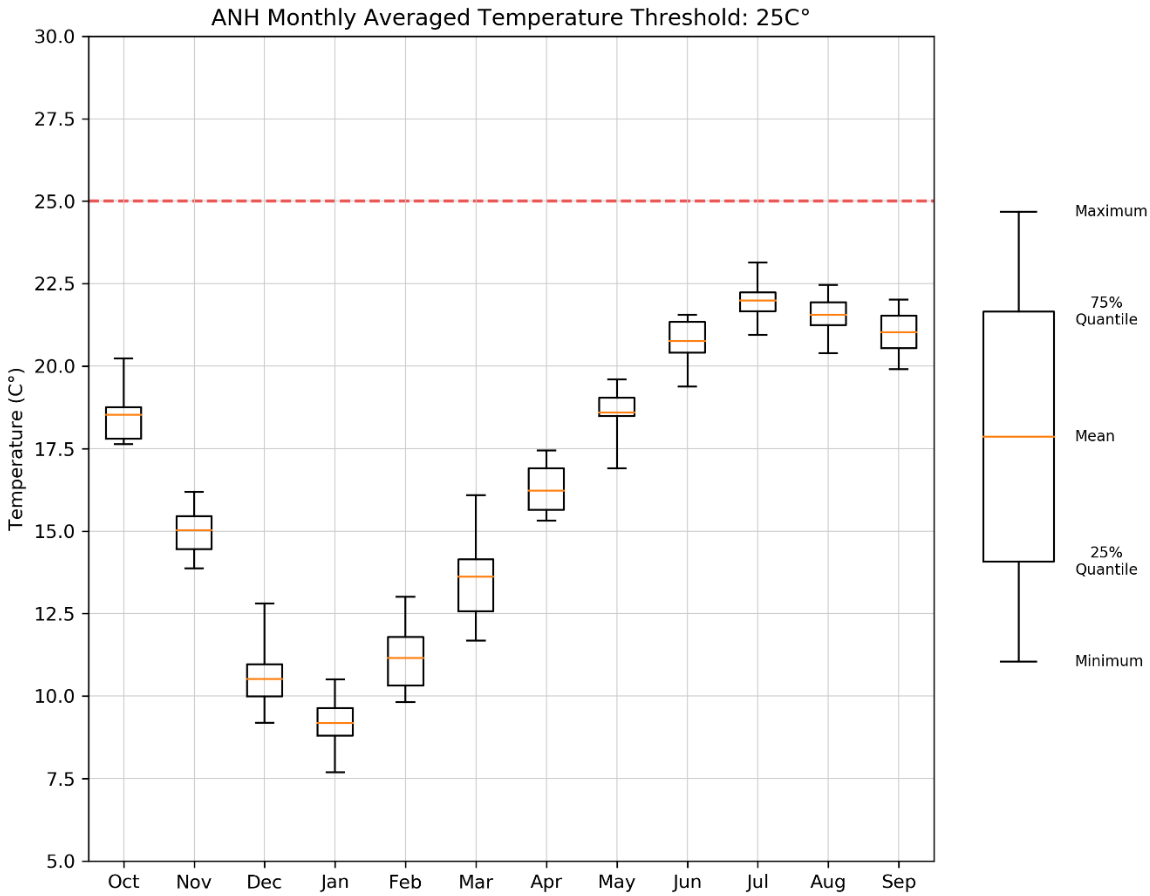

Figure 6. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ANH – San Joaquin River at Antioch

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

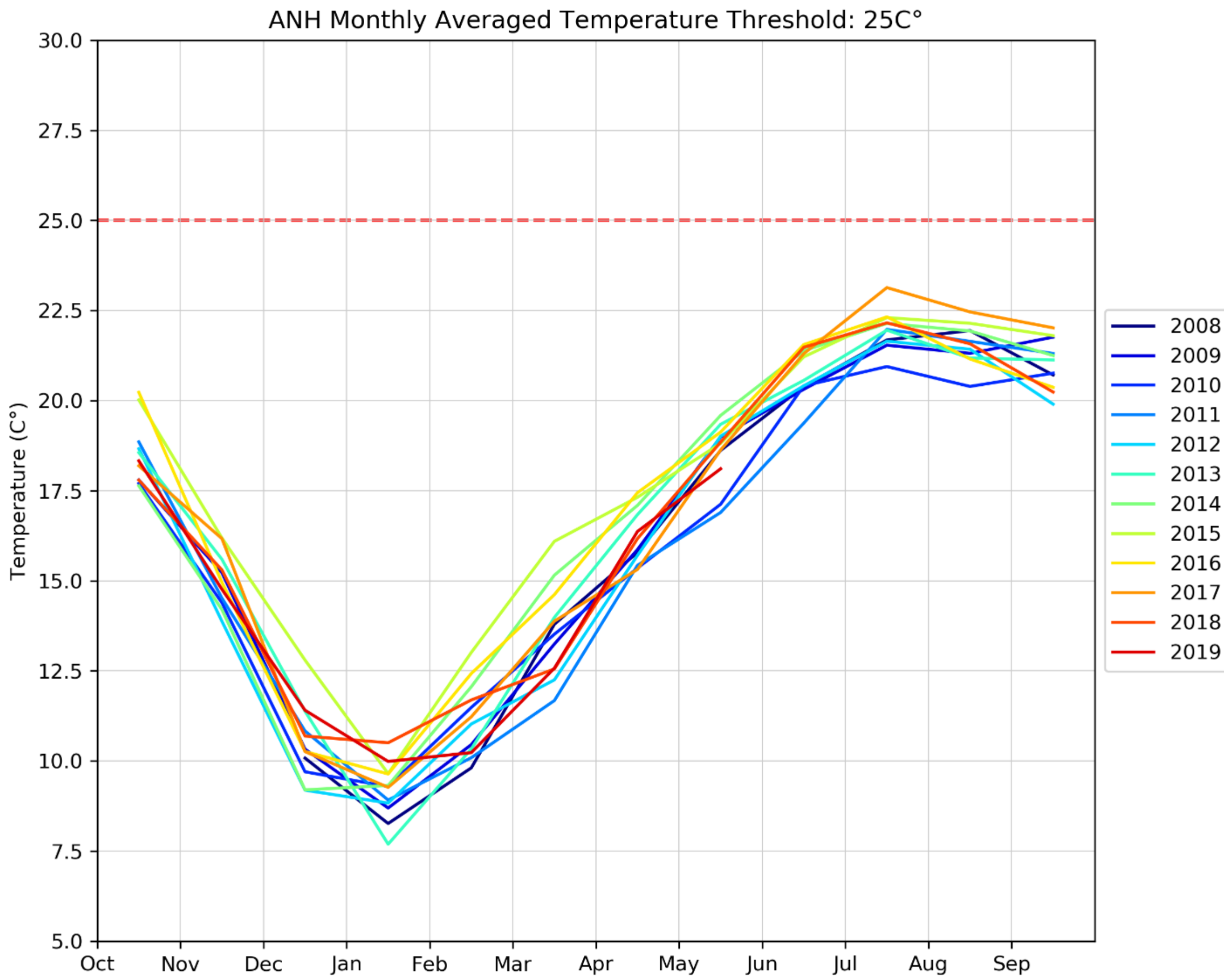

Figure 7. Monthly Average Temperature for the Period of Record at Station ANH – San Joaquin River at Antioch

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

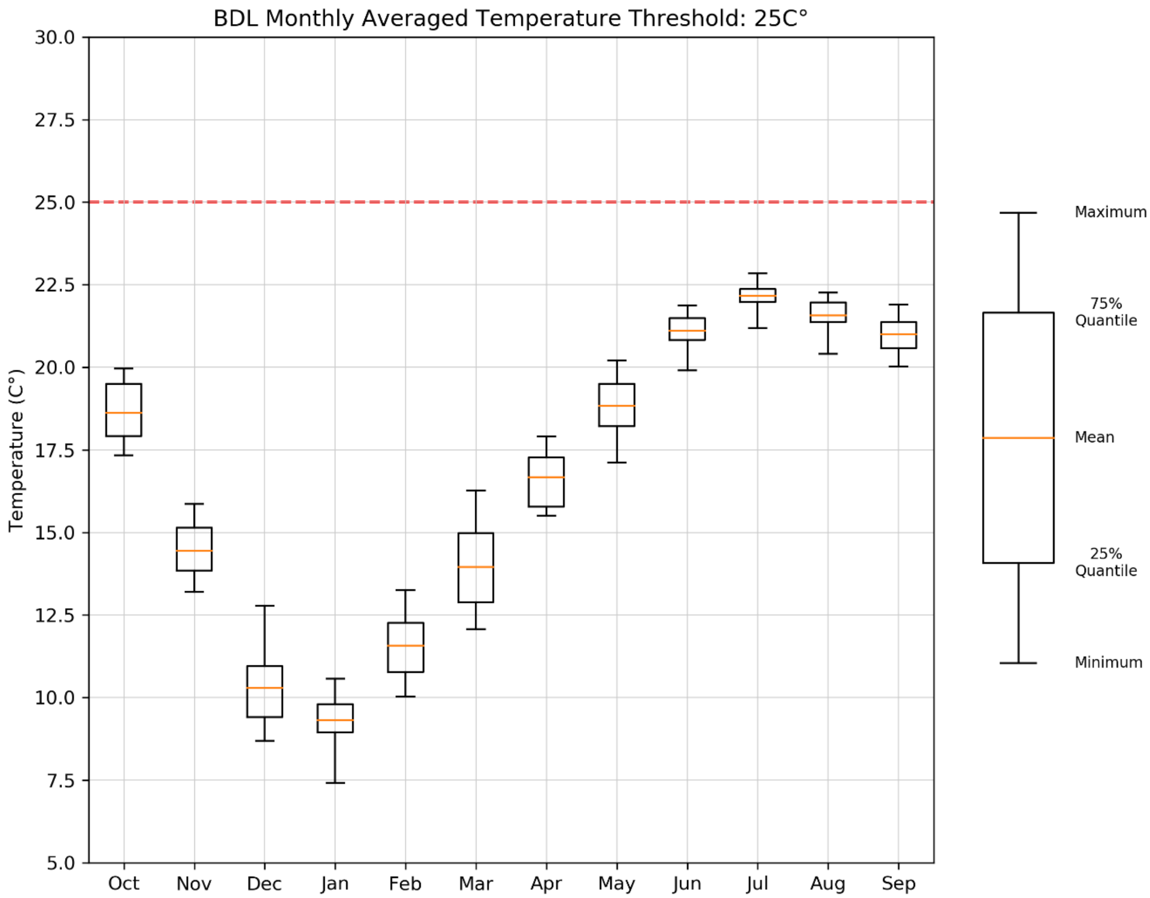

Figure 8. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BDL – Montezuma Slough at Beldon Landing

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

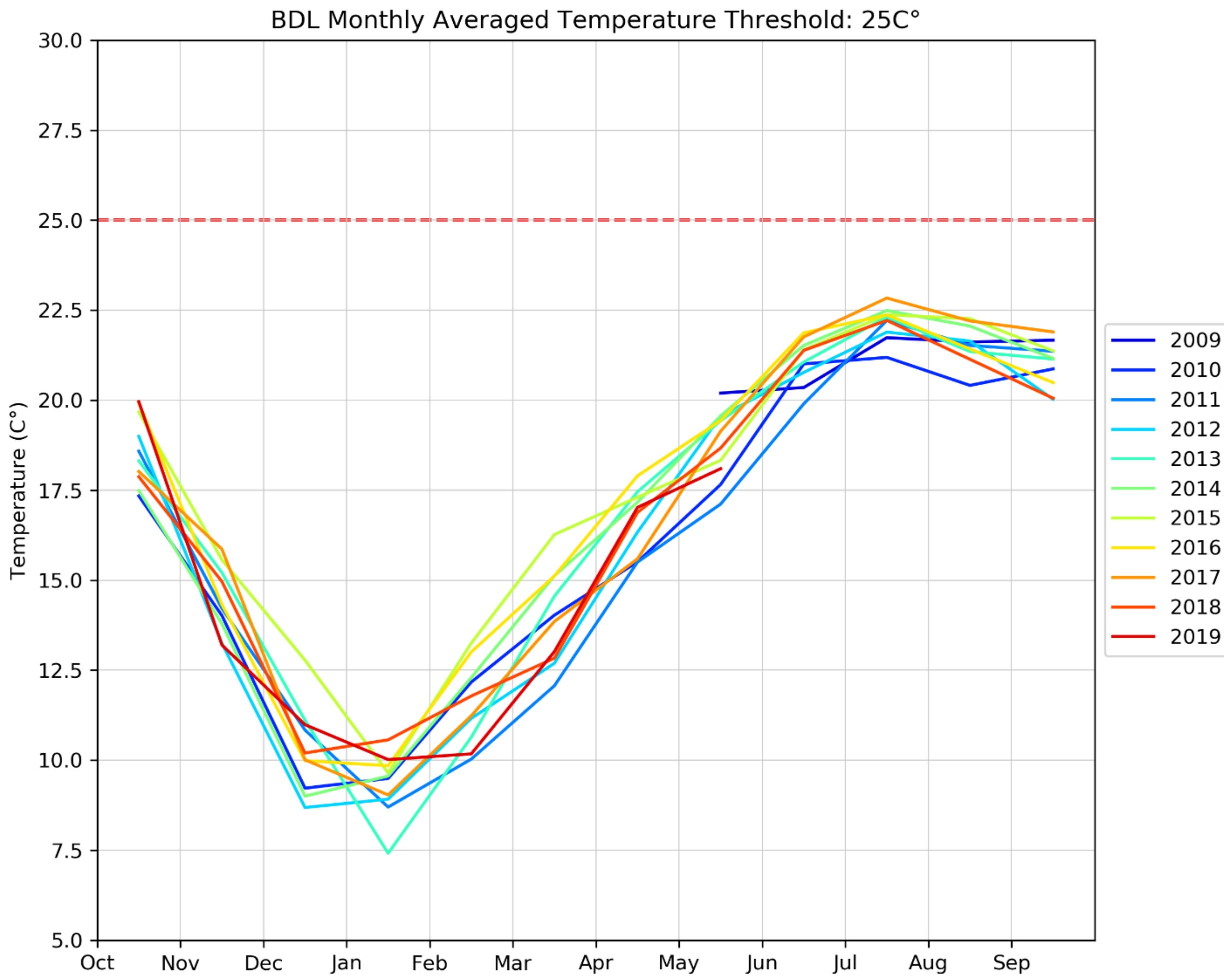

Figure 9. Monthly Average Temperature for the Period of Record at Station BDL – Montezuma Slough at Beldon Landing

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

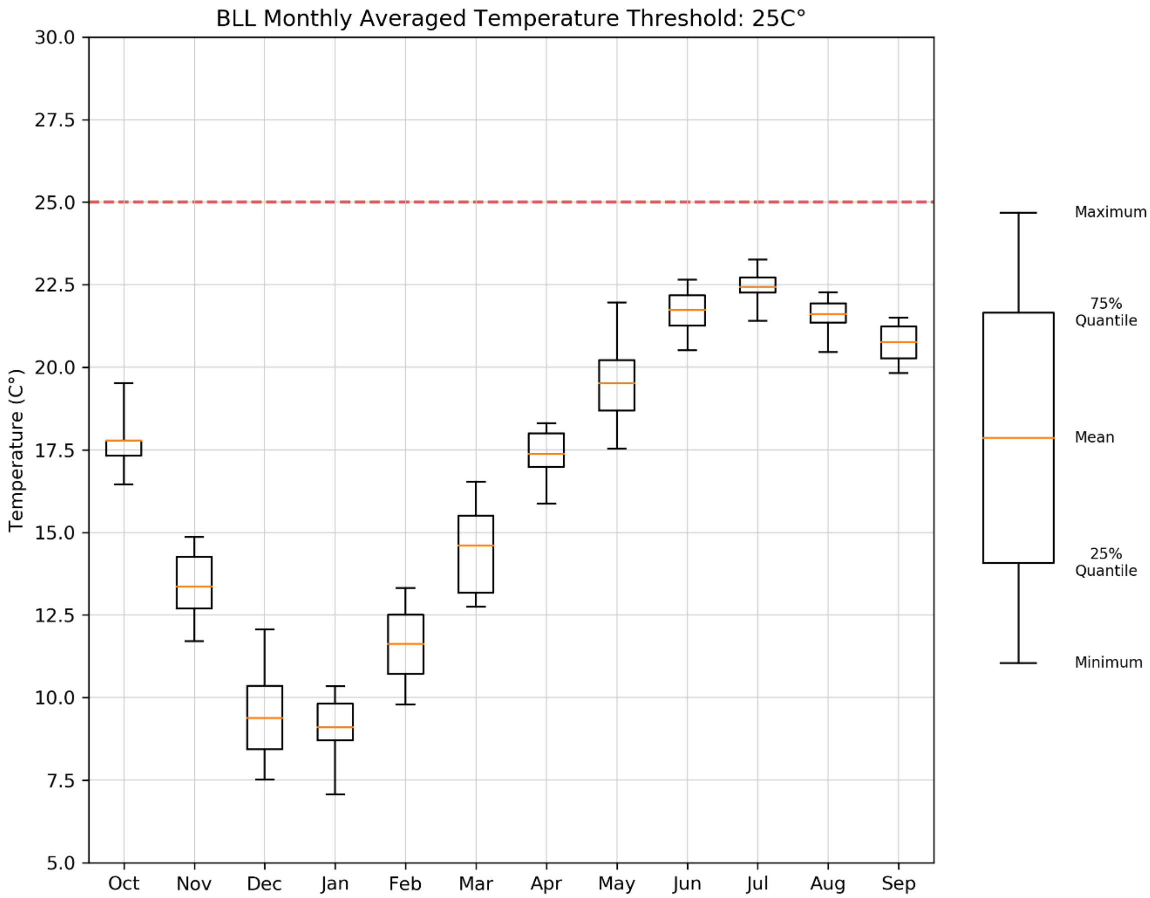

Figure 10. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BLL – Blacklock

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

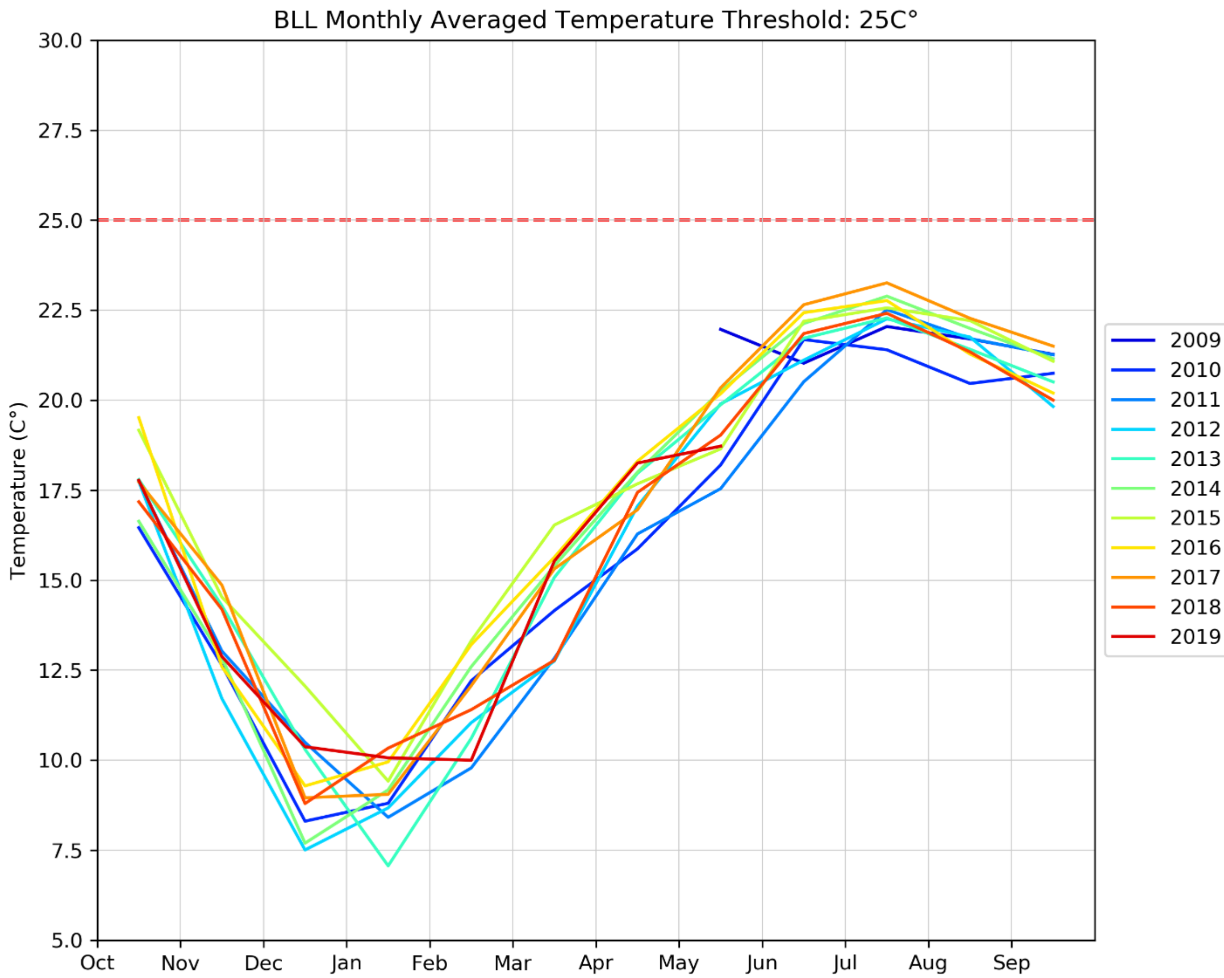

Figure 11. Monthly Average Temperature for the Period of Record at Station BLL – Blacklock

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

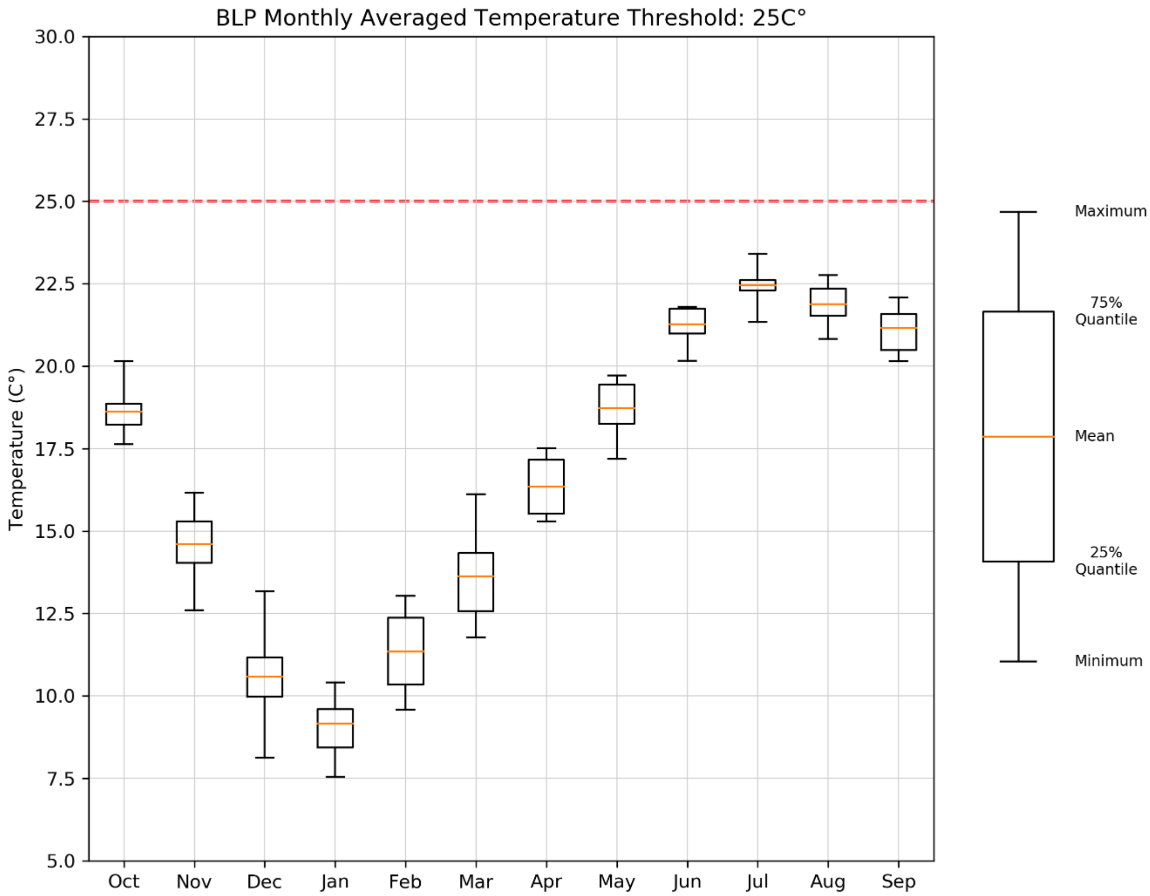

Figure 12. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station BLP – Blind Point

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

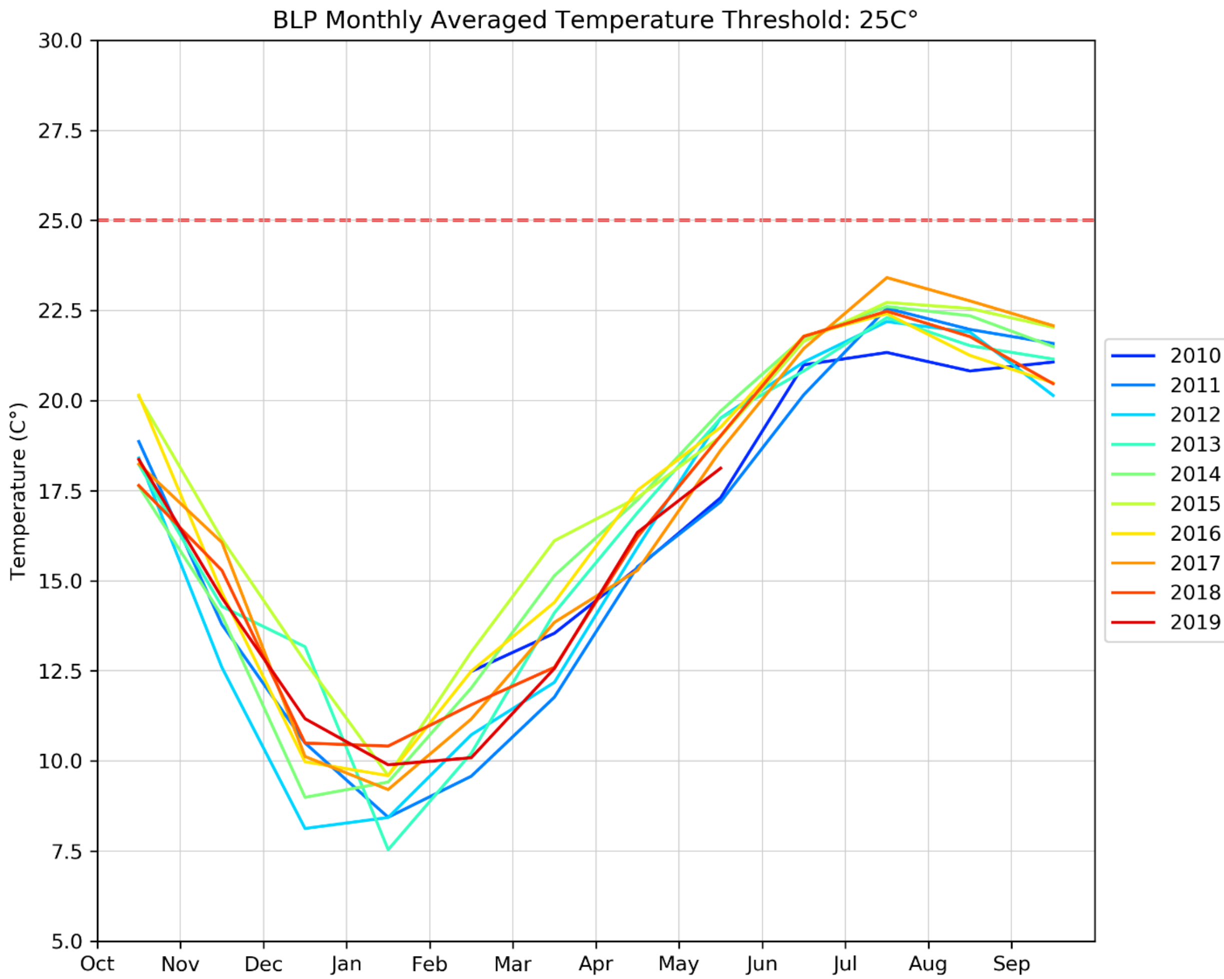

Figure 13. Monthly Average Temperature for the Period of Record at Station BLP – Blind Point

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

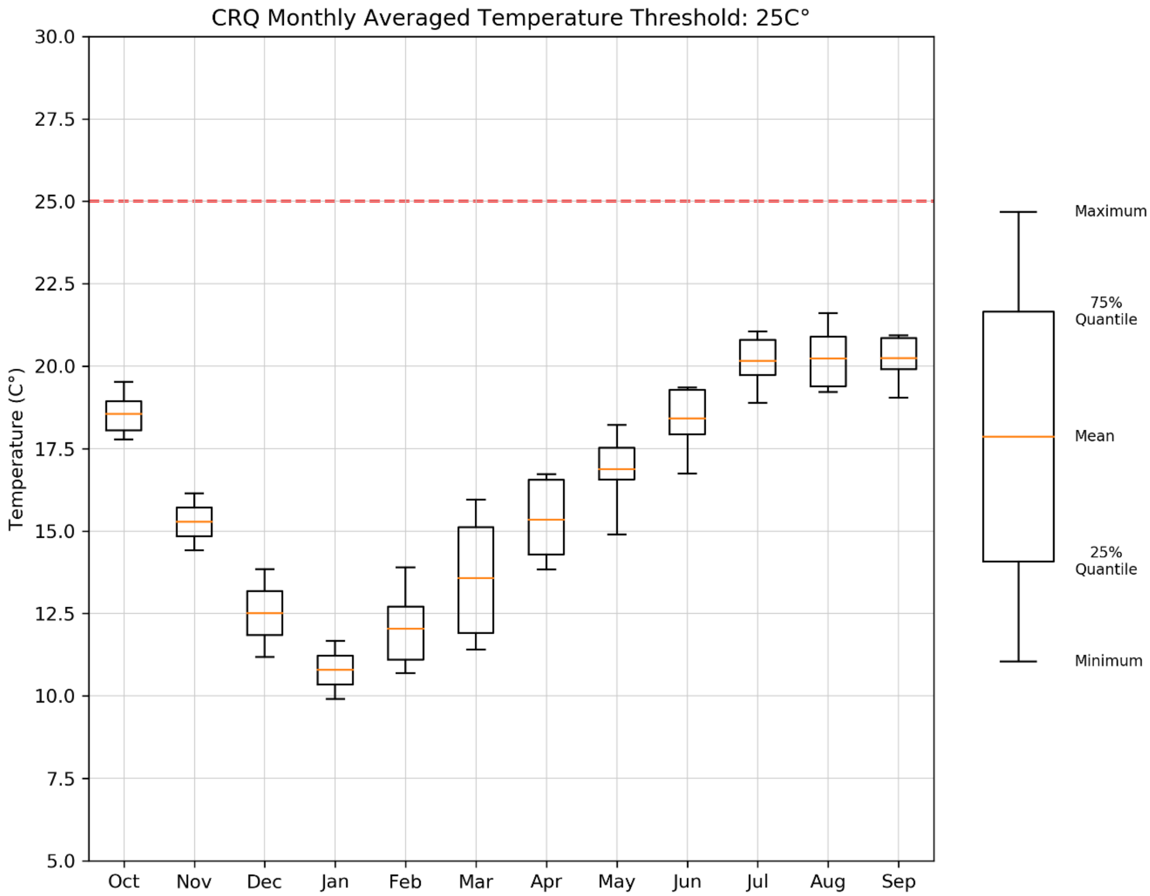

Figure 14. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station CRQ – Carquinez Straight at Carquinez Bridge Near Crockett

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

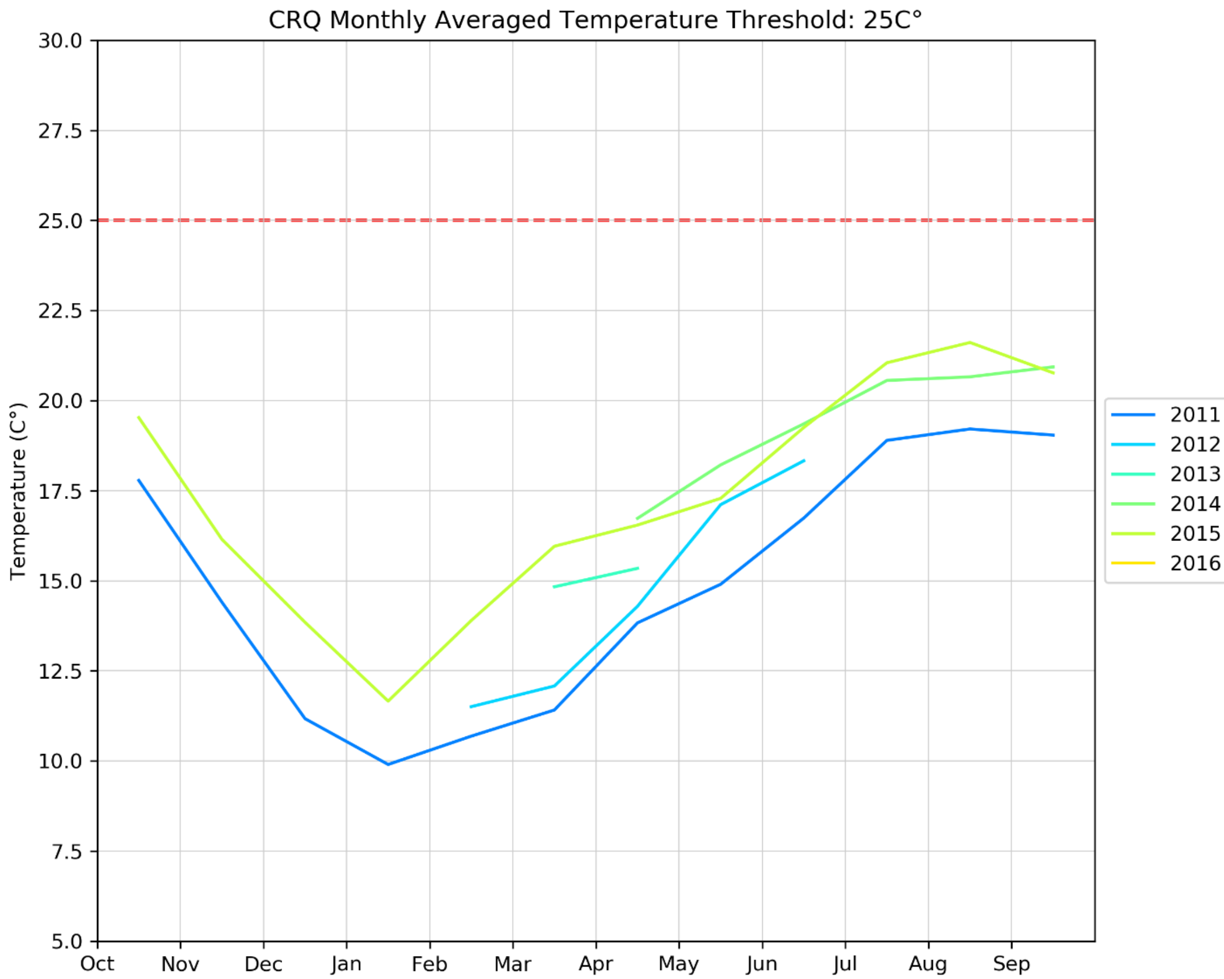

Figure 15. Monthly Average Temperature for the Period of Record at Station CRQ – Carquinez Straight at Carquinez Bridge Near Crockett

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

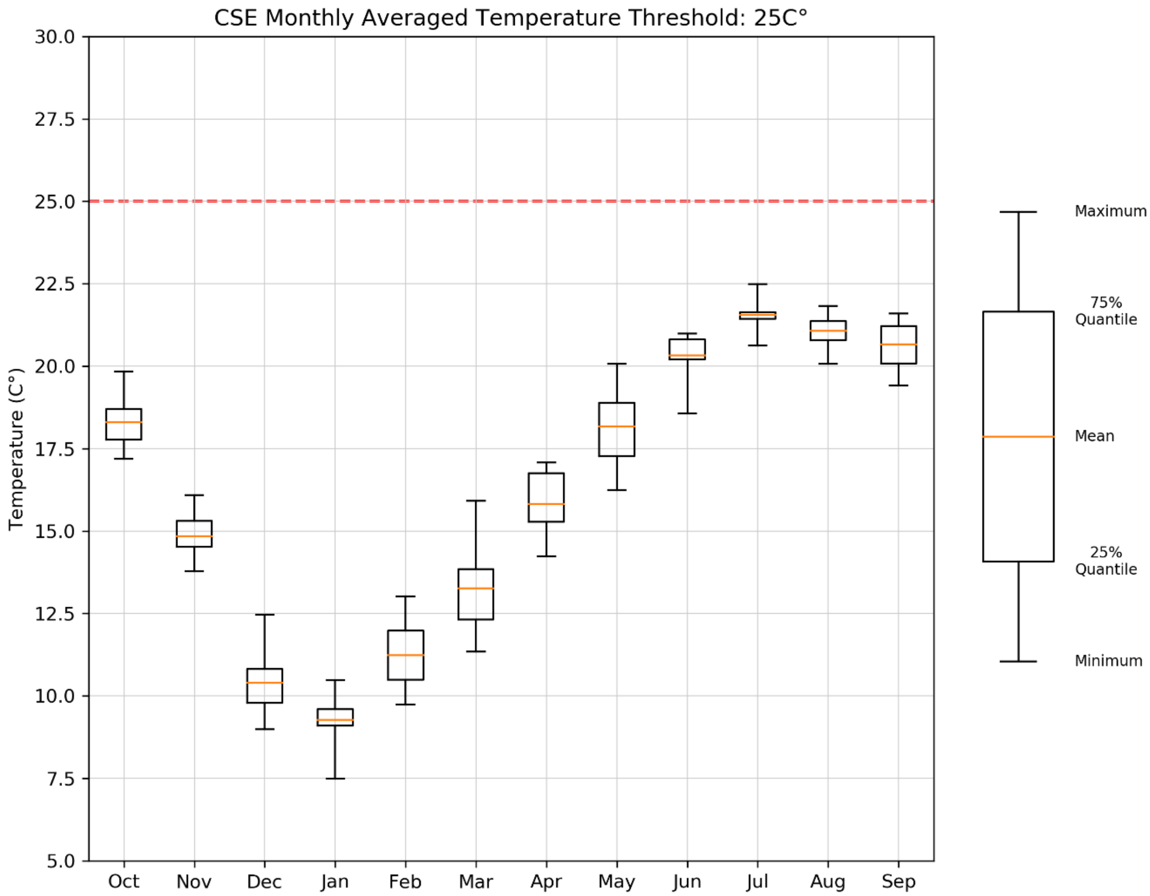

Figure 16. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station CSE – Sacramento River at Collinsville

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

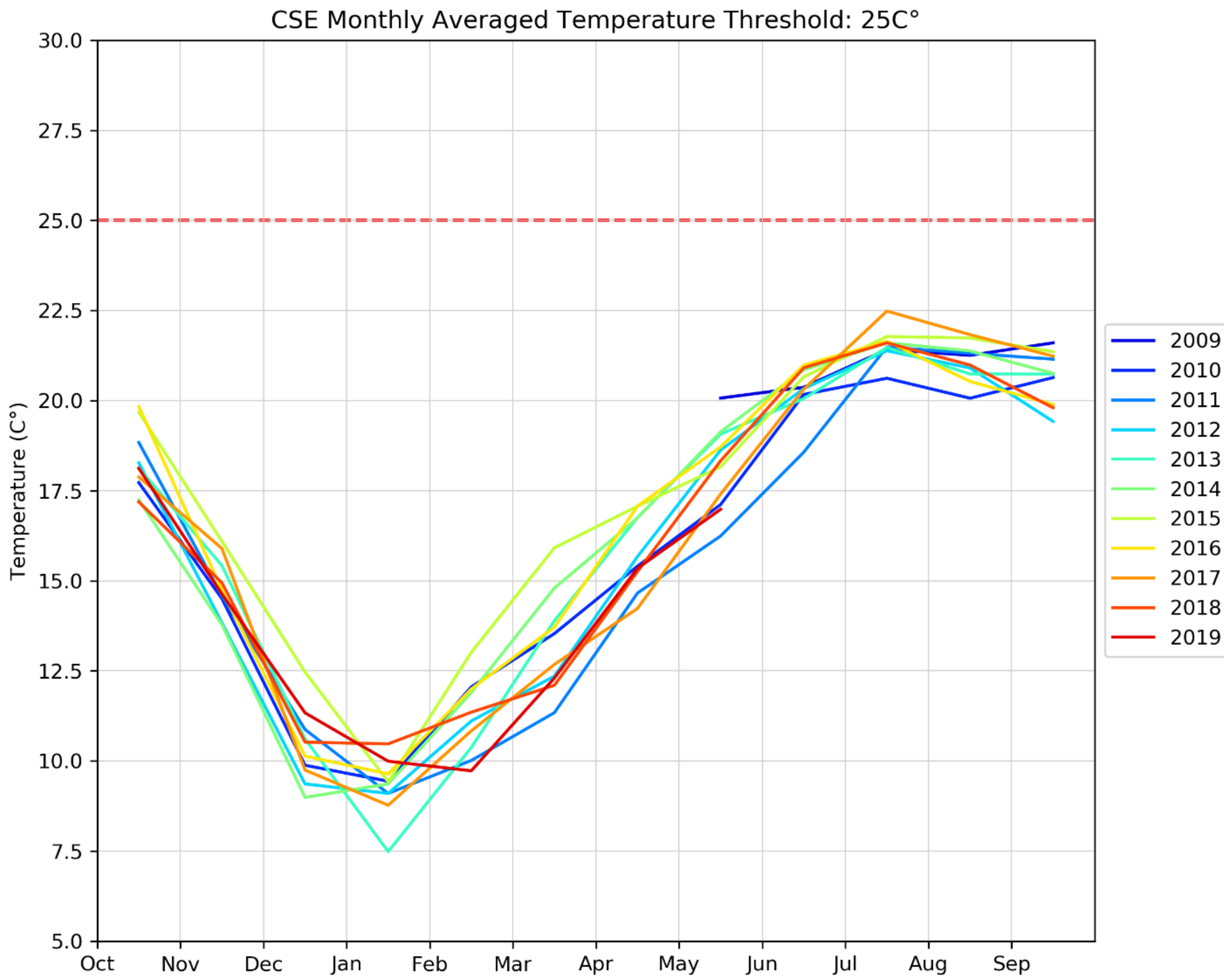

Figure 17. Monthly Average Temperature for the Period of Record at Station CSE – Sacramento River at Collinsville

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

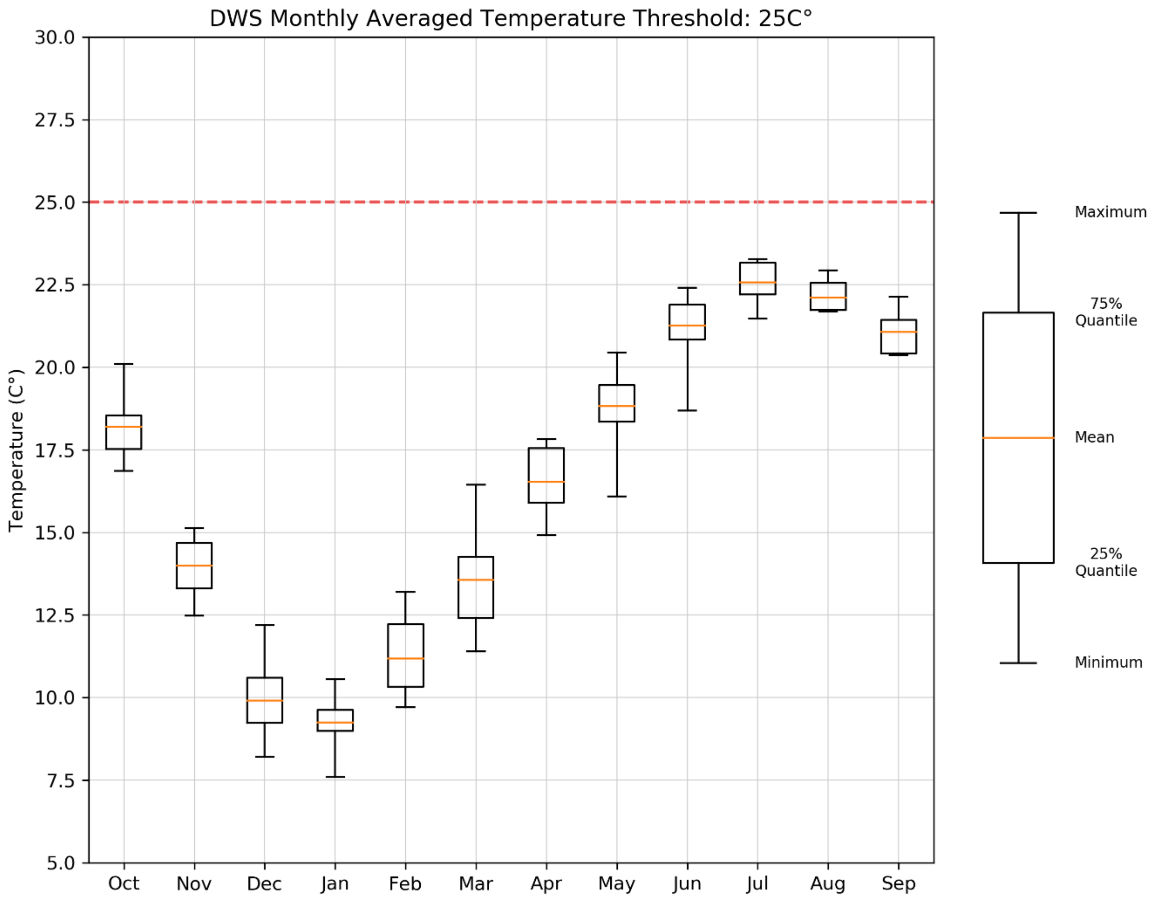

Figure 18. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station DWS – Sacramento Deep Water Shipping Channel

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

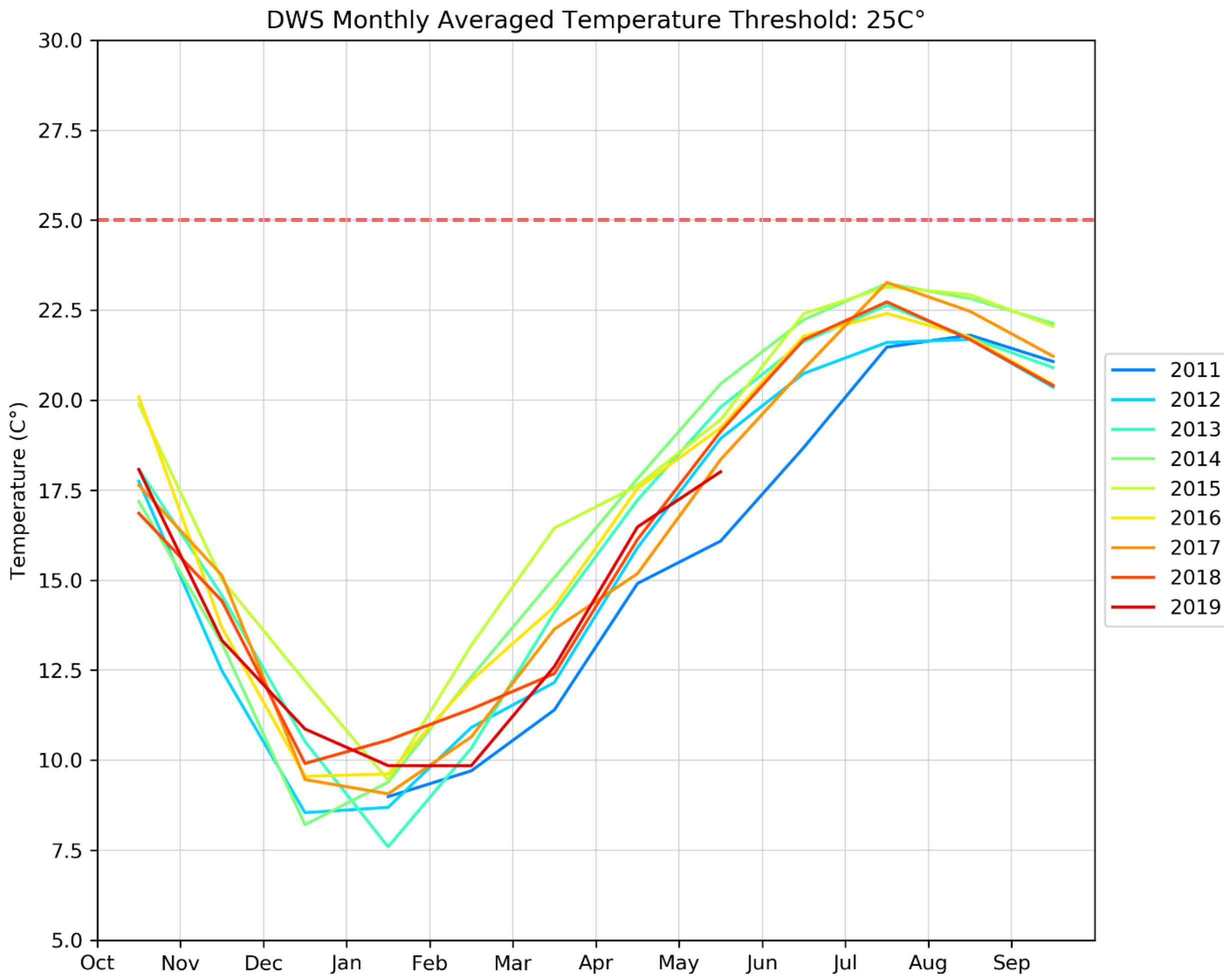

Figure 19. Monthly Average Temperature for the Period of Record at Station DWS – Sacramento Deep Water Shipping Channel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

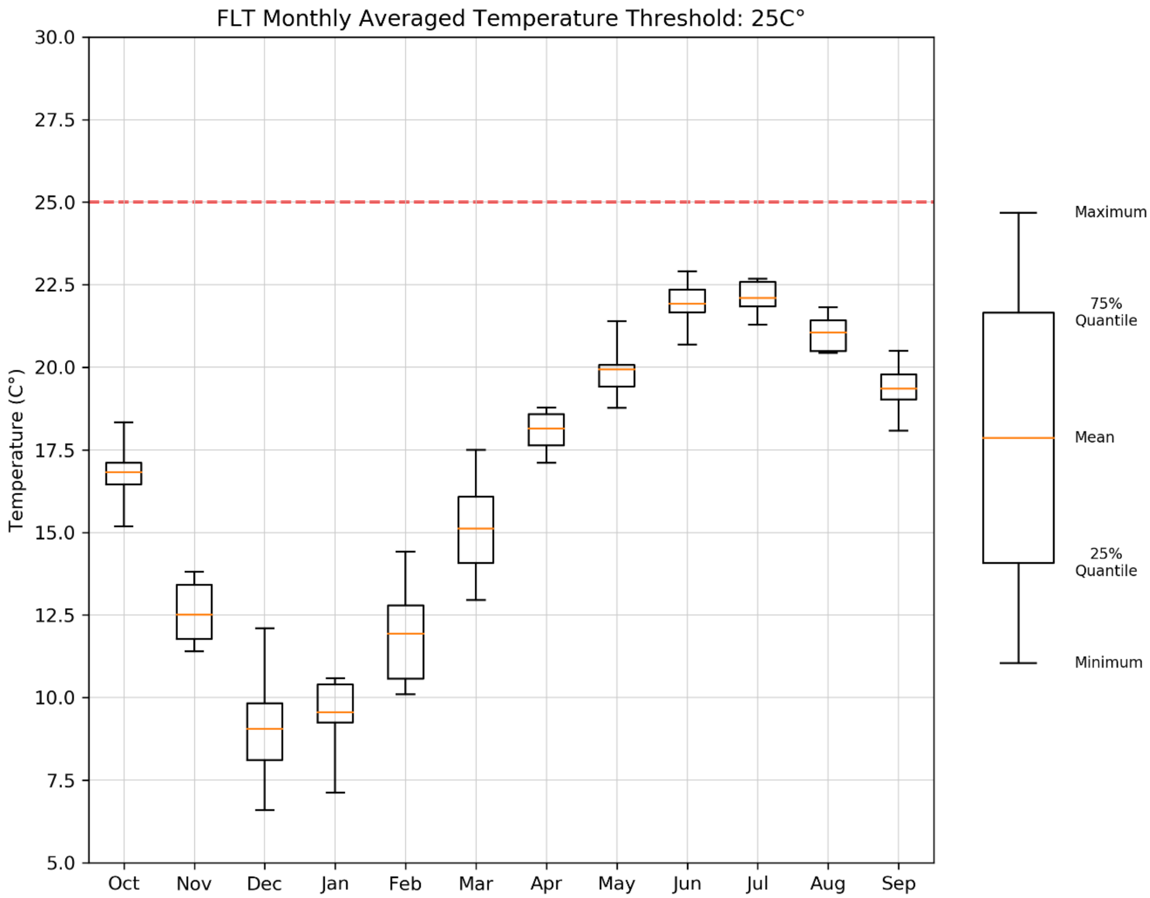

Figure 20. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station FLT – Goodyear Slough Outfall at Naval Fleet

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

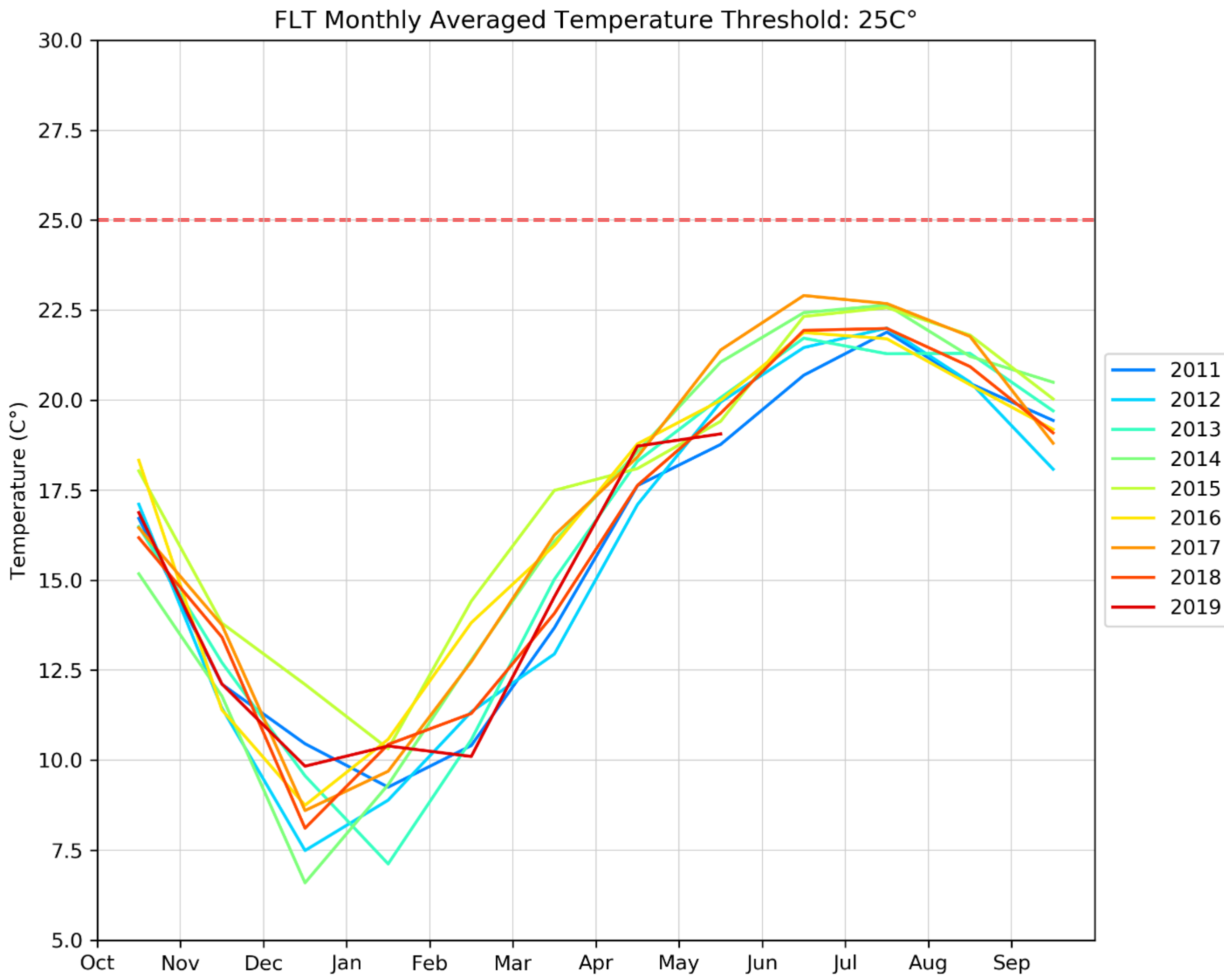

Figure 21. Monthly Average Temperature for the Period of Record at Station FLT – Goodyear Slough Outfall at Naval Fleet

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

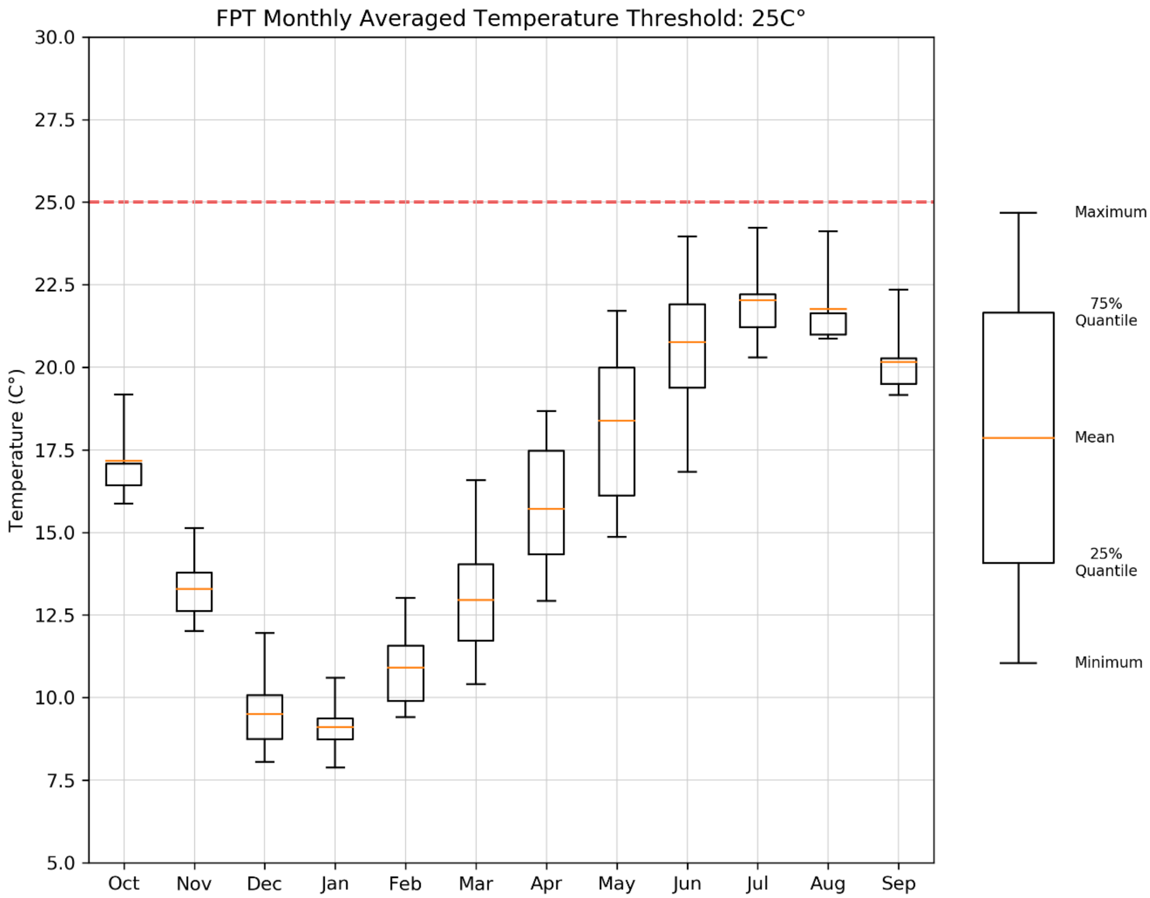

Figure 22. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station FPT – Sacramento River at Freeport

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

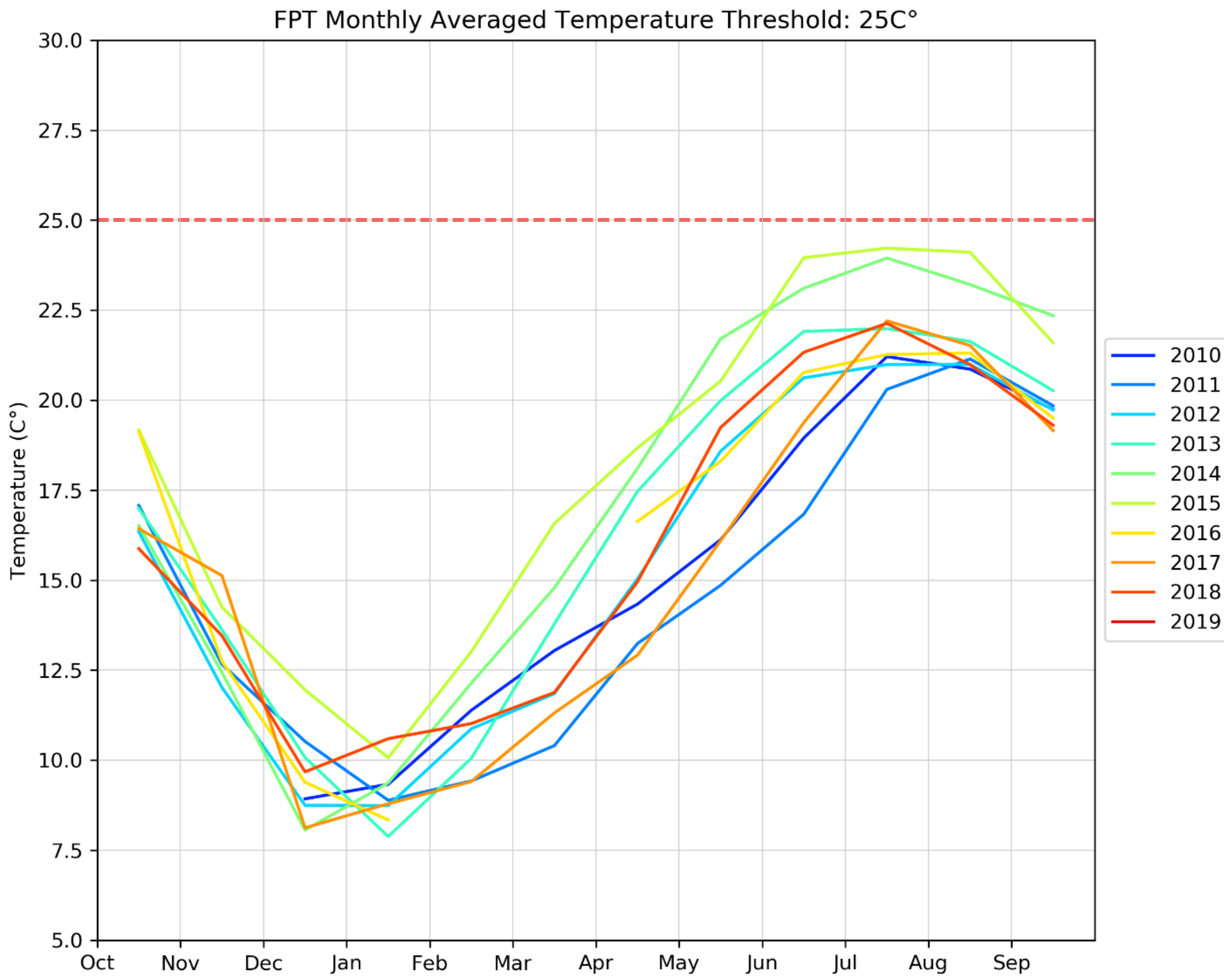

Figure 23. Monthly Average Temperature for the Period of Record at Station FPT – Sacramento River at Freeport

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

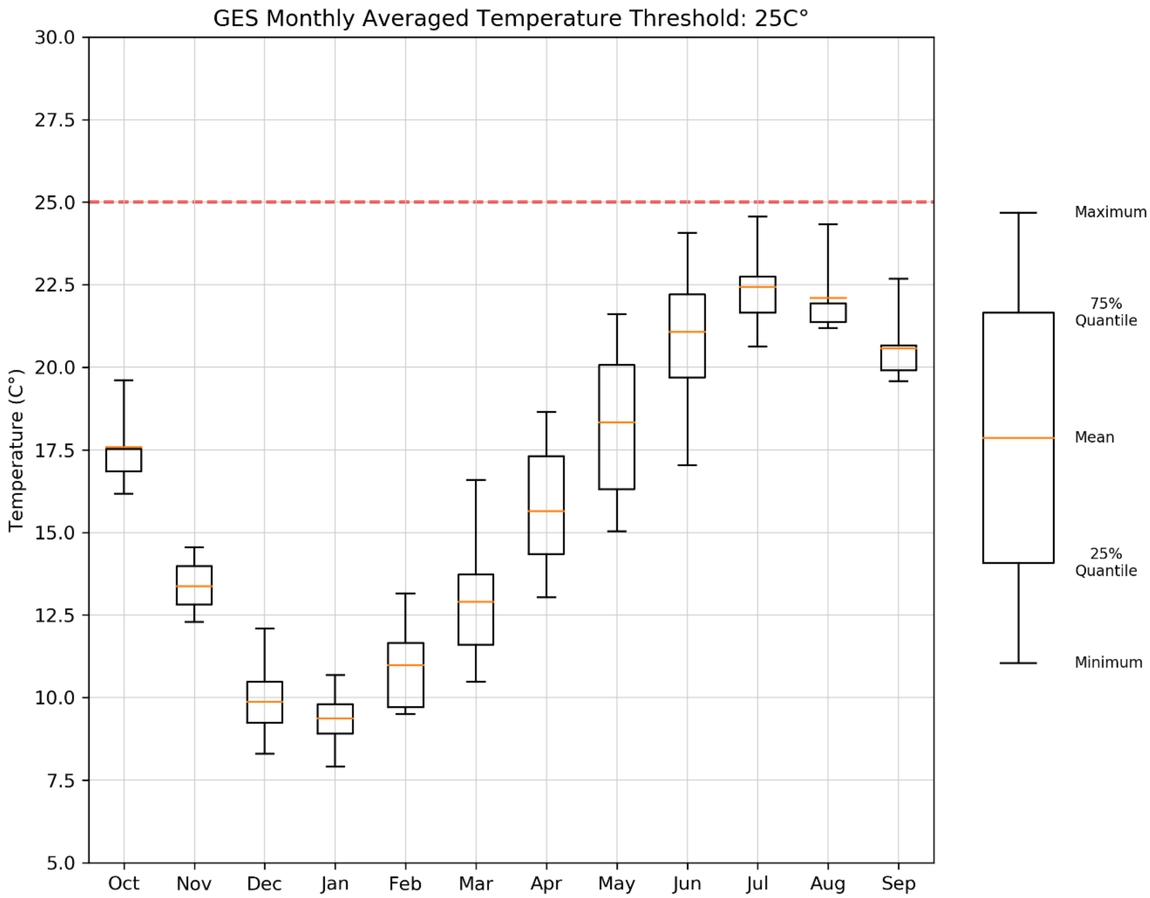

Figure 24. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GES – Sacramento River below Georgiana Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

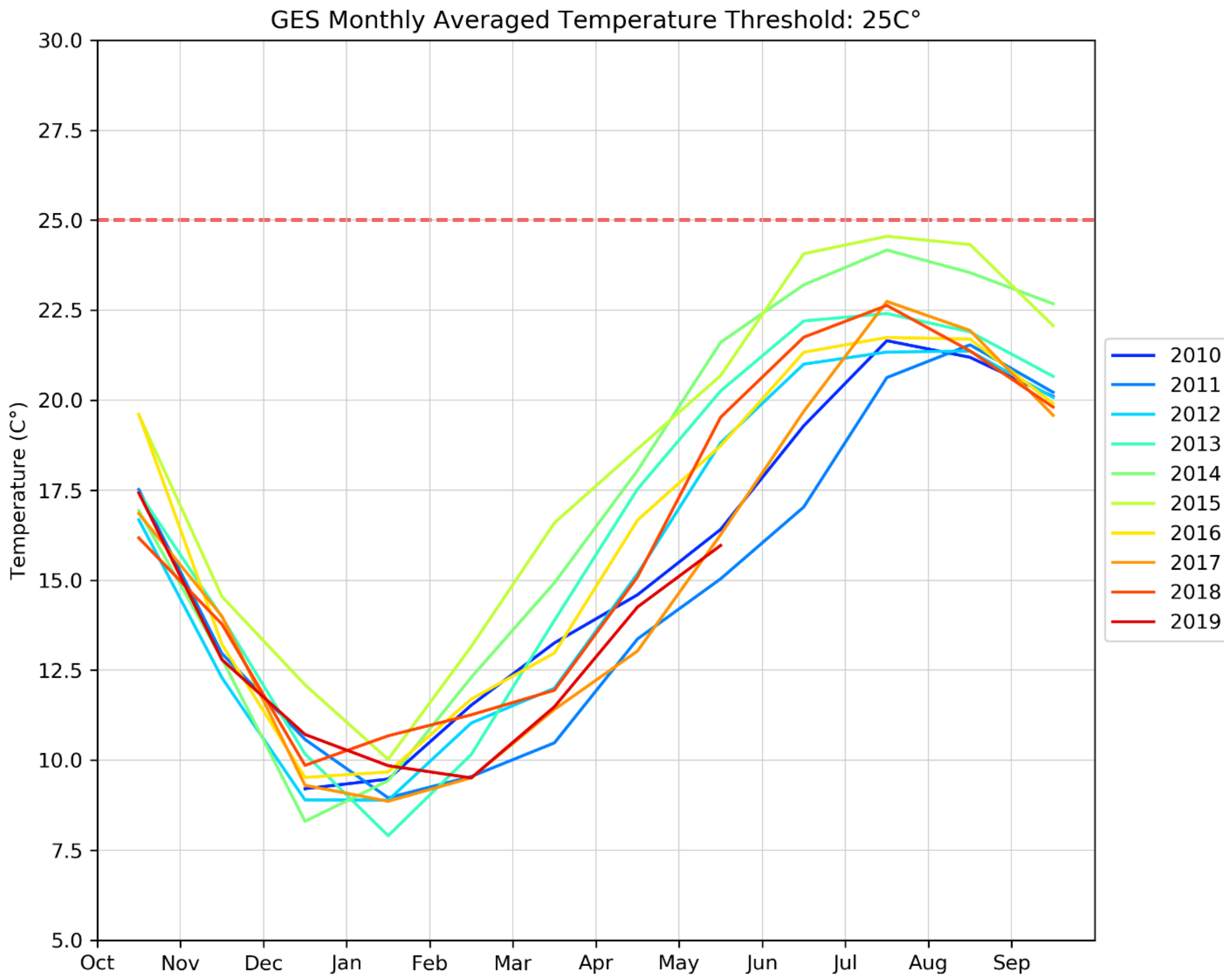

Figure 25. Monthly Average Temperature for the Period of Record at Station GES – Sacramento River below Georgiana Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

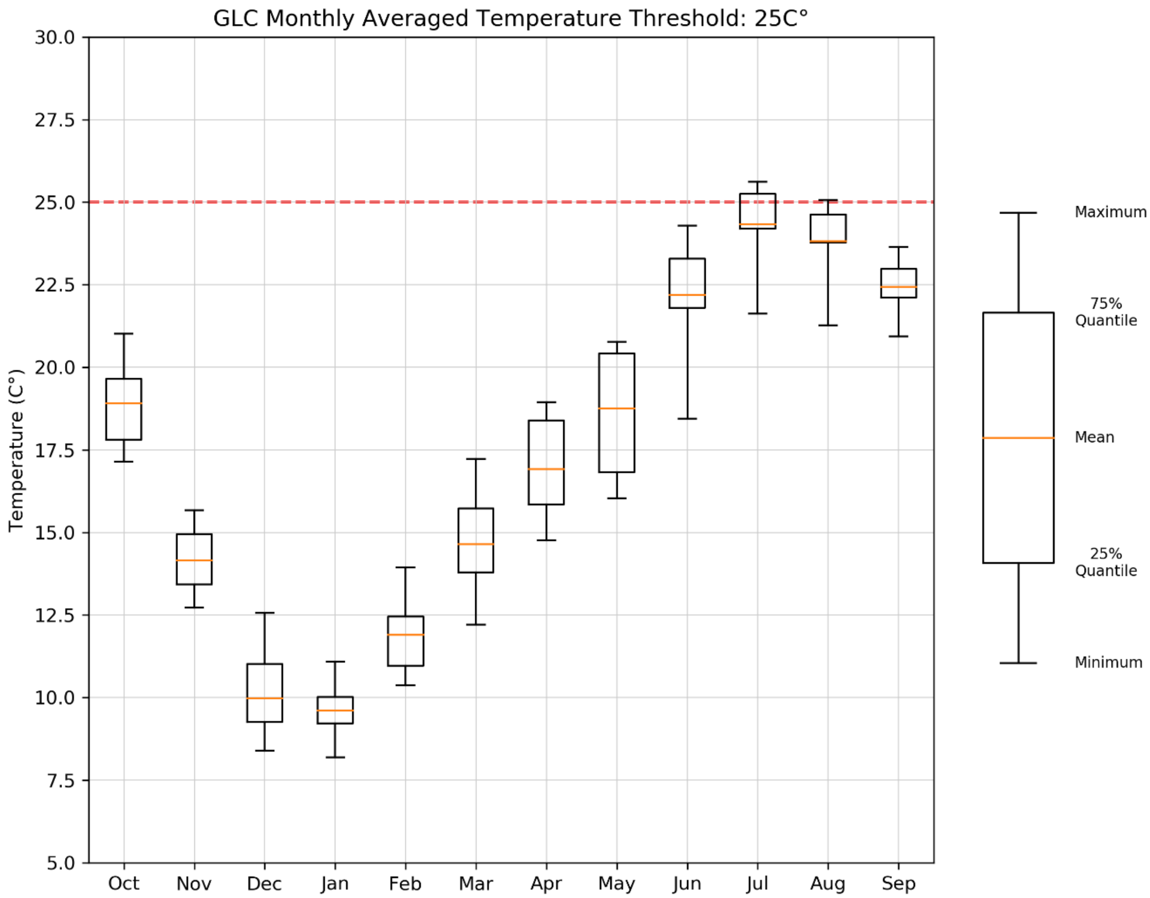

Figure 26. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GLC – Grantline Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

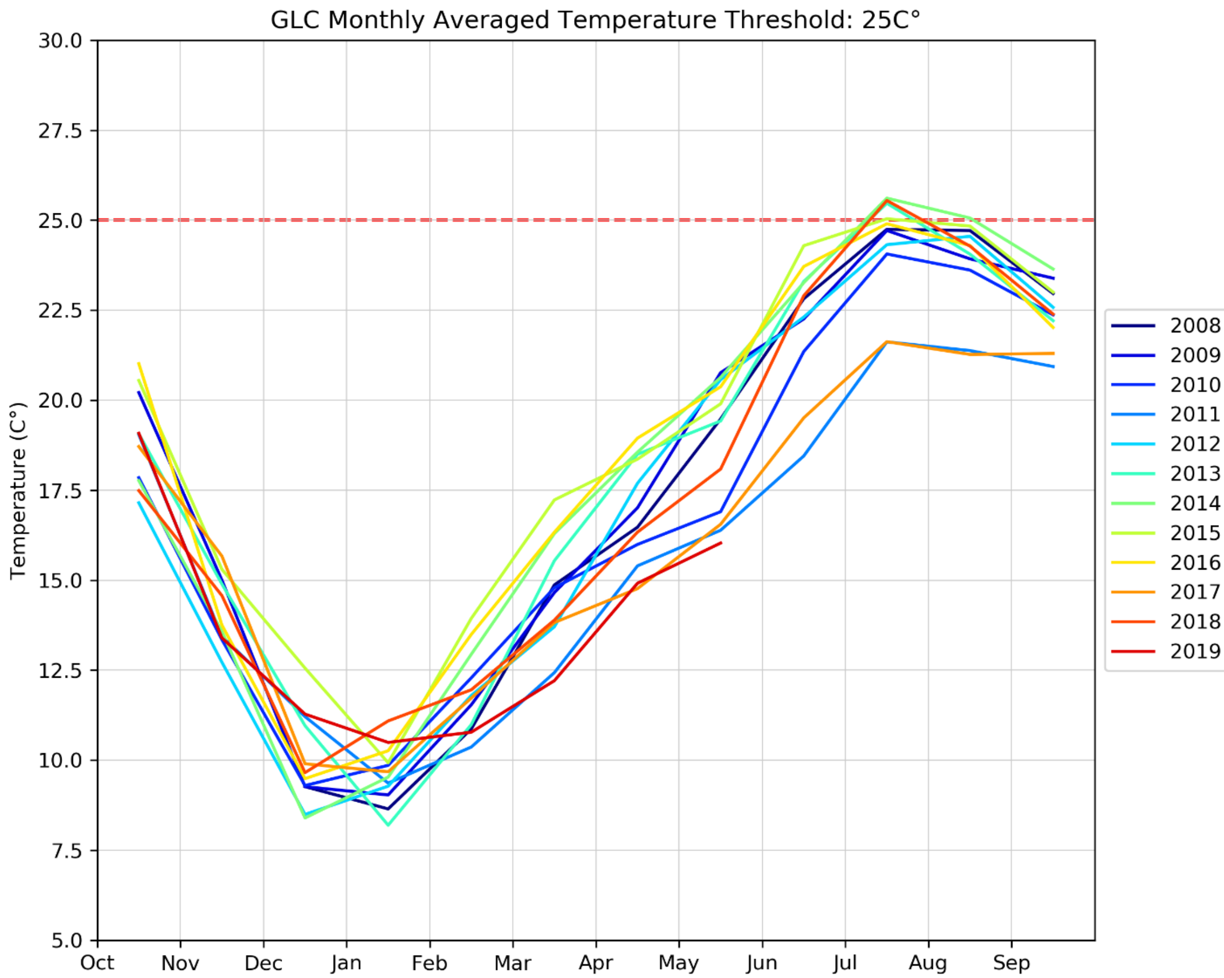

Figure 27. Monthly Average Temperature for the Period of Record at Station GLC – Grantline Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

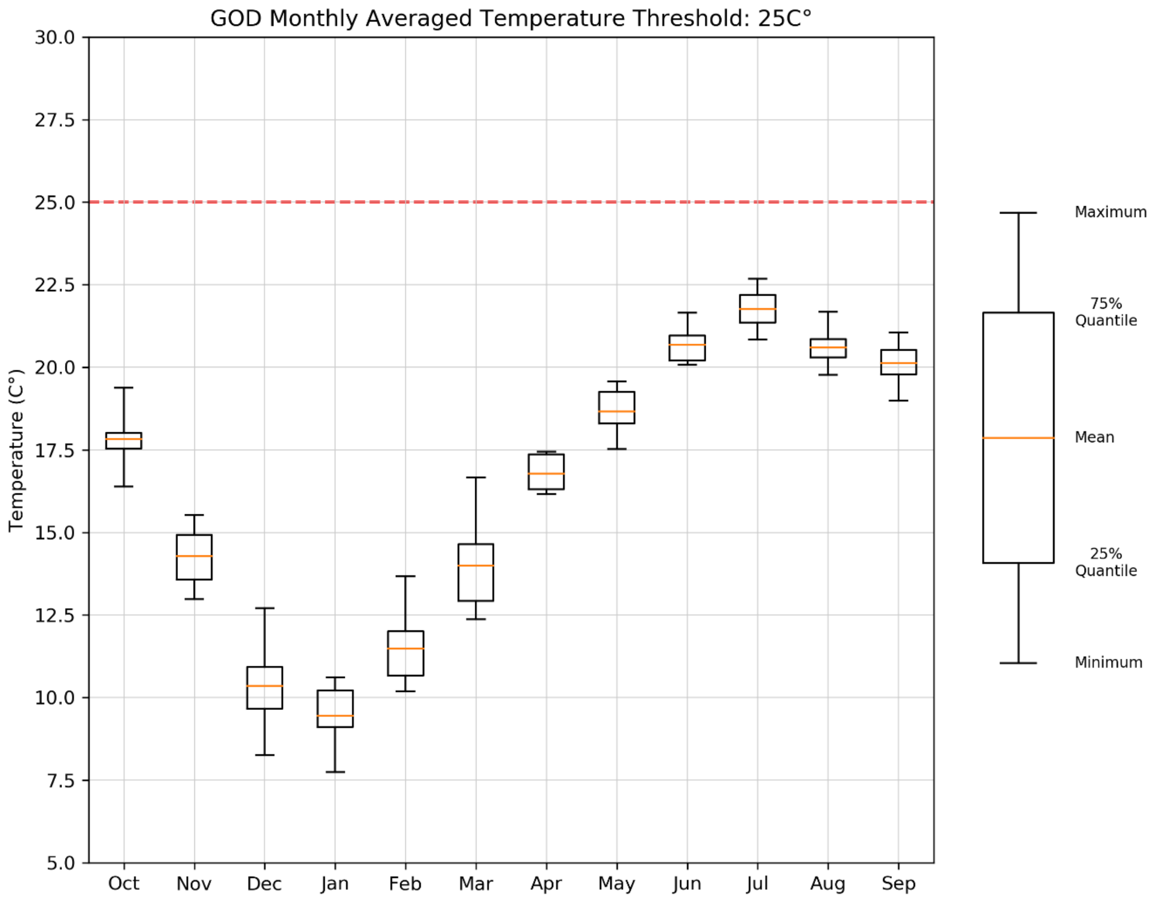

Figure 28. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GOD – Godfather II on Suisun Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

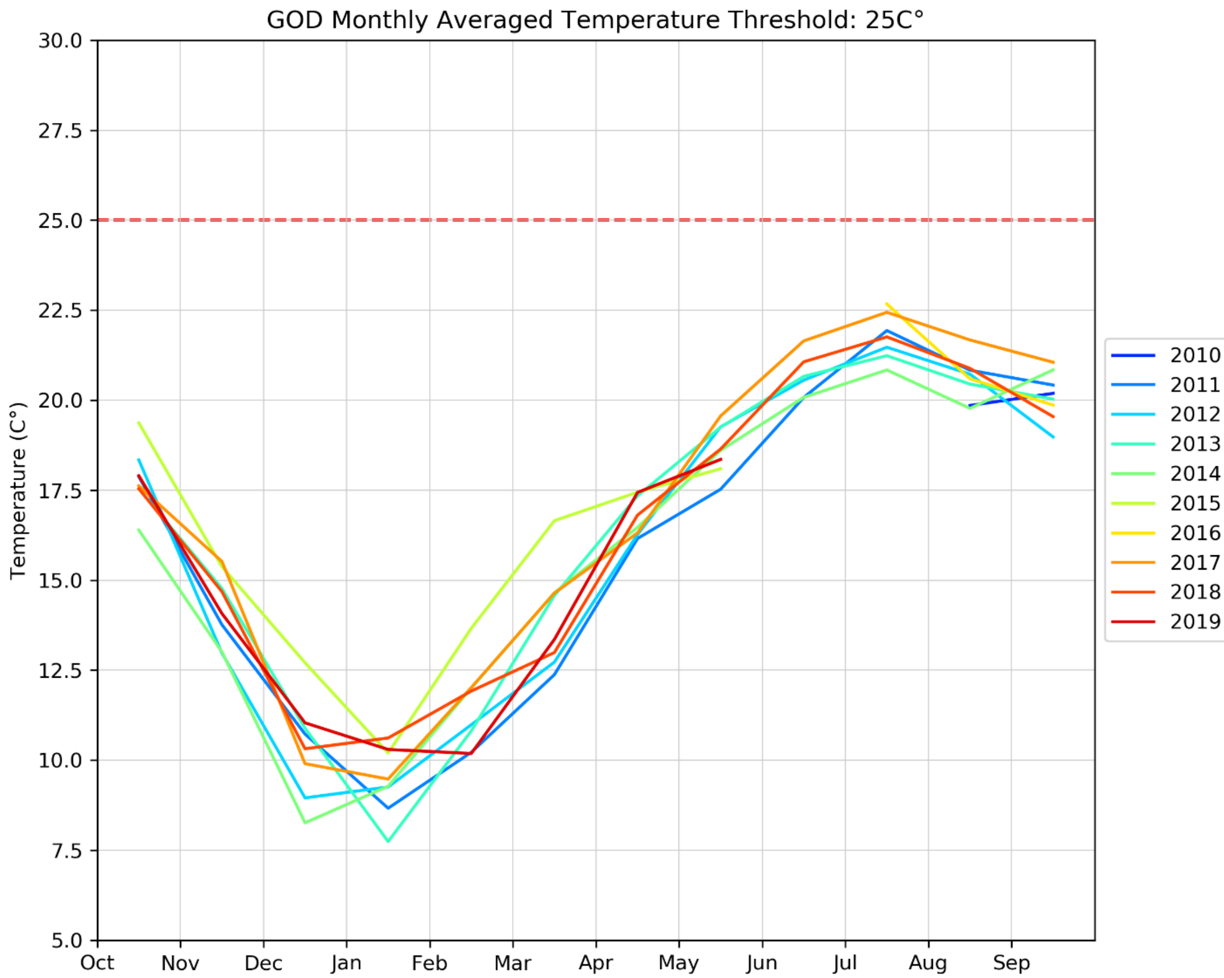

Figure 29. Monthly Average Temperature for the Period of Record at Station GOD – Godfather II on Suisun Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

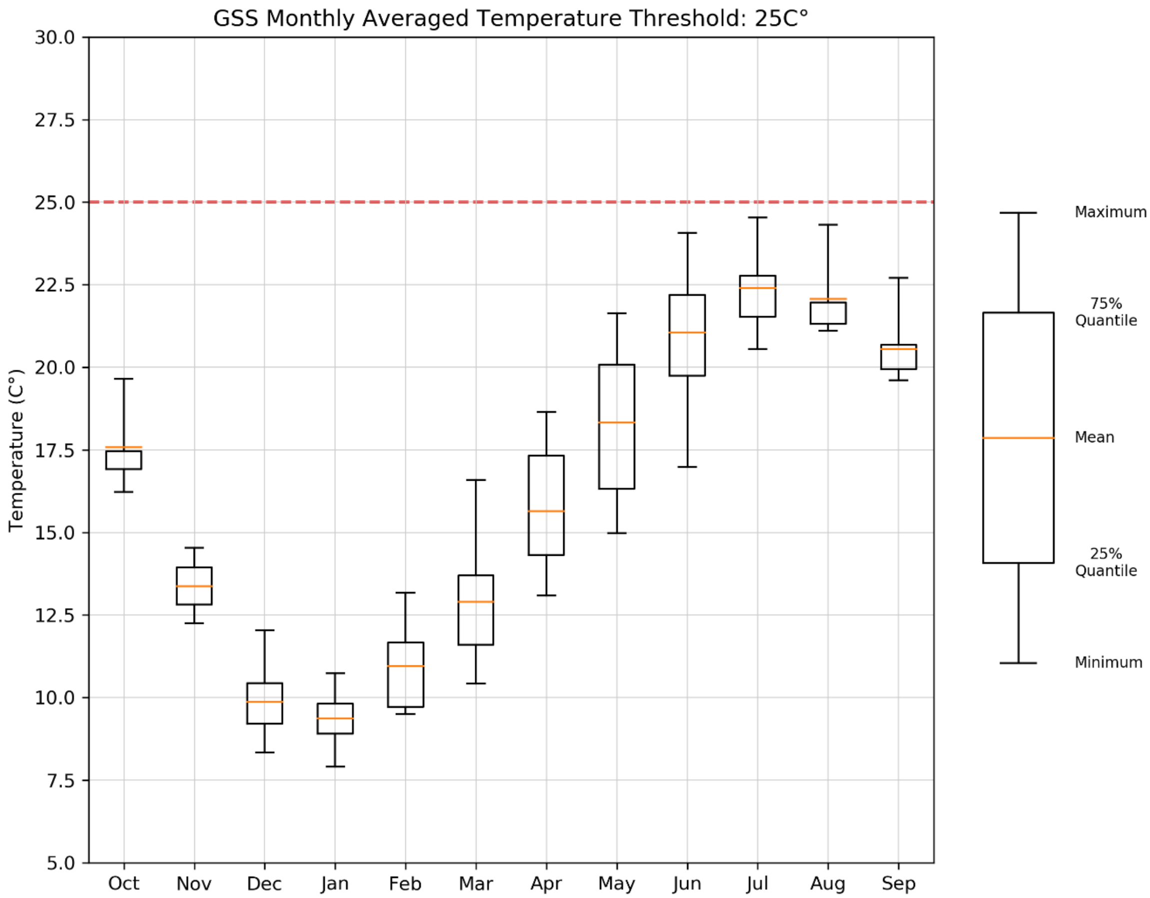

Figure 30. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GSS – Georgiana Slough at Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

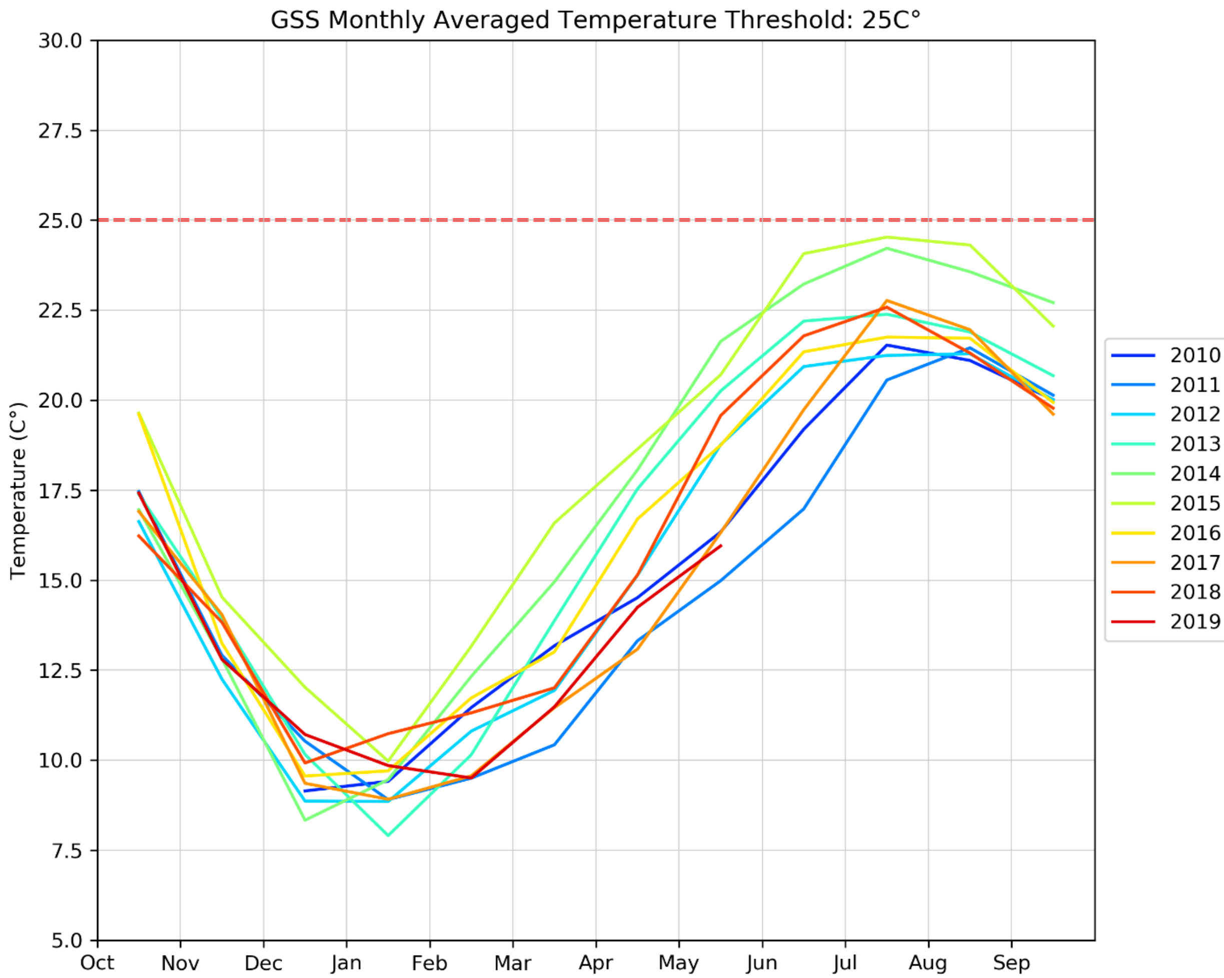

Figure 31. Monthly Average Temperature for the Period of Record at Station GSS – Georgiana Slough at Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

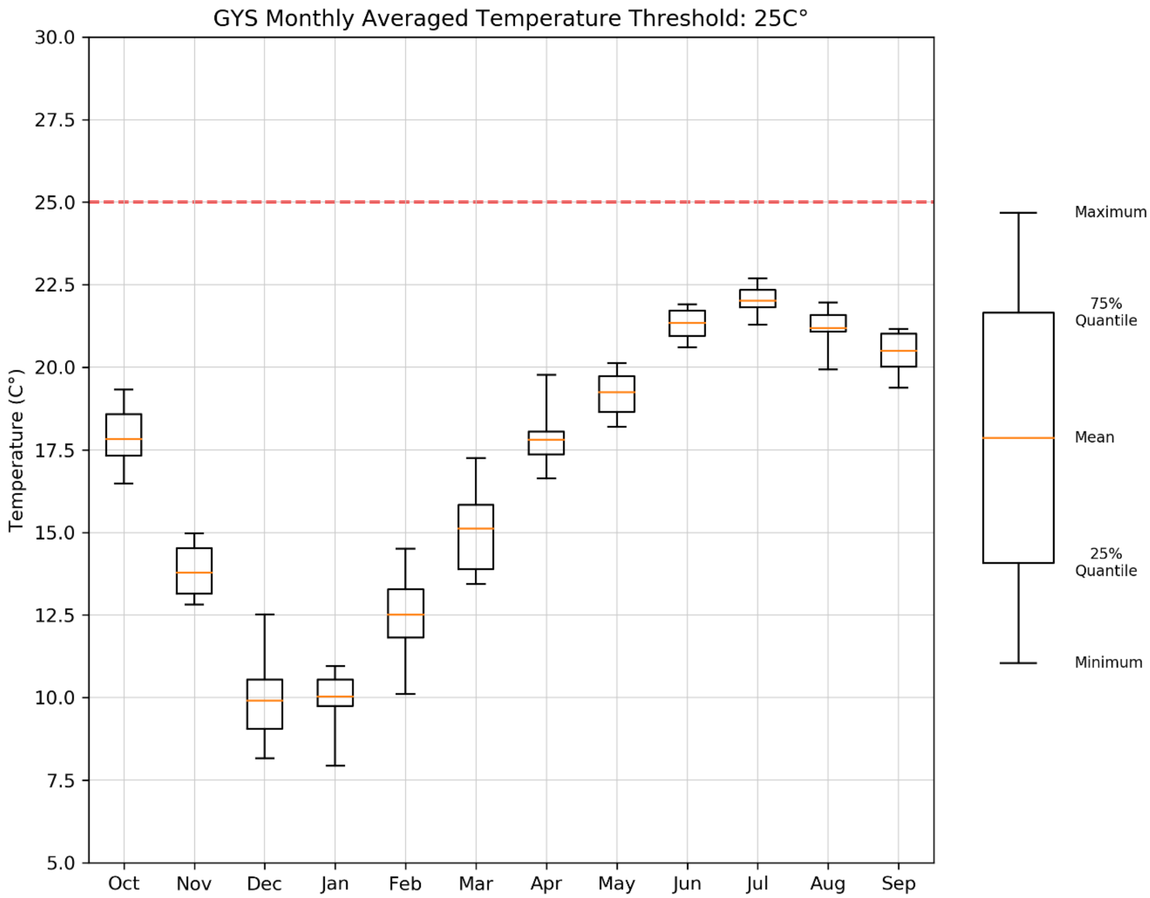

Figure 32. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GYS - Goodyear Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

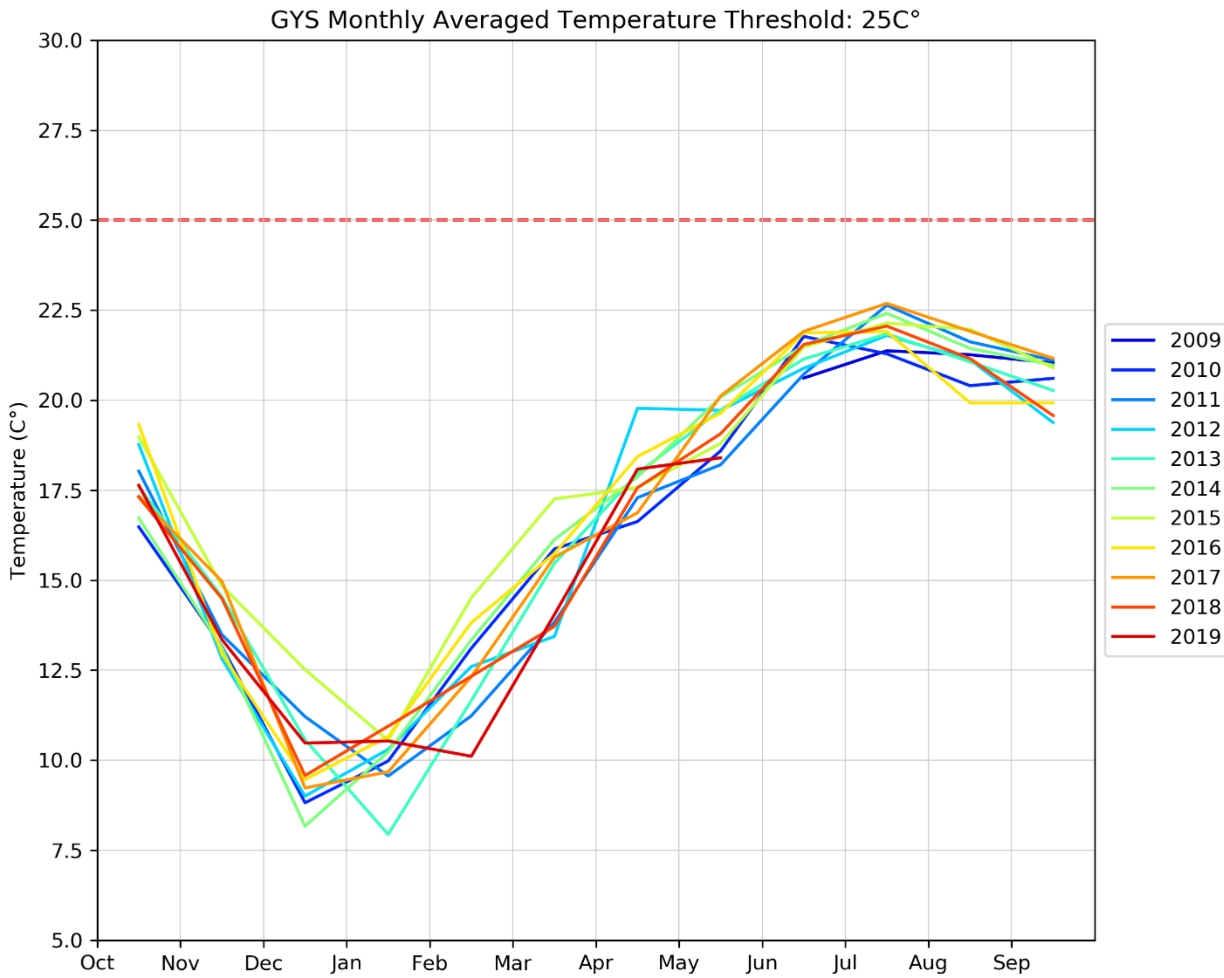

Figure 33. Monthly Average Temperature for the Period of Record at Station GYS – Goodyear Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

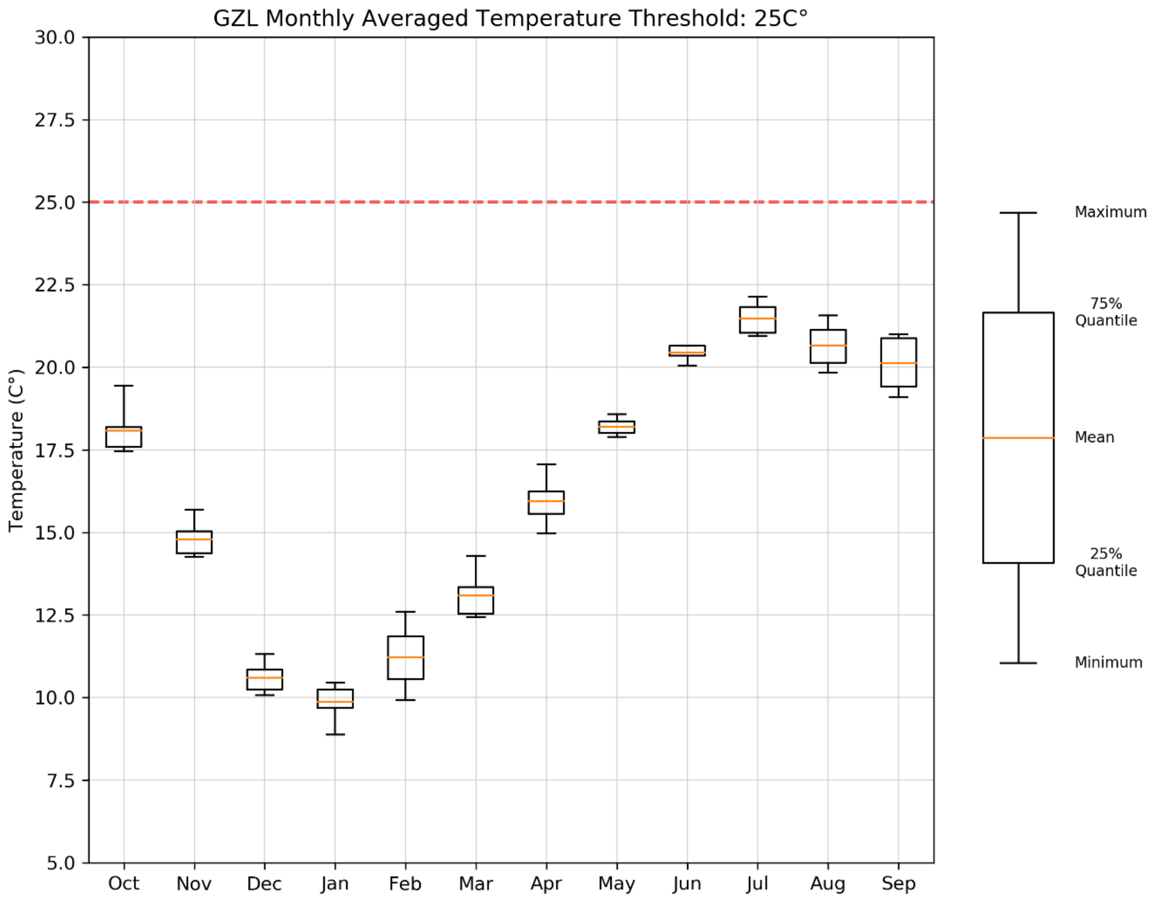

Figure 34. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station GZL – Grizzly Bay

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

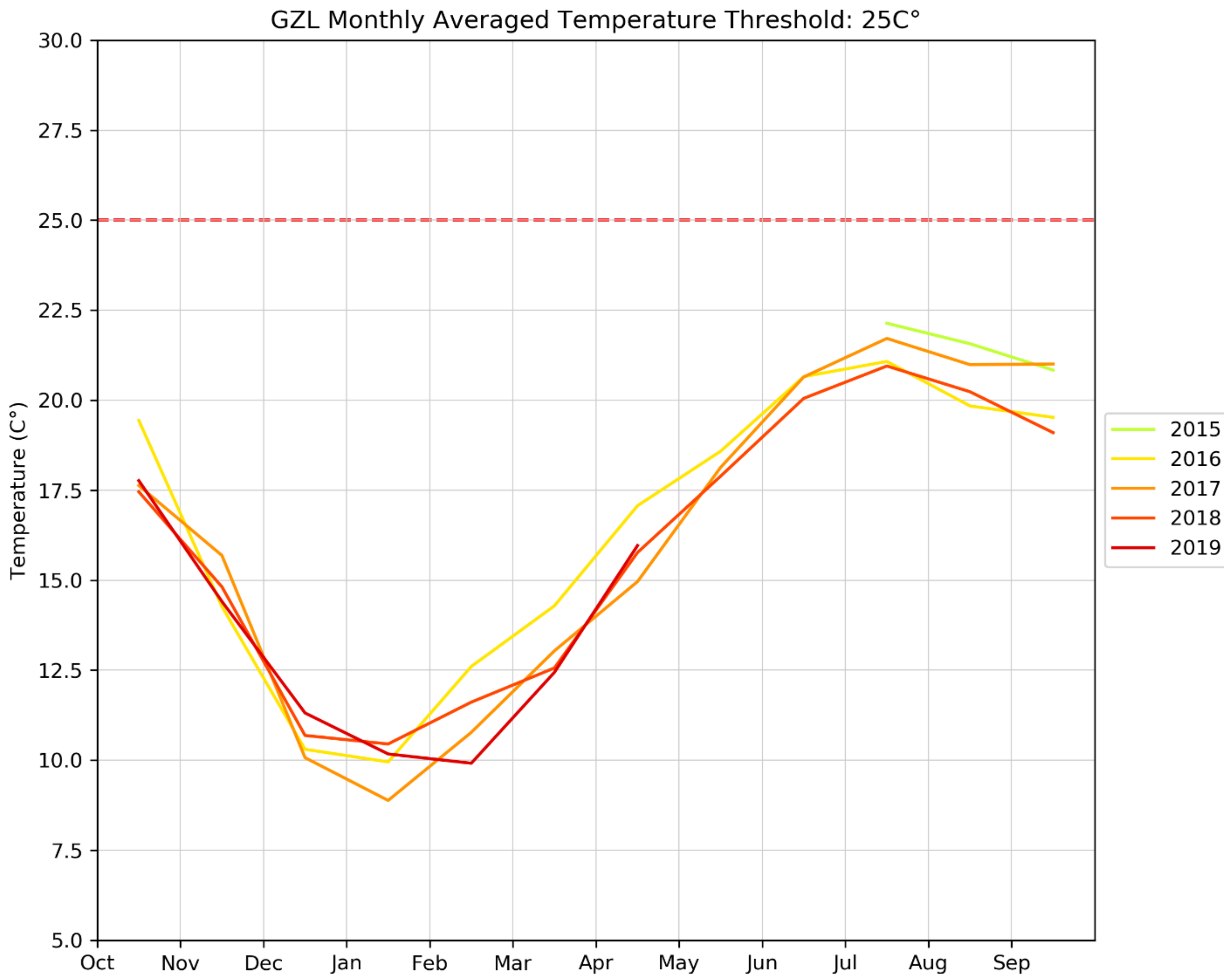

Figure 35. Monthly Average Temperature for the Period of Record at Station GZL – Grizzly Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

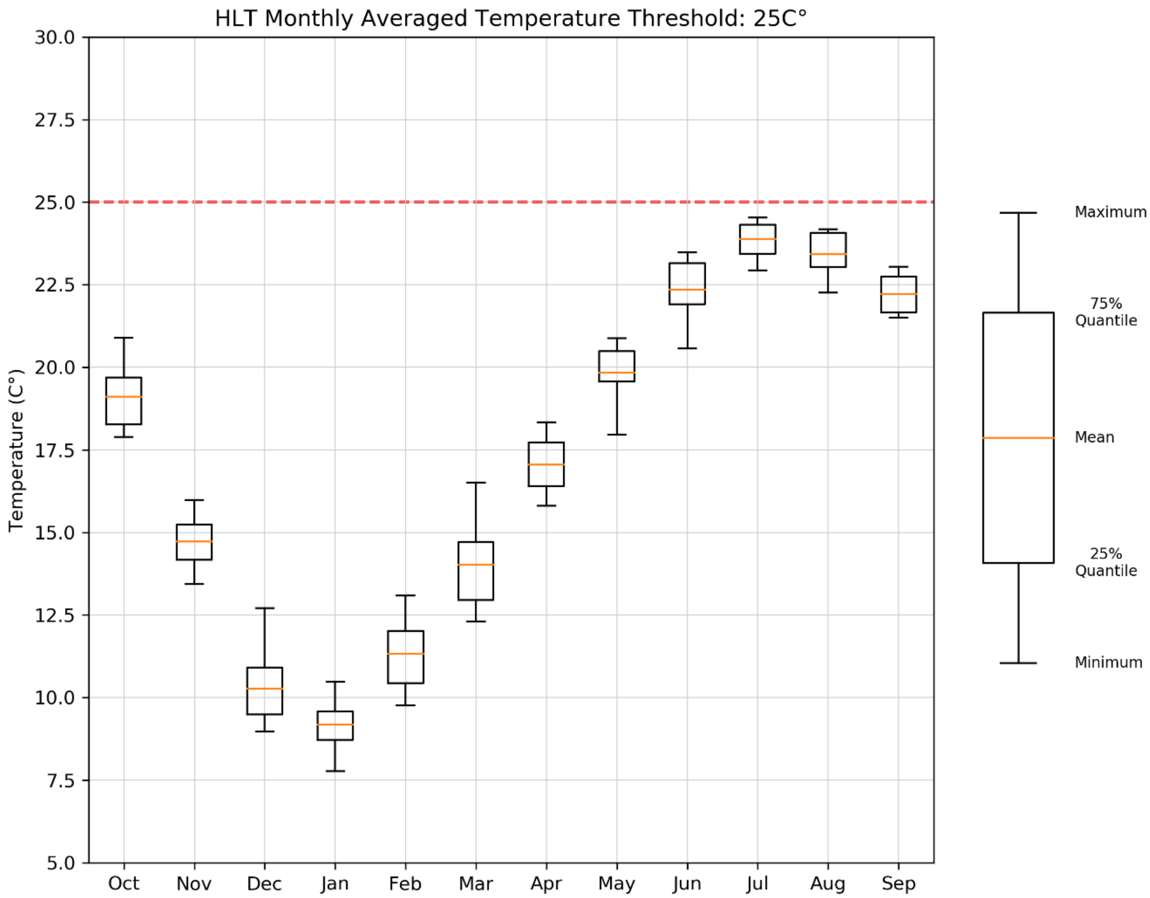

Figure 36. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HLT – Middle River Near Holt

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

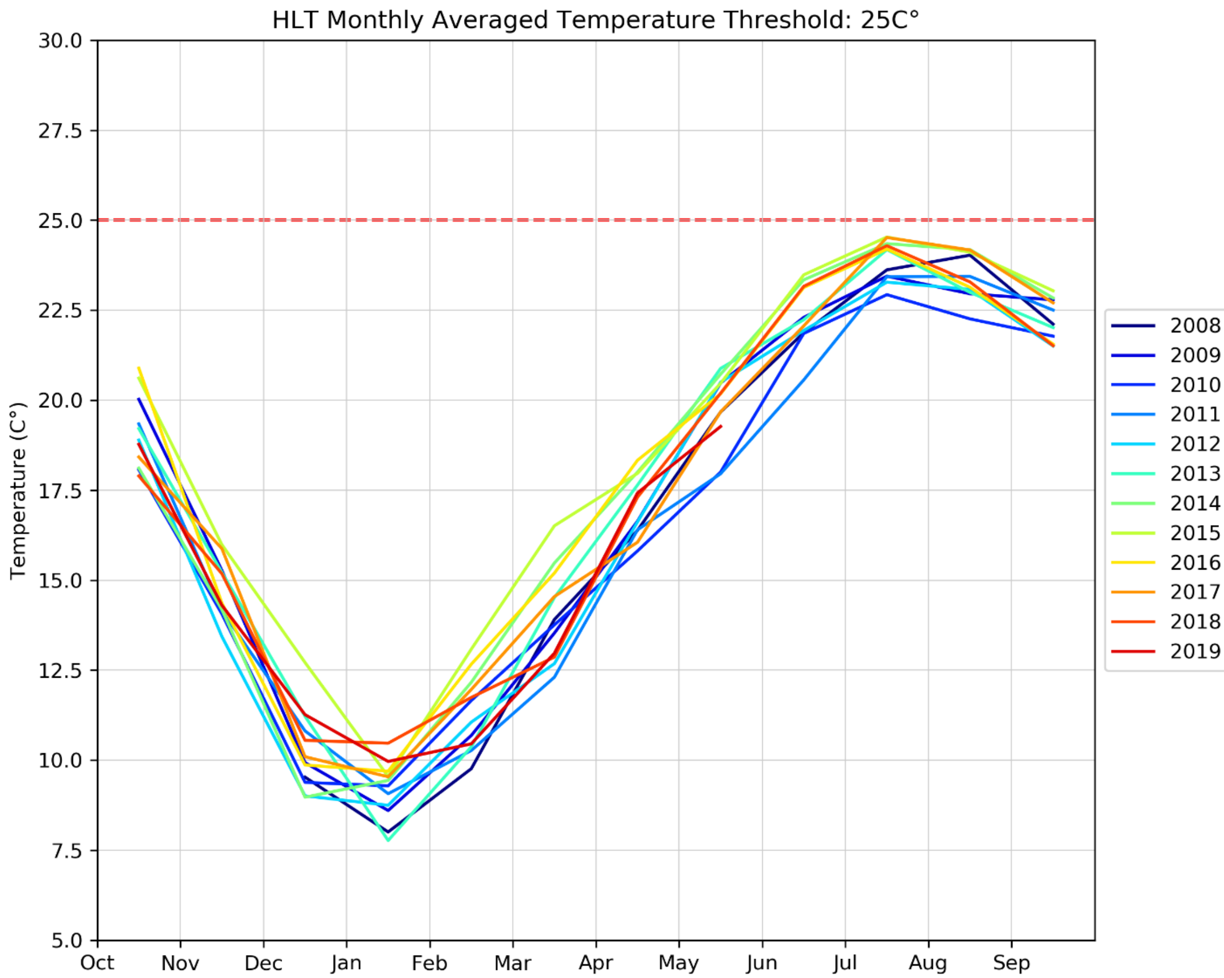

Figure 37. Monthly Average Temperature for the Period of Record at Station HLT – Middle River Near Holt

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

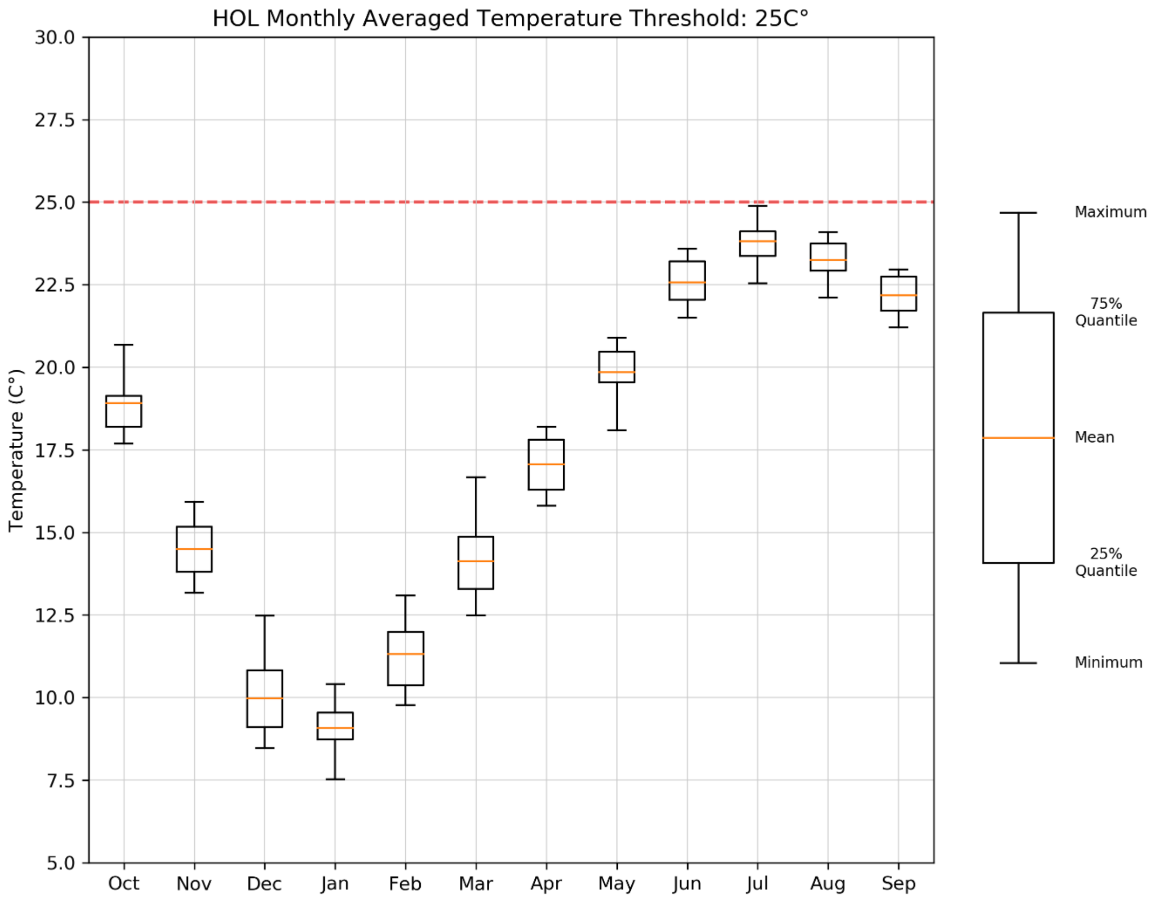

Figure 38. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HOL – Holland Cut Near Bethel Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

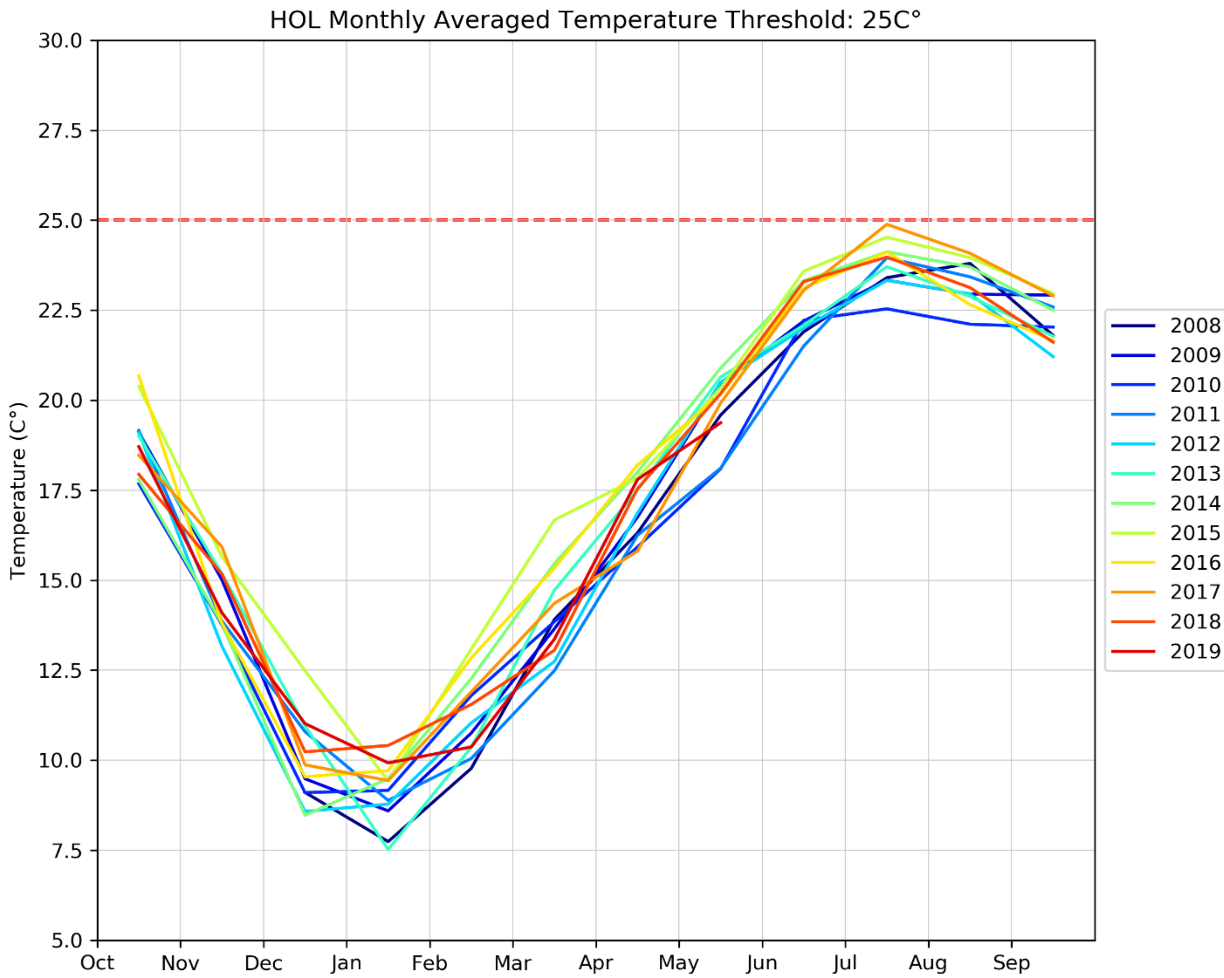

Figure 39. Monthly Average Temperature for the Period of Record at Station HOL – Holland Cut Near Bethel Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

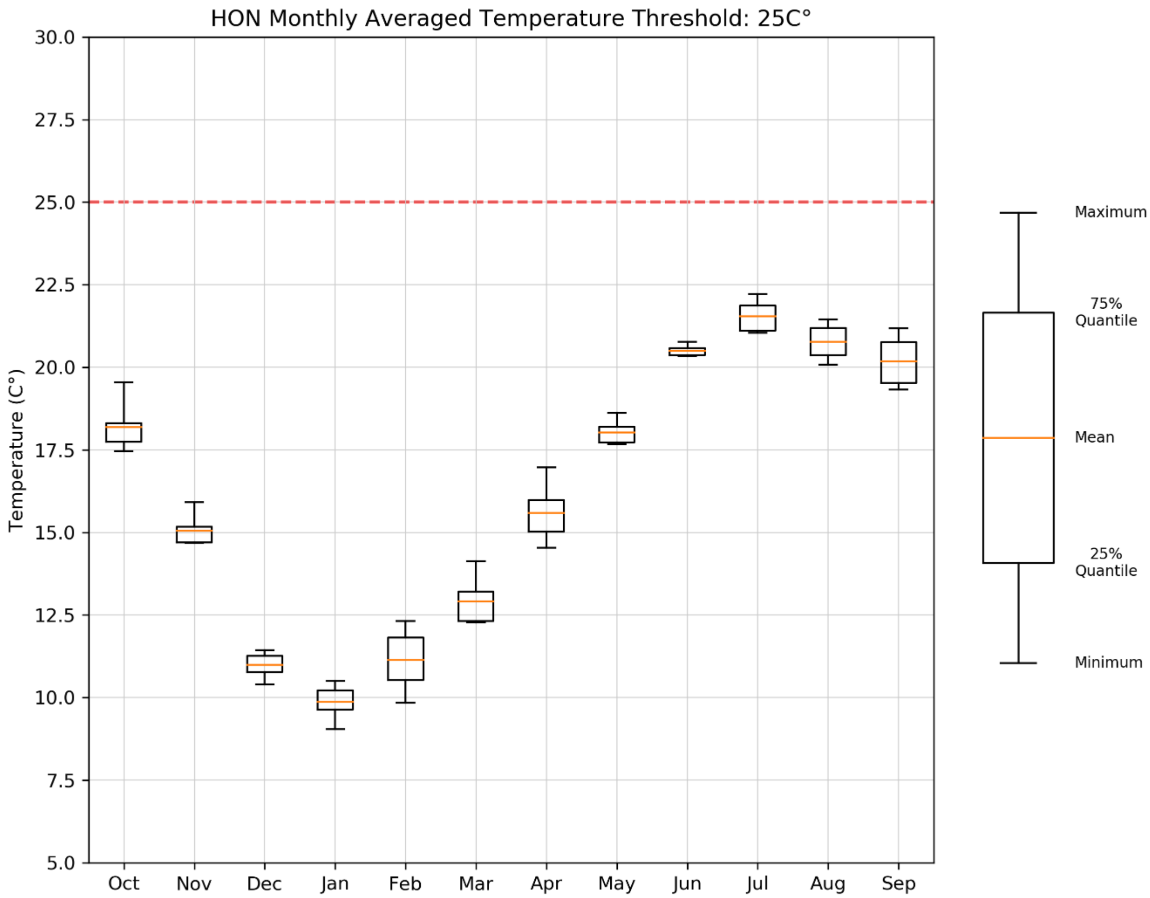

Figure 40. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HON – Honker Bay

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

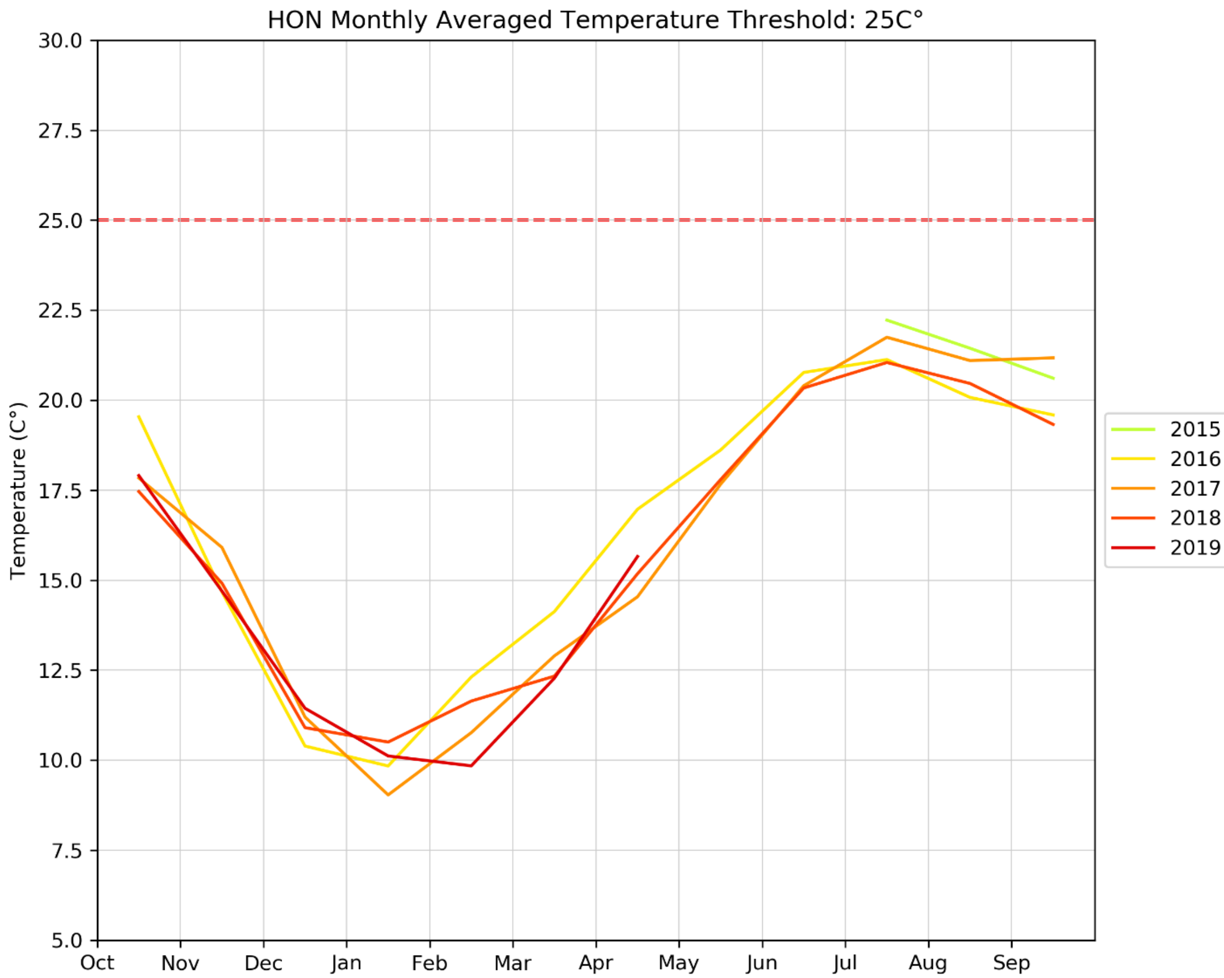

Figure 41. Monthly Average Temperature for the Period of Record at Station HON – Honker Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

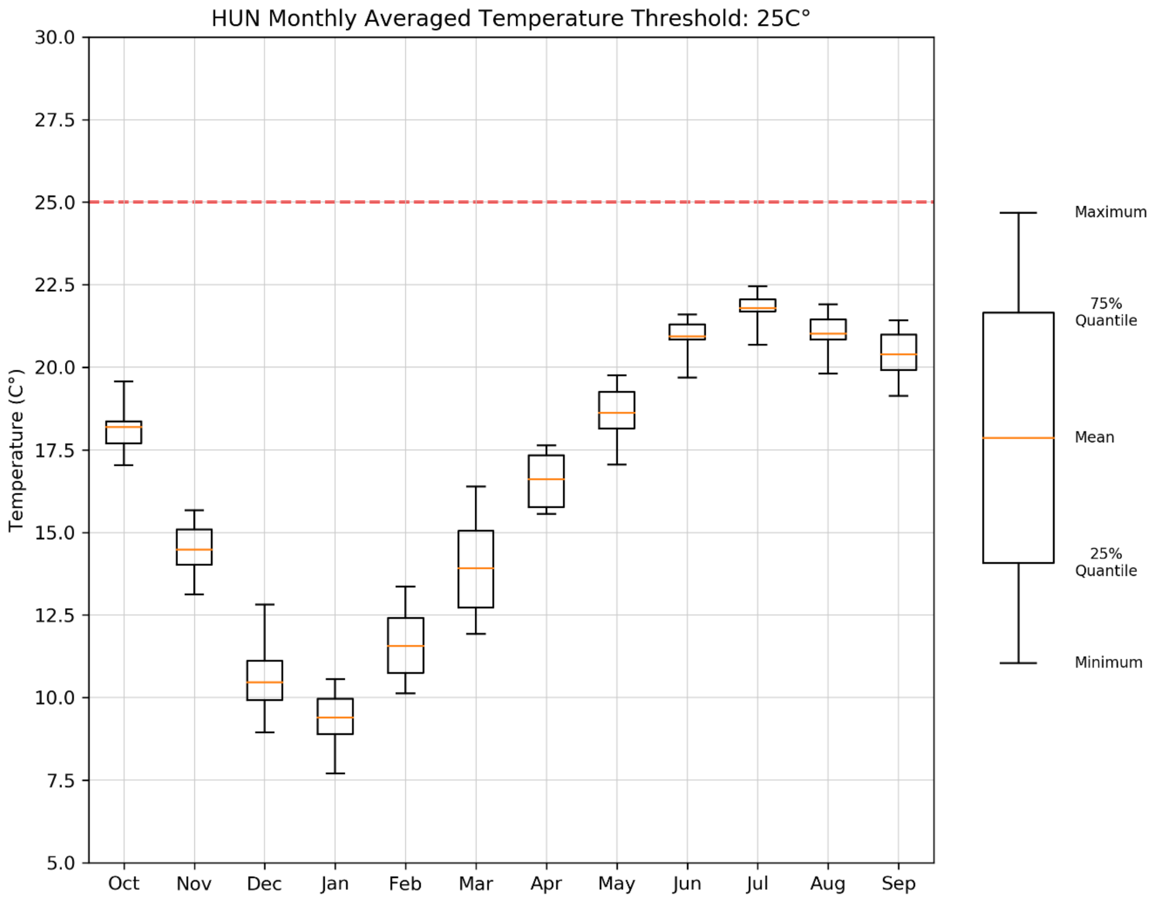

Figure 42. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HUN – Hunter Cut at Montezuma Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

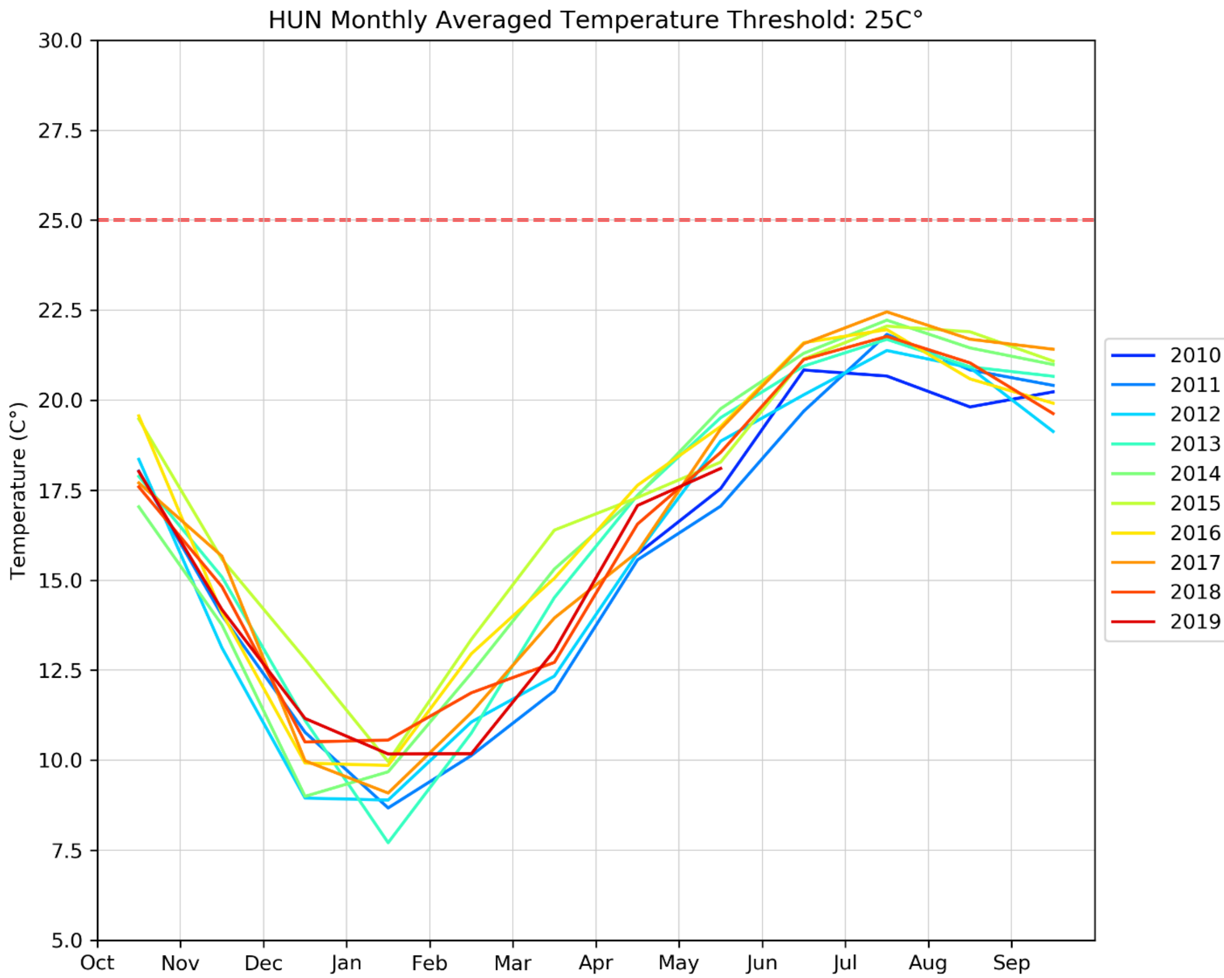

Figure 43. Monthly Average Temperature for the Period of Record at Station HUN – Hunter Cut at Montezuma Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

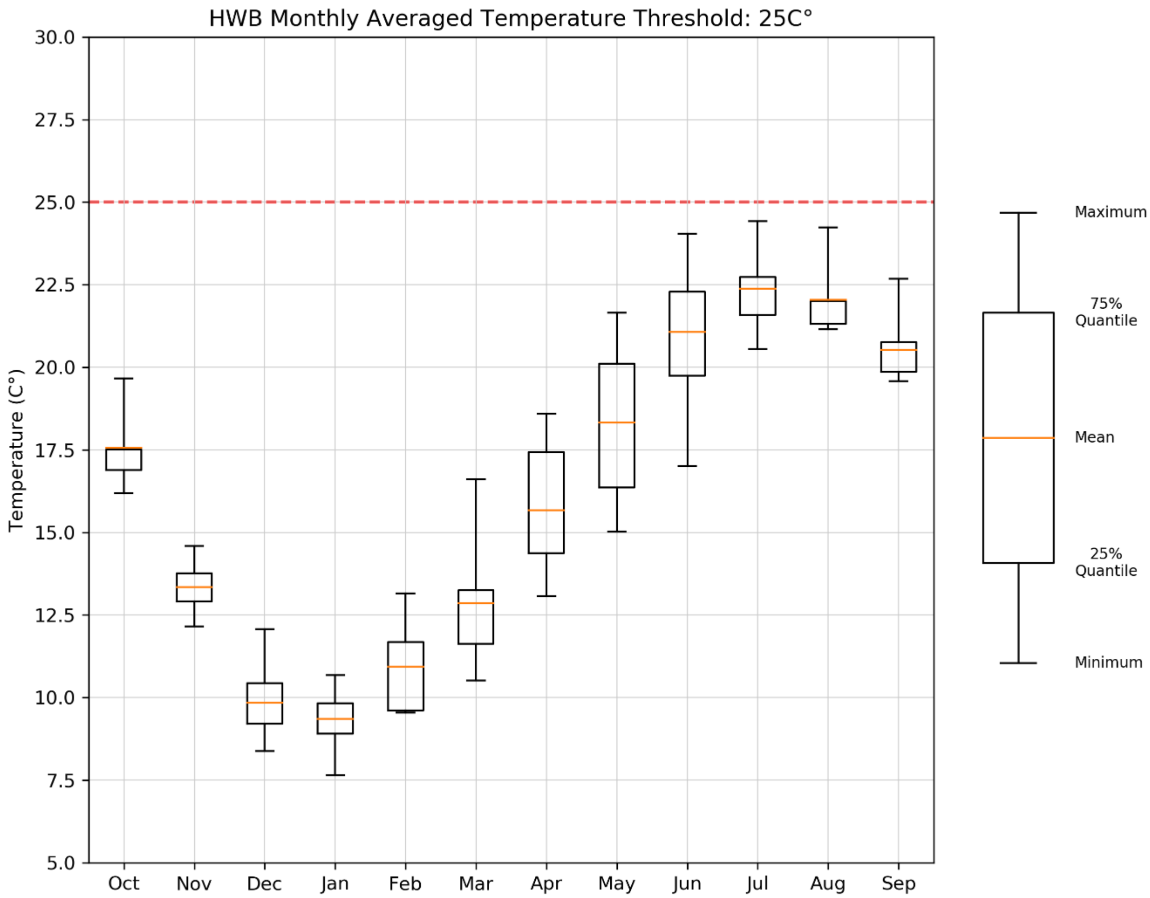

Figure 44. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

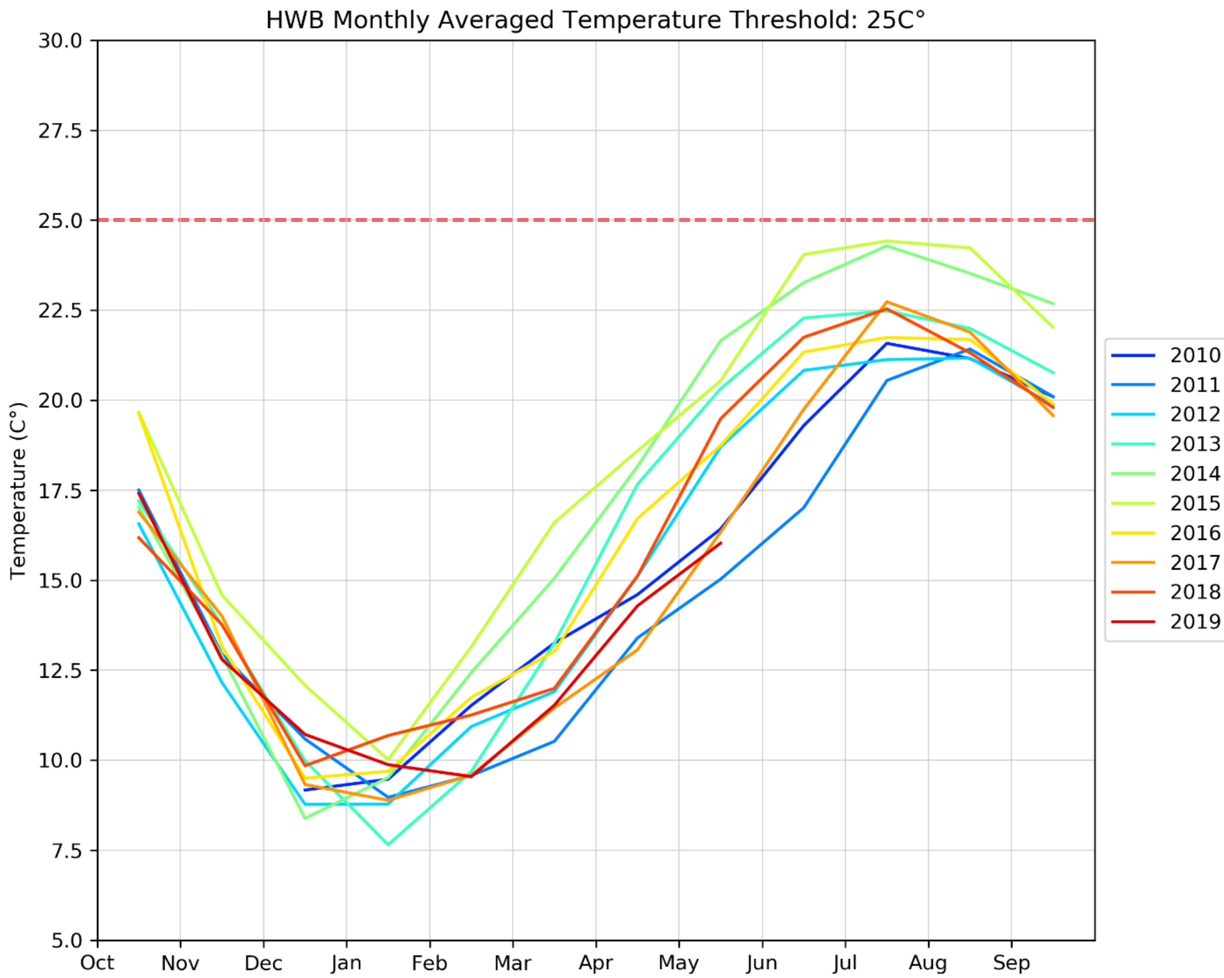

Figure 45. Monthly Average Temperature for the Period of Record at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

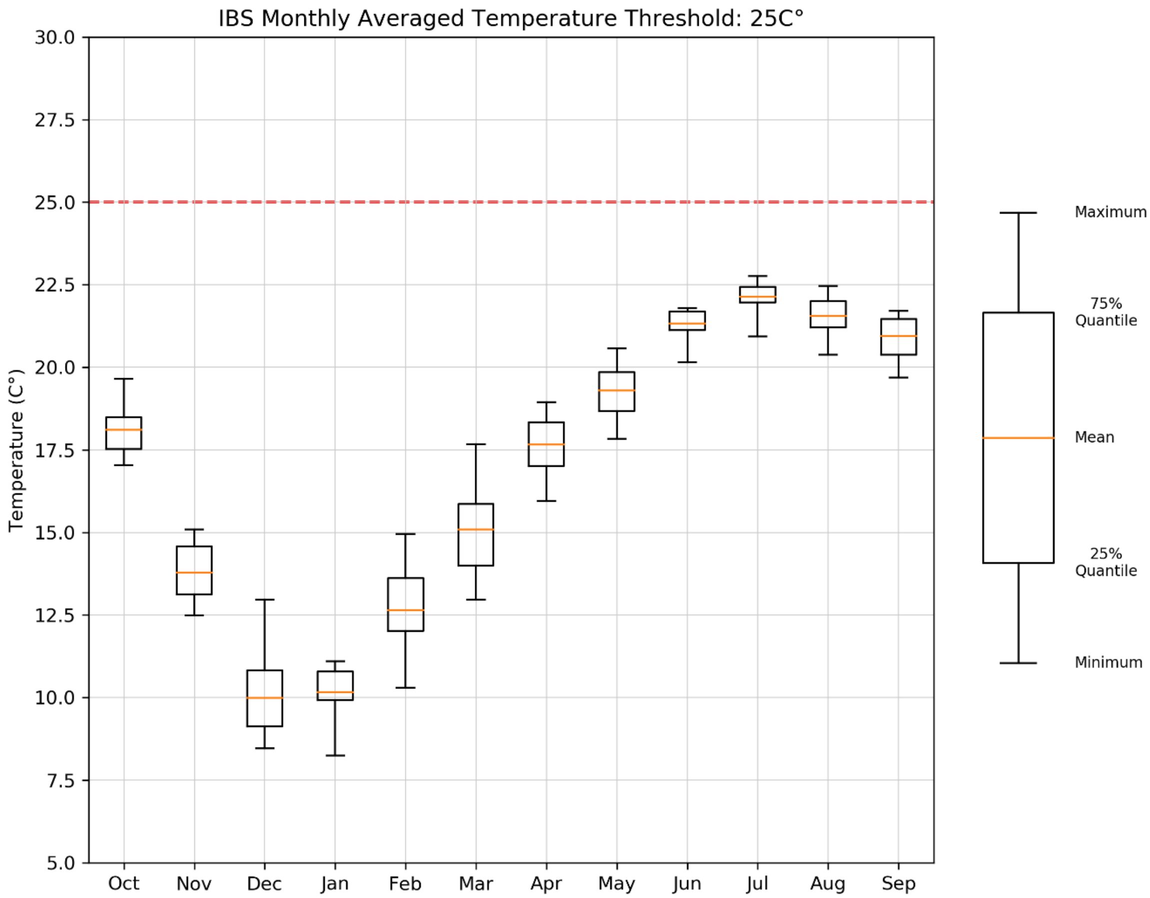

Figure 46. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station IBS – Cordelia Slough at Ibis

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

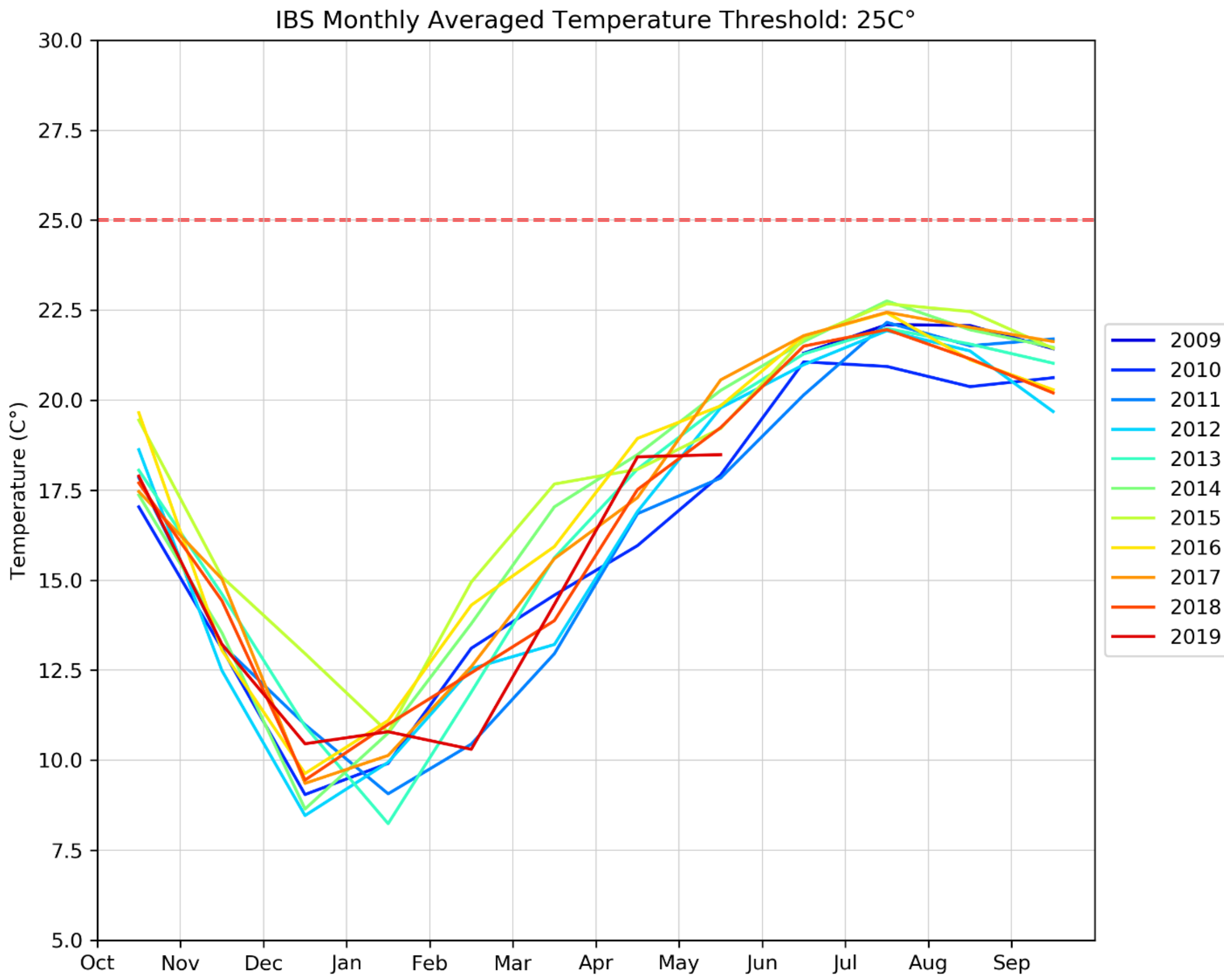

Figure 47. Monthly Average Temperature for the Period of Record at Station IBS - Cordelia Slough at Ibis

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

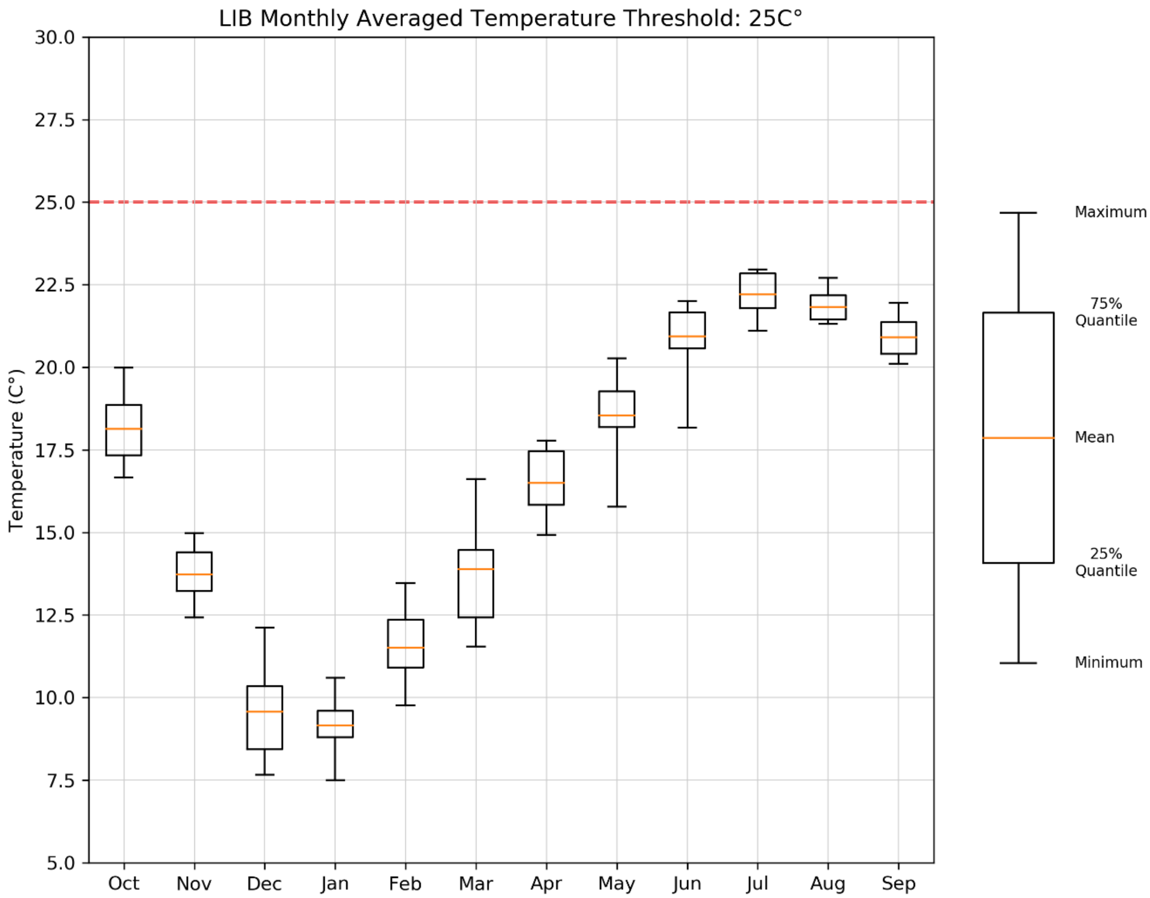

Figure 48. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LIB – Liberty Island at Approximately Center South End

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

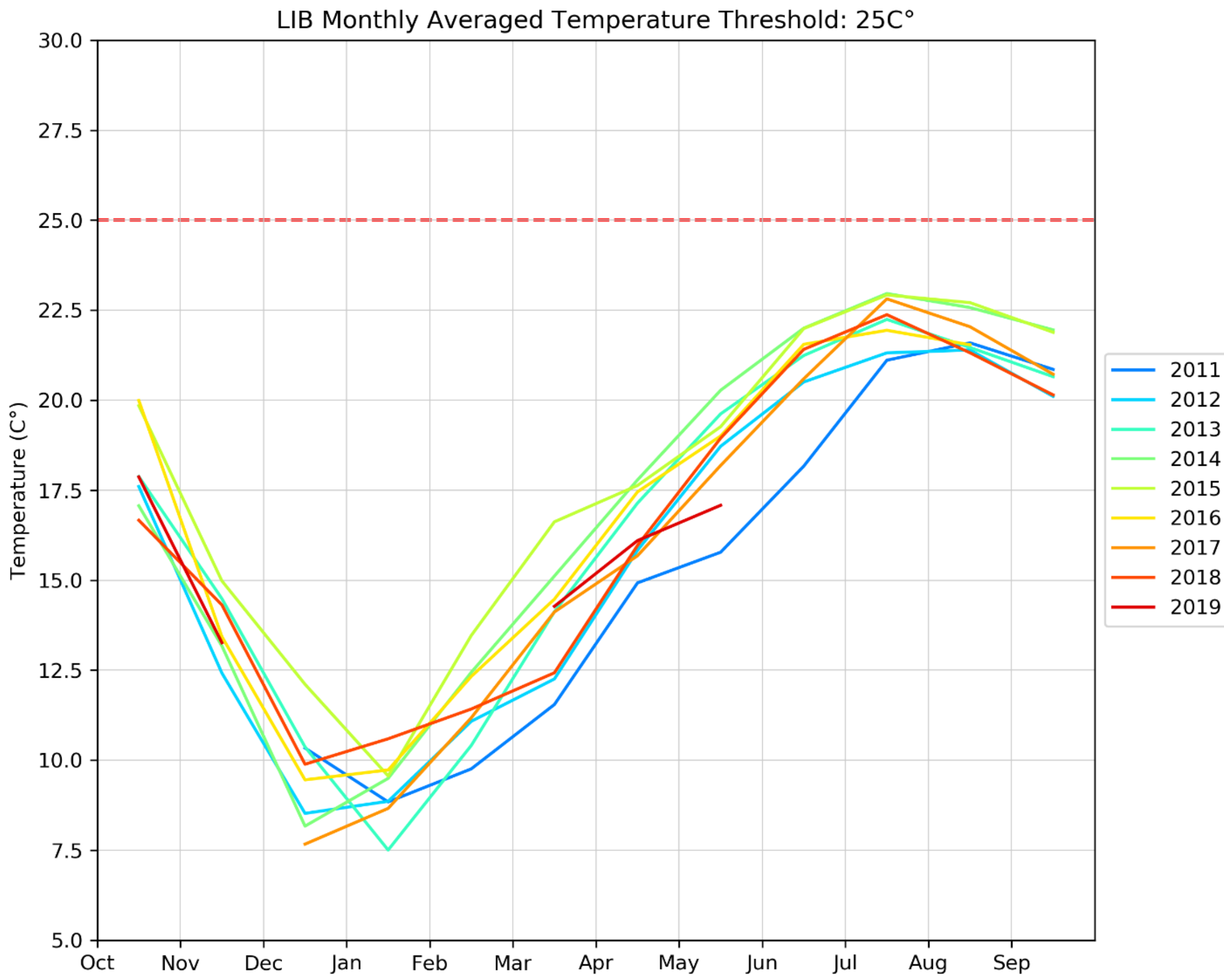

Figure 49. Monthly Average Temperature for the Period of Record at Station LIB – Liberty Island at Approximately Center South End

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

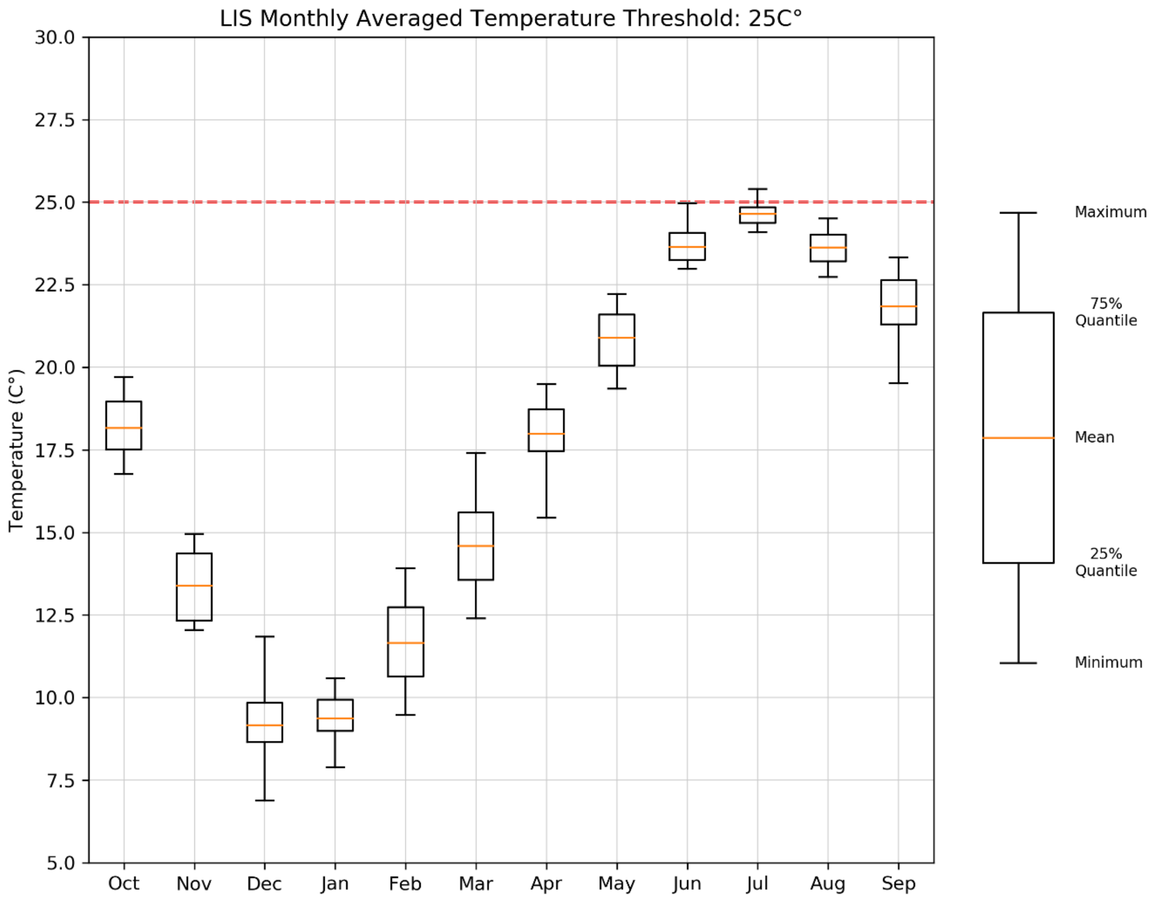

Figure 50. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LIS – Yolo Bypass at Lisbon

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

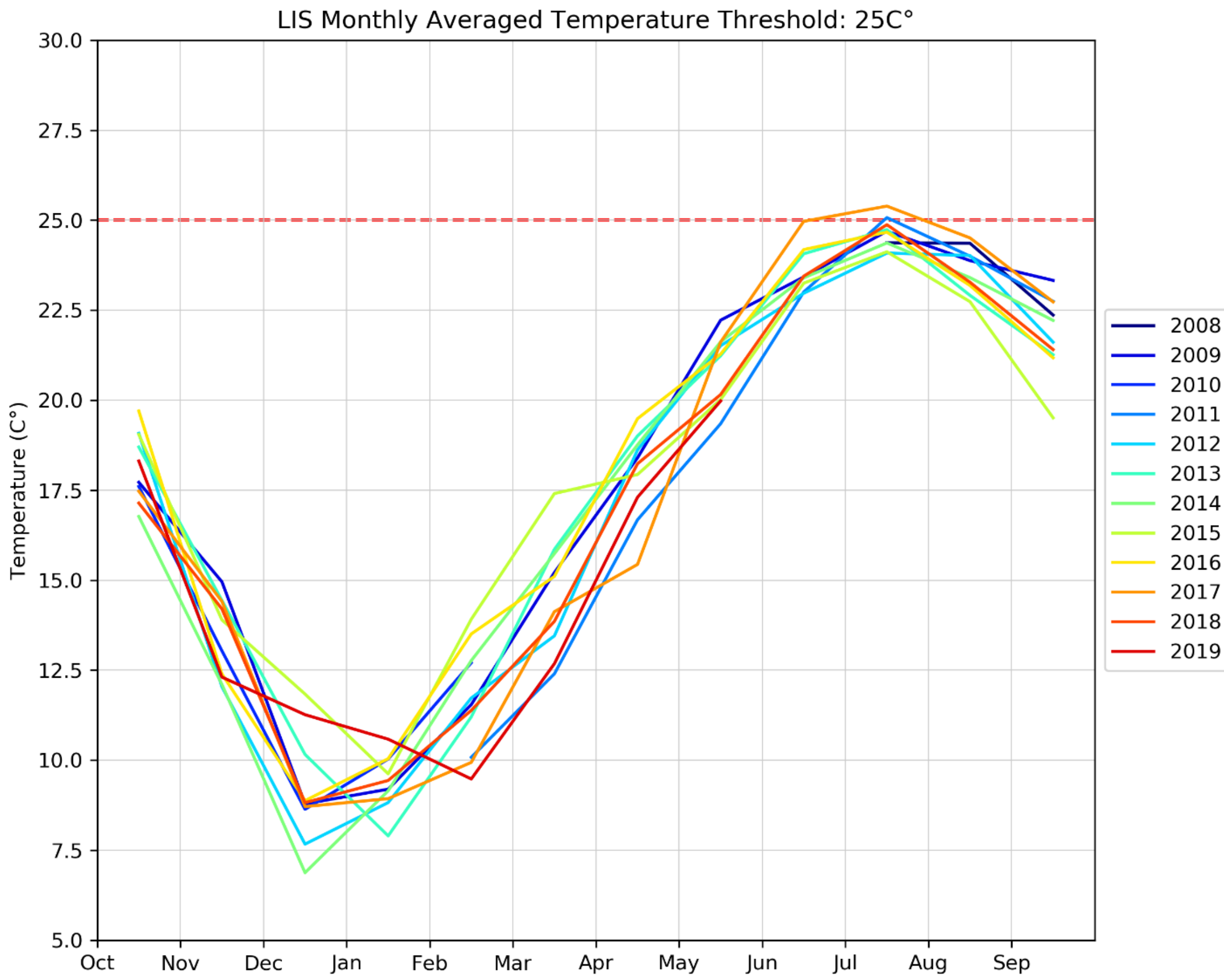

Figure 51. Monthly Average Temperature for the Period of Record at Station LIS – Yolo Bypass at Lisbon

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

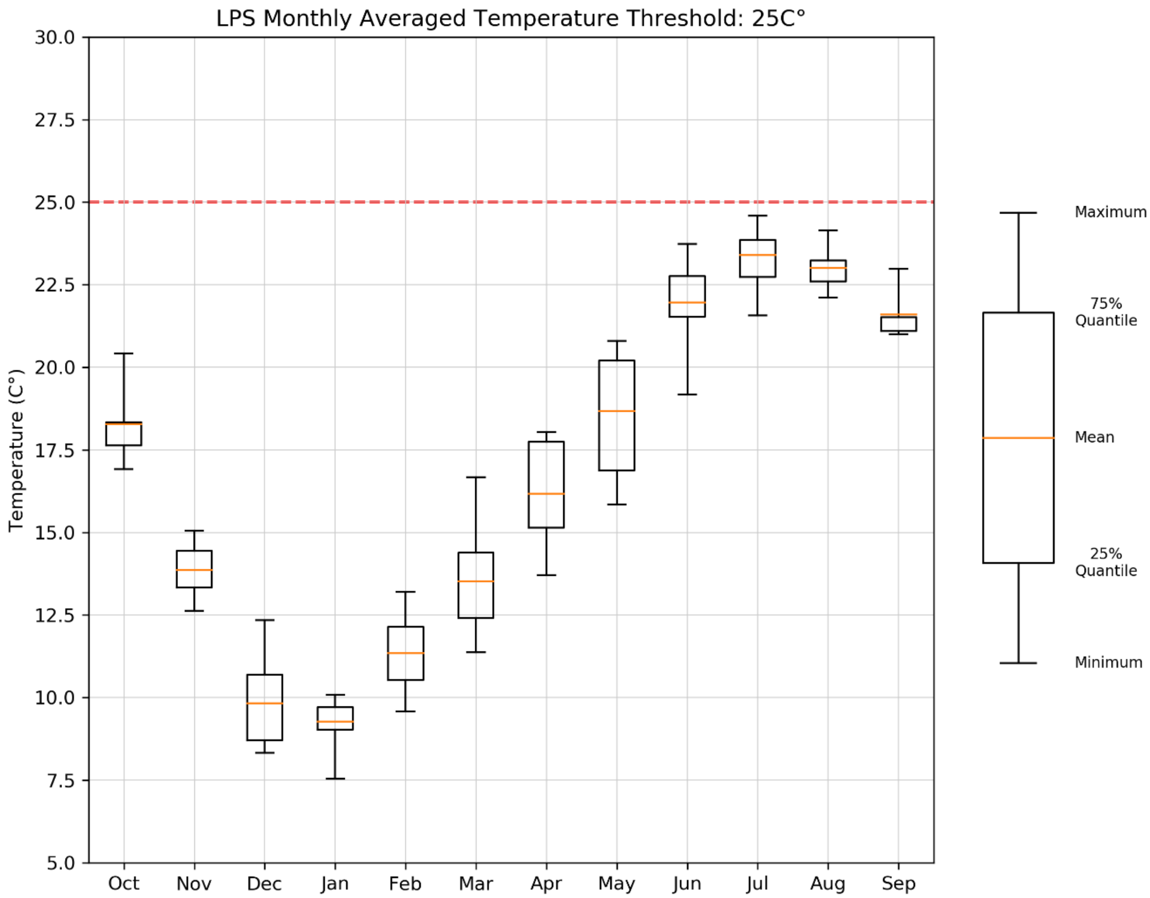

Figure 52. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station LPS – Little Potato Slough at Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

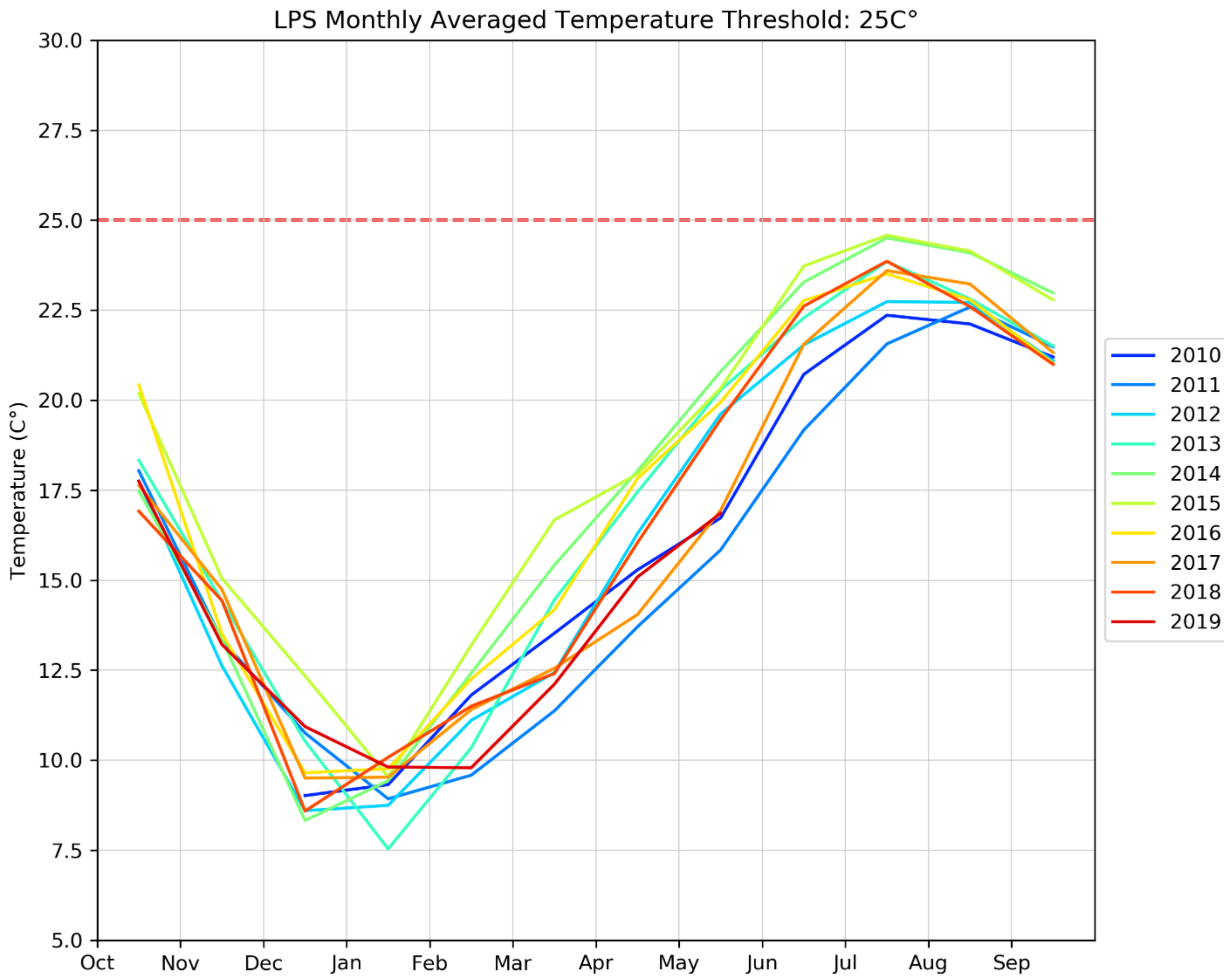

Figure 53. Monthly Average Temperature for the Period of Record at Station LPS – Little Potato Slough at Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

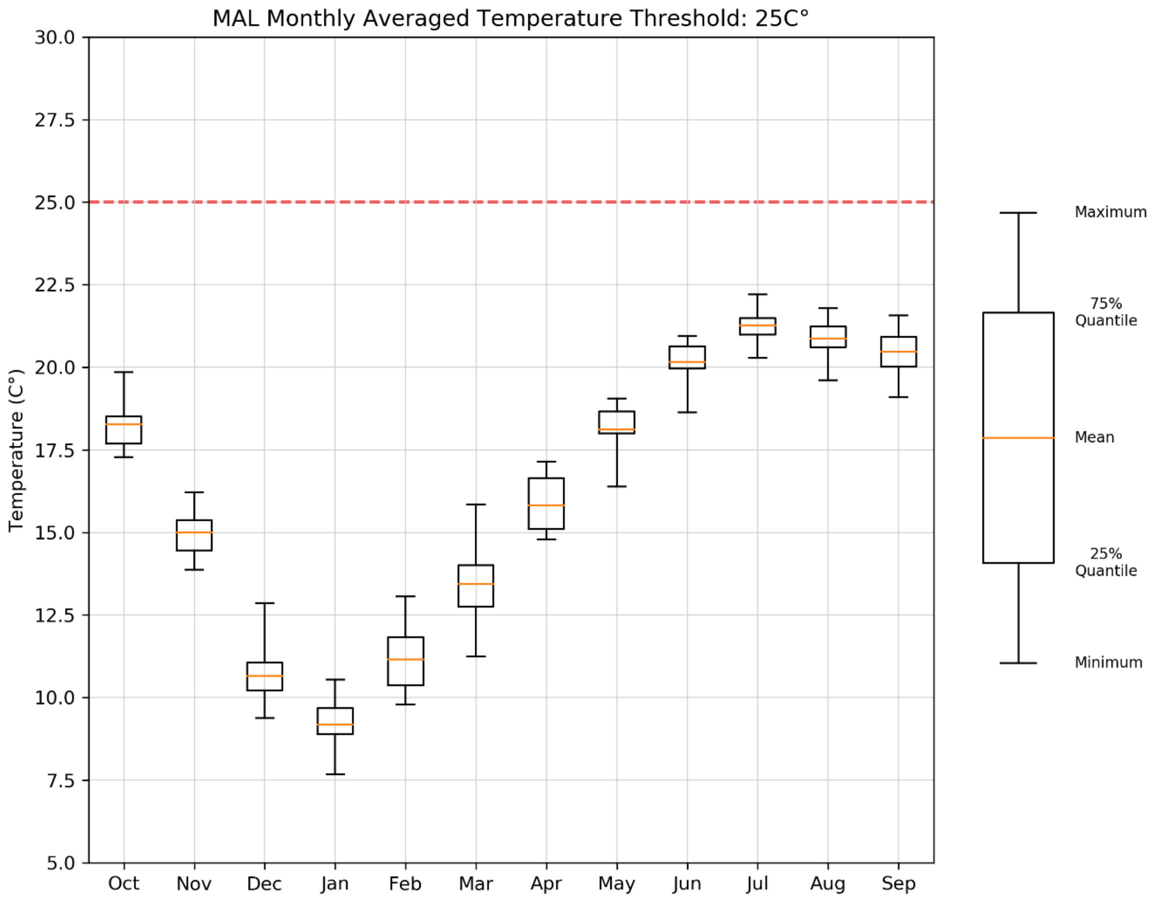

Figure 54. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MAL – Sacramento River at Mallard Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

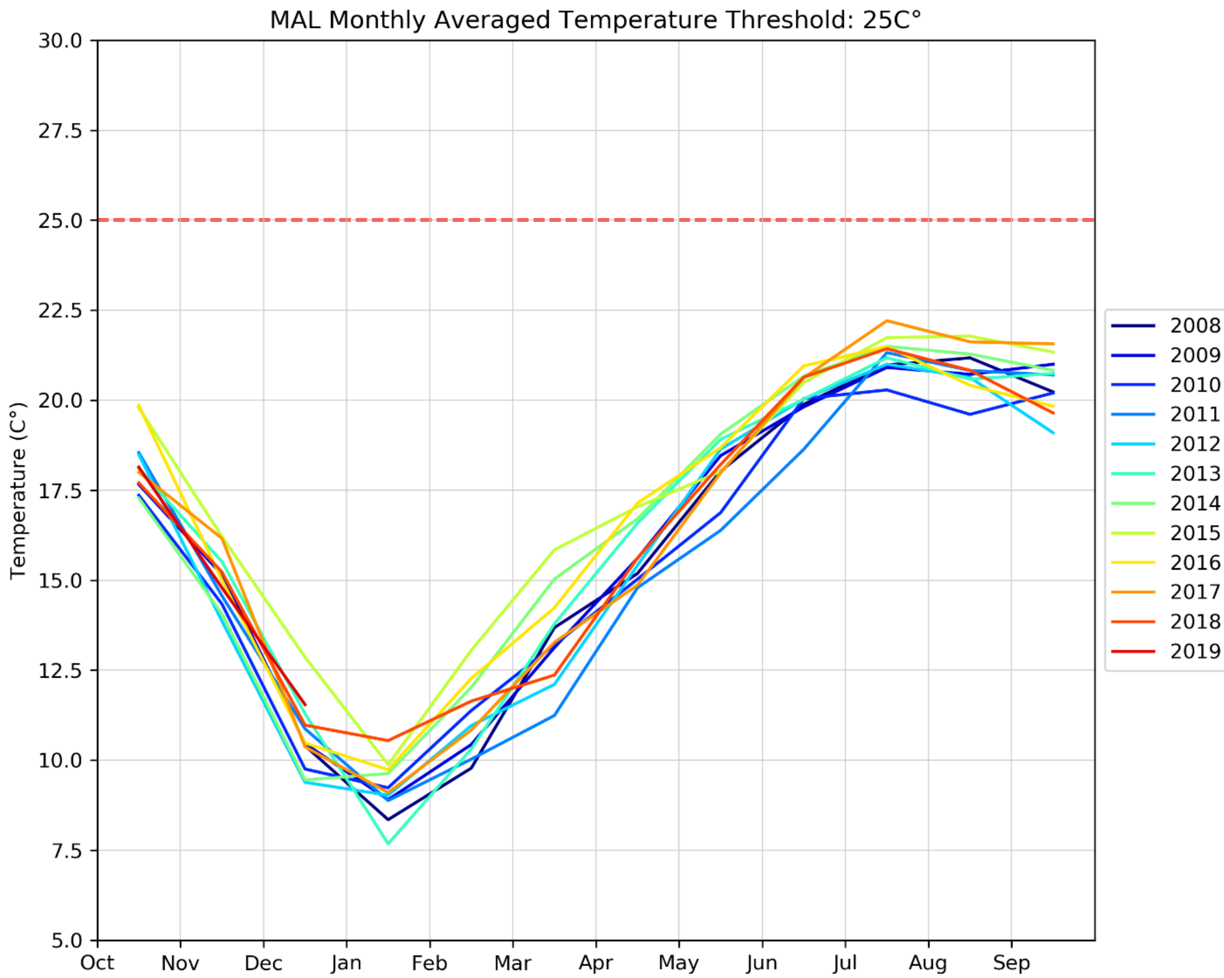

Figure 55. Monthly Average Temperature for the Period of Record at Station MAL – Sacramento River at Mallard Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

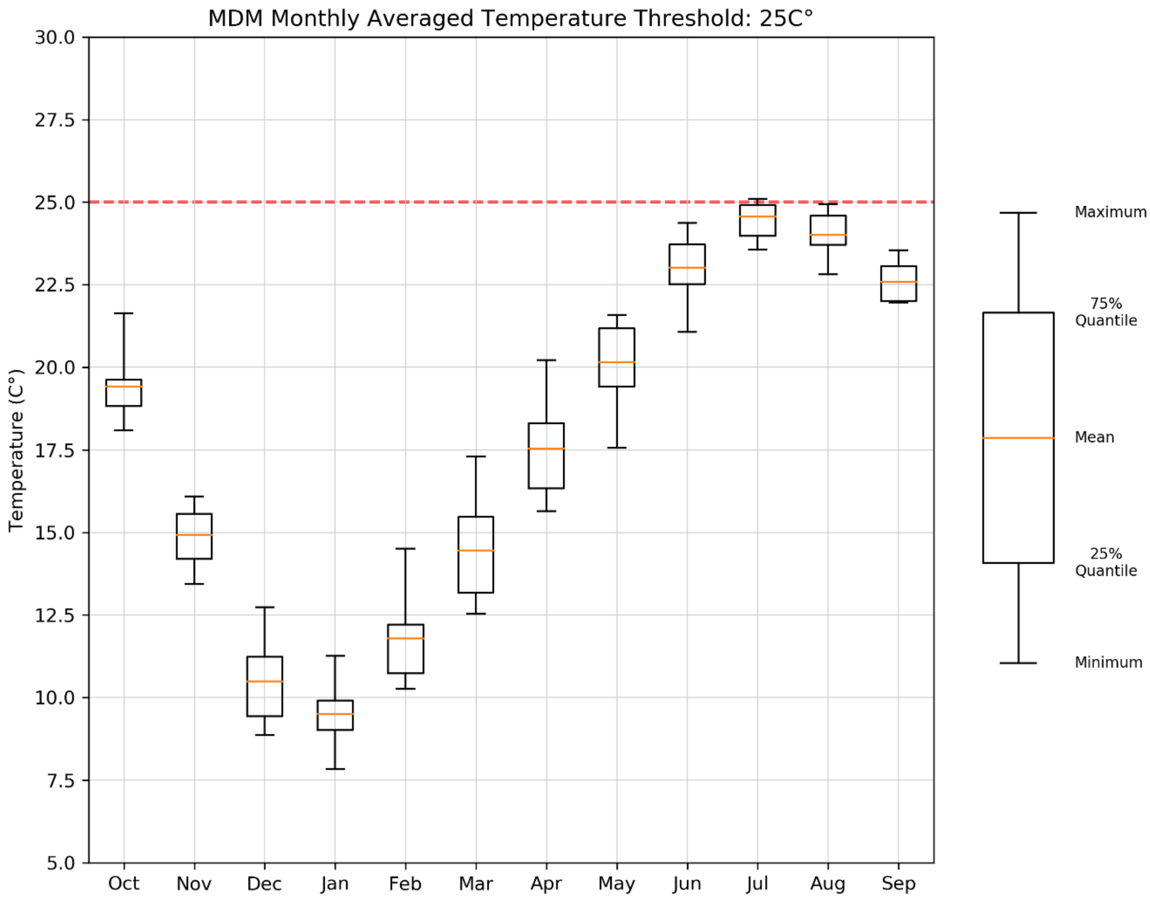

Figure 56. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MDM – Middle River at Middle River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

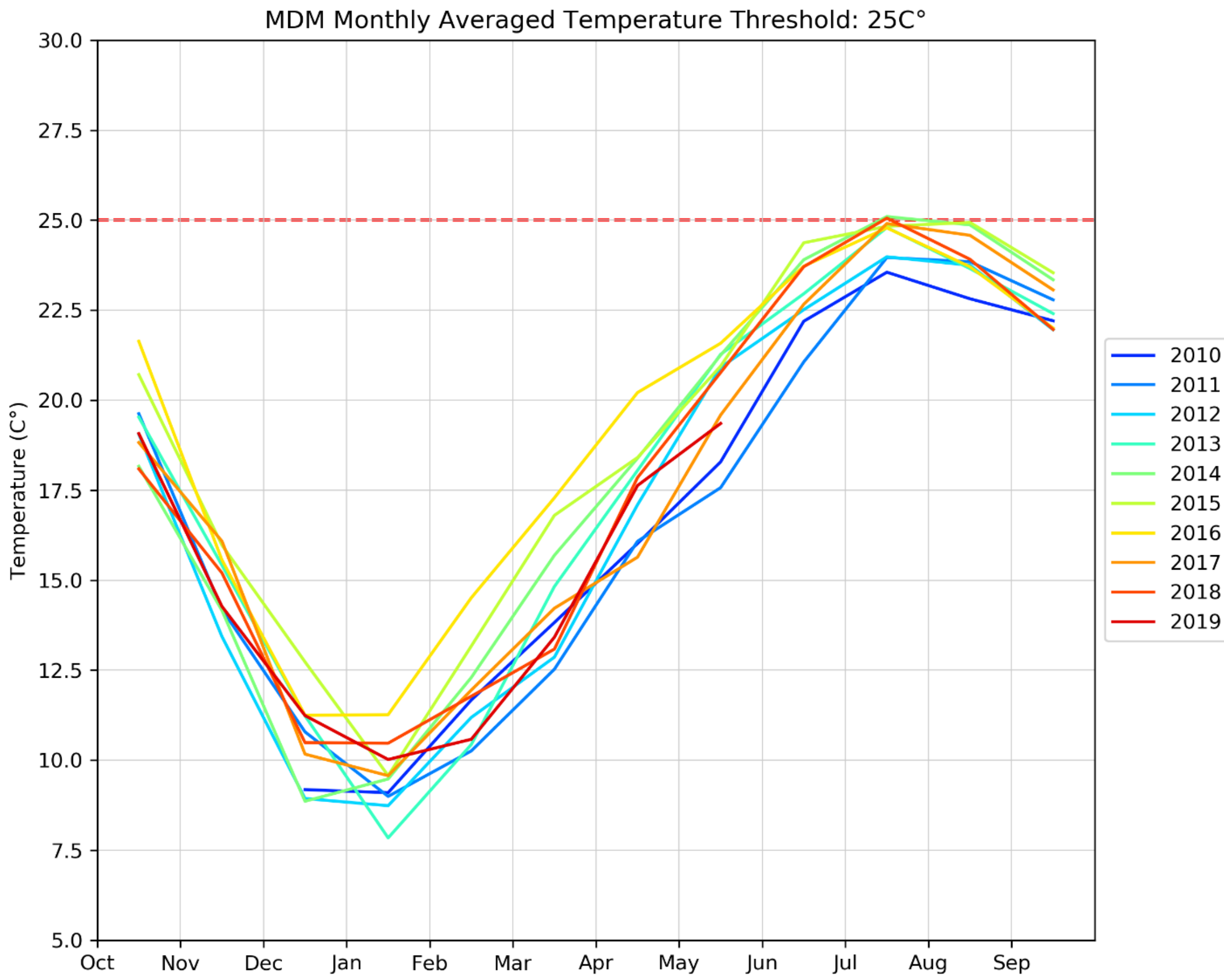

Figure 57. Monthly Average Temperature for the Period of Record at Station MDM – Middle River at Middle River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

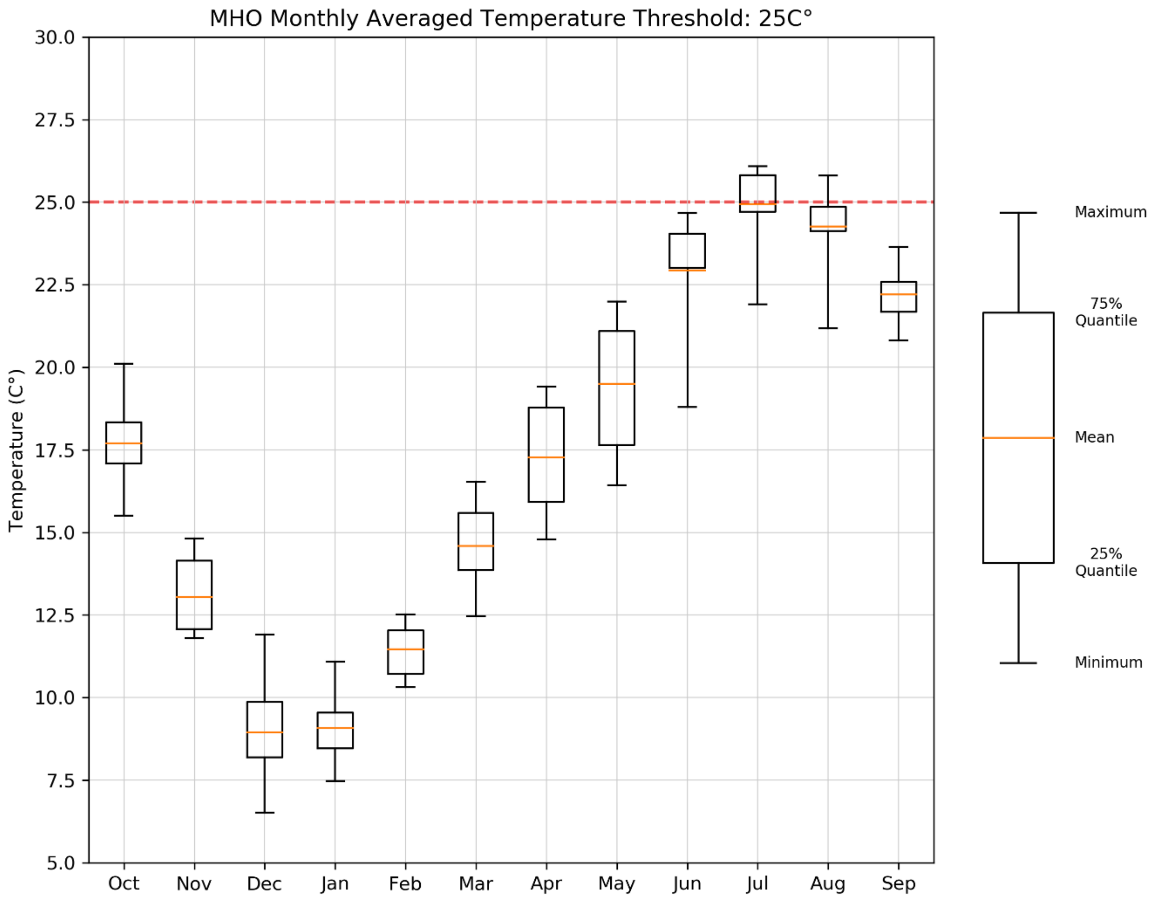

Figure 58. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MHO – Middle River near Howard Road Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

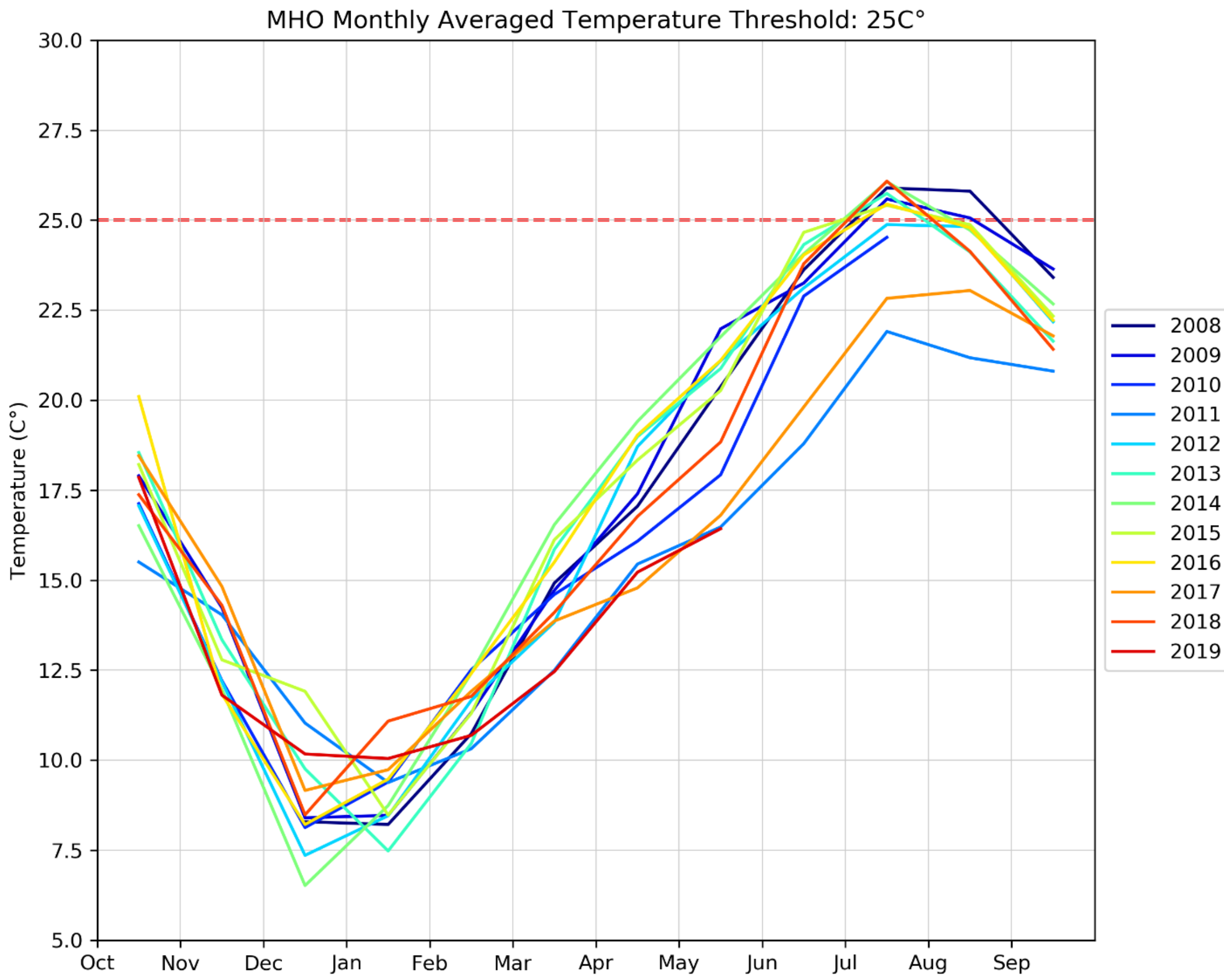

Figure 59. Monthly Average Temperature for the Period of Record at Station MHO – Middle River near Howard Road Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

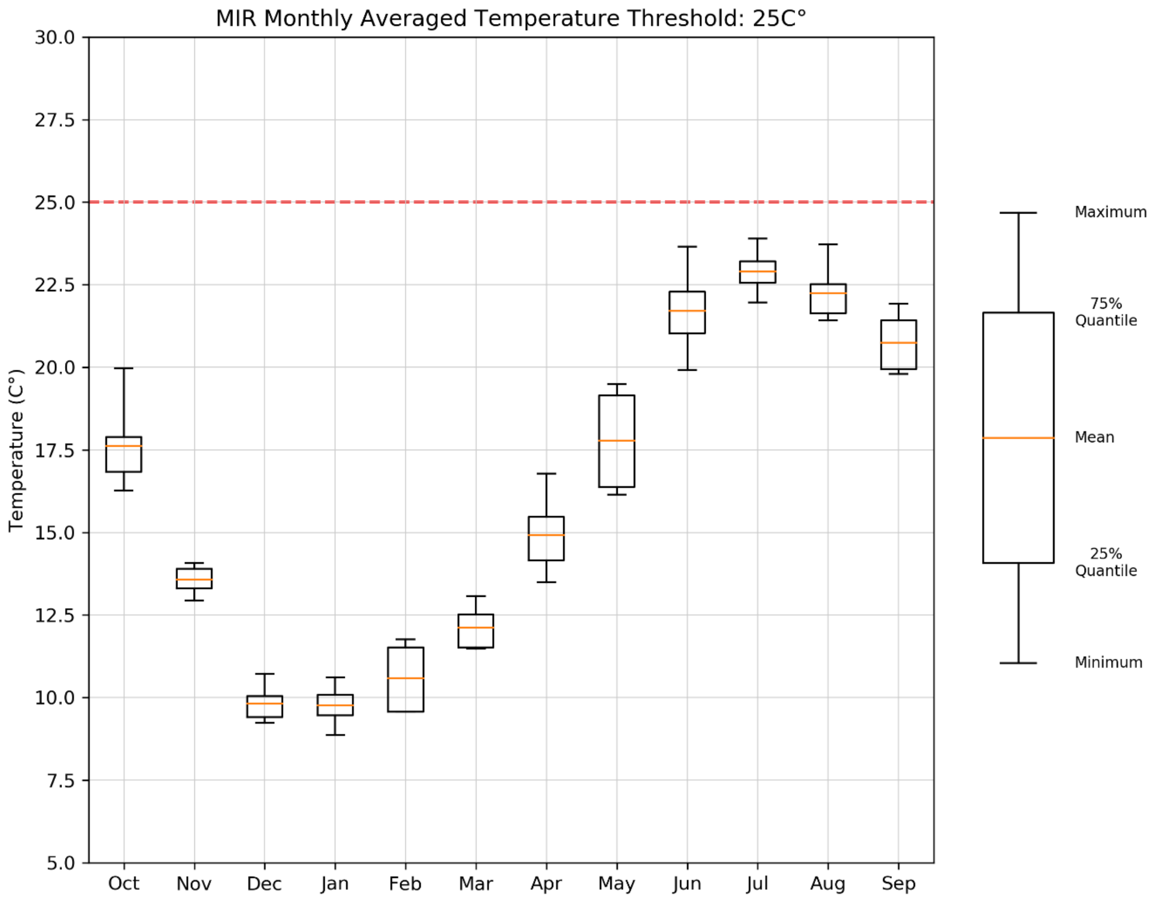

Figure 60. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MIR – Miner Slough near Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

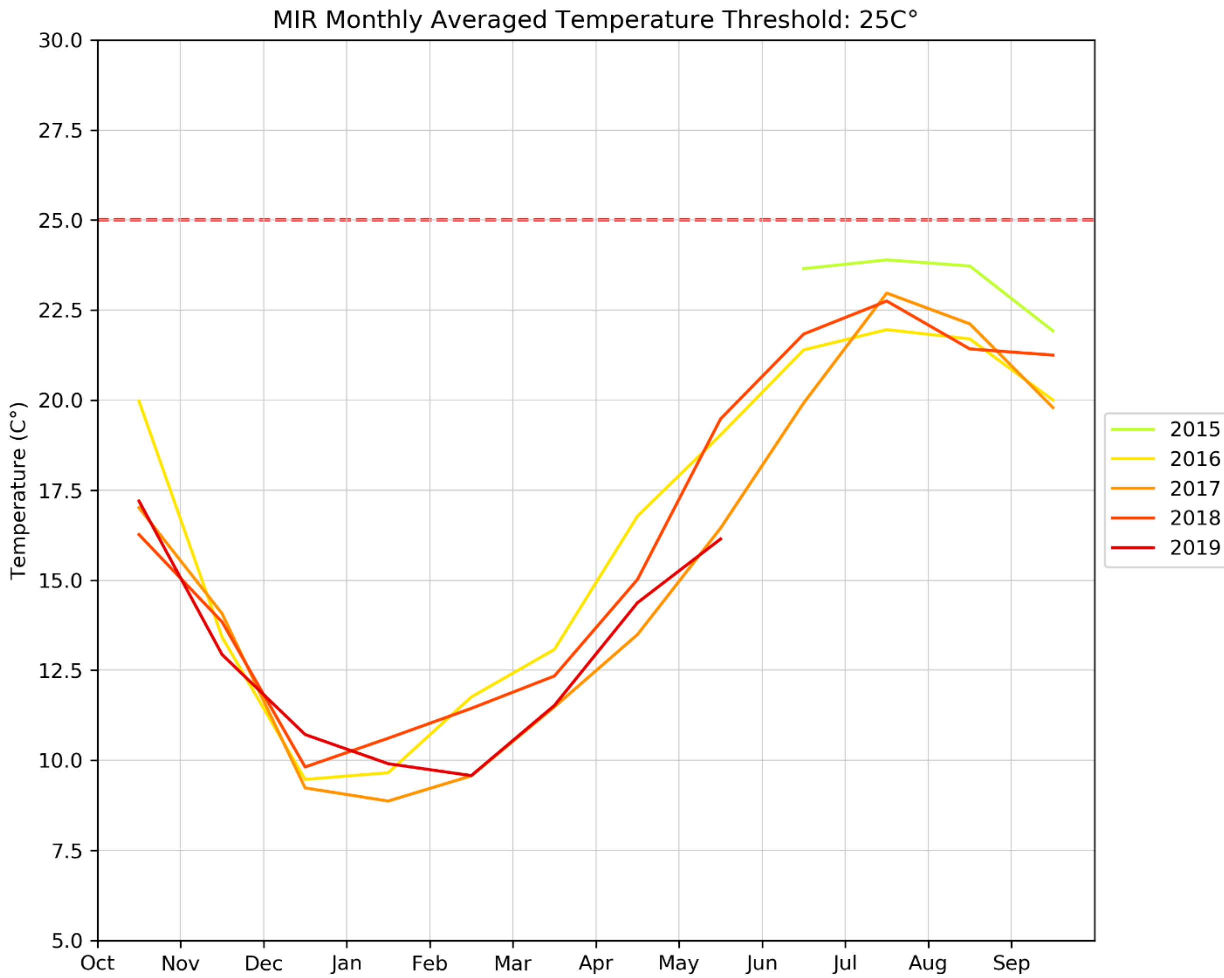

Figure 61. Monthly Average Temperature for the Period of Record at Station MIR – Miner Slough near Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

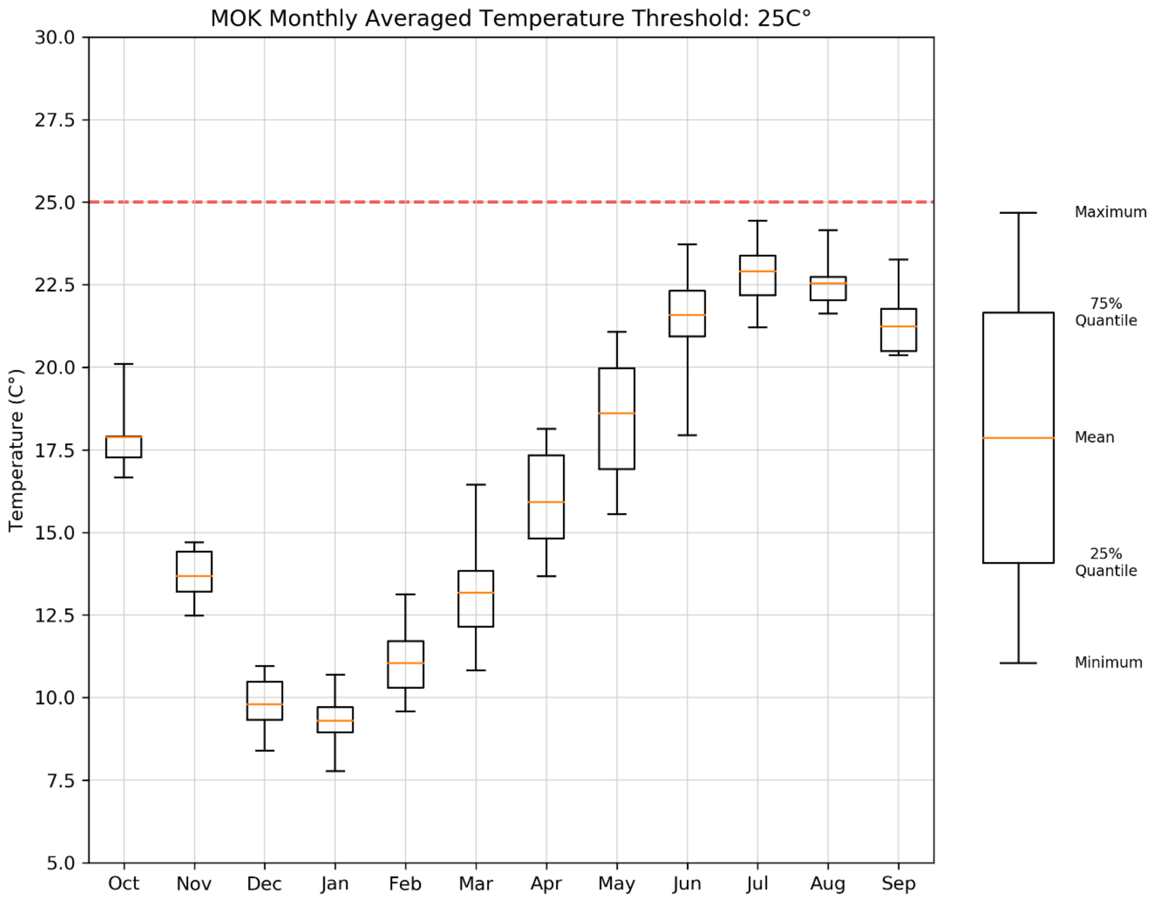

Figure 62. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MOK – Mokelumne River at San Joaquin River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

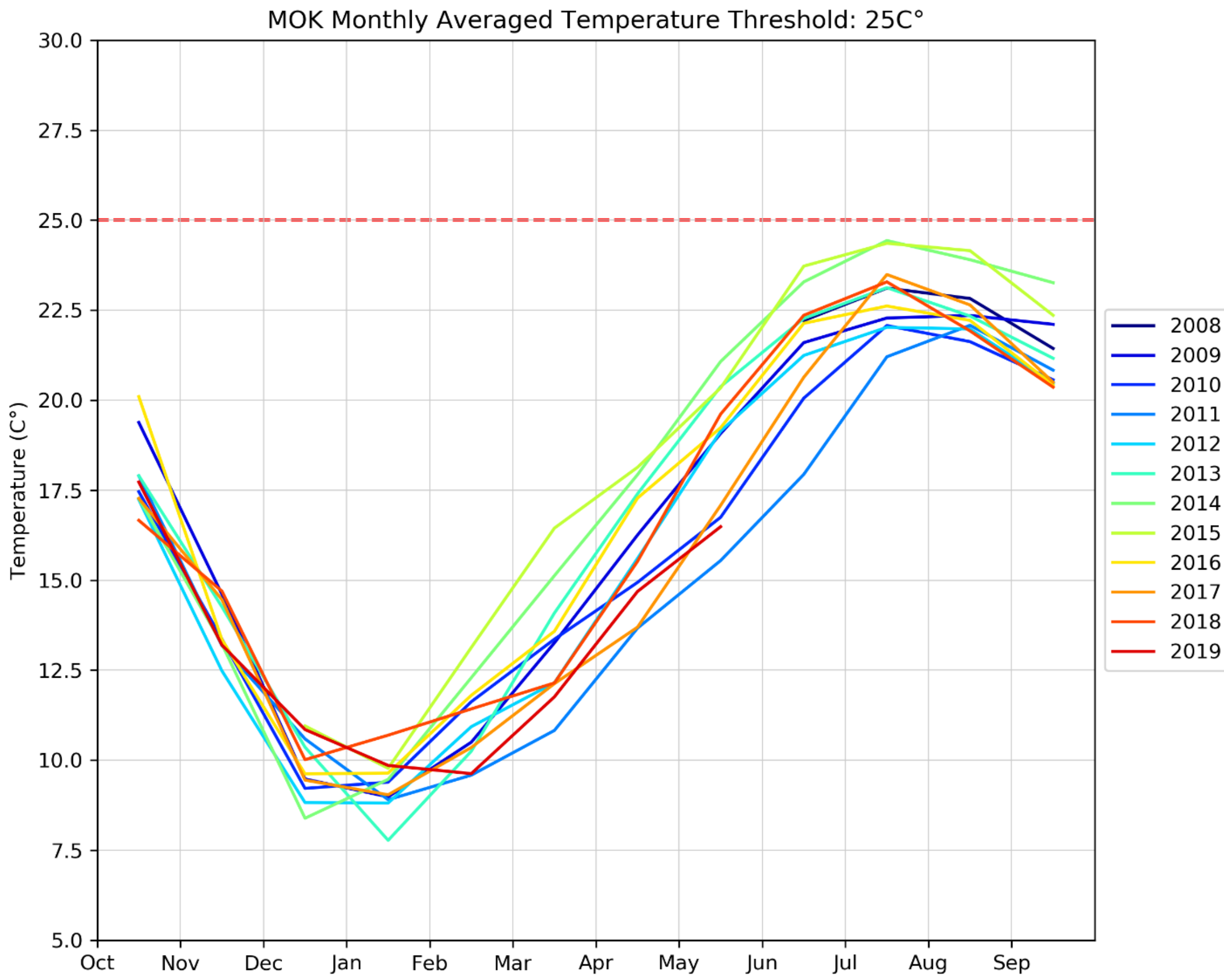

Figure 63. Monthly Average Temperature for the Period of Record at Station MOK – Mokelumne River at San Joaquin River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

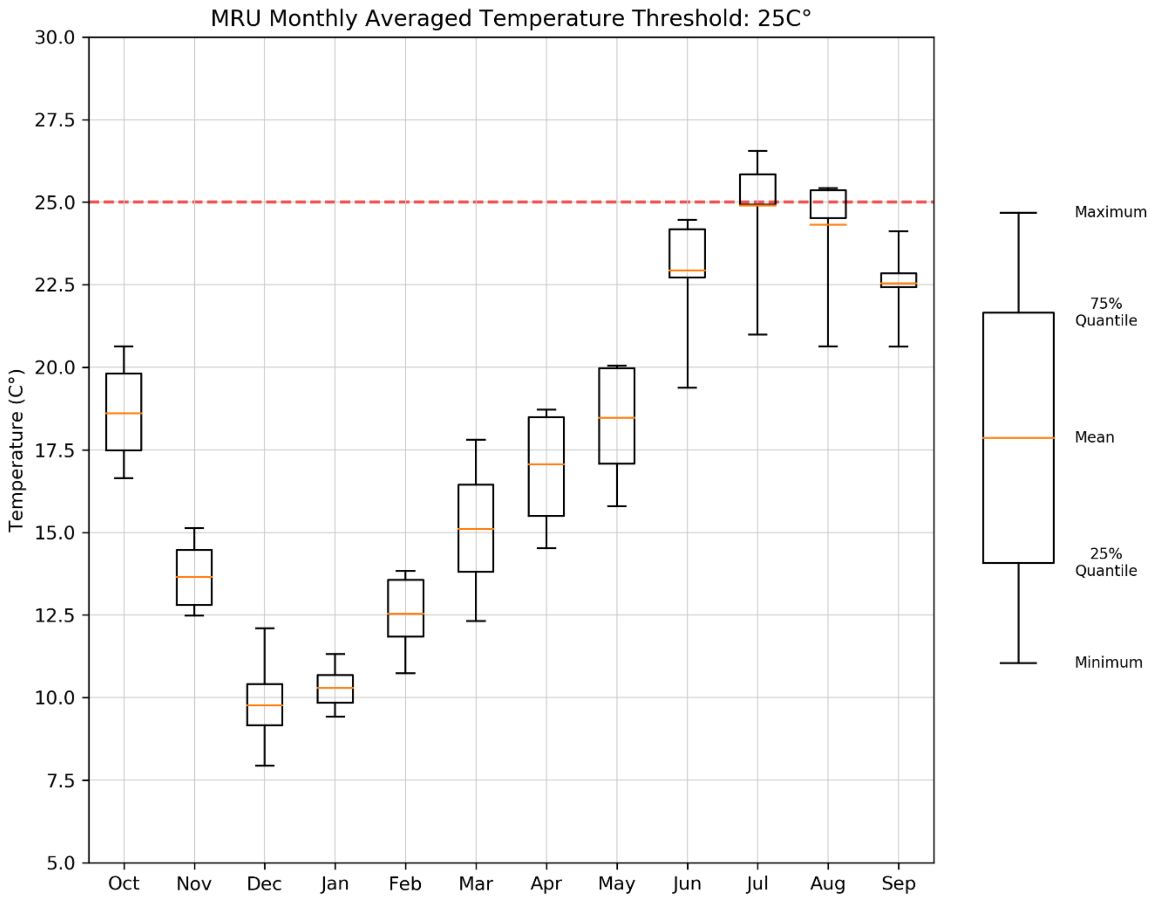

Figure 64. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MRU – Middle River at Undine Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

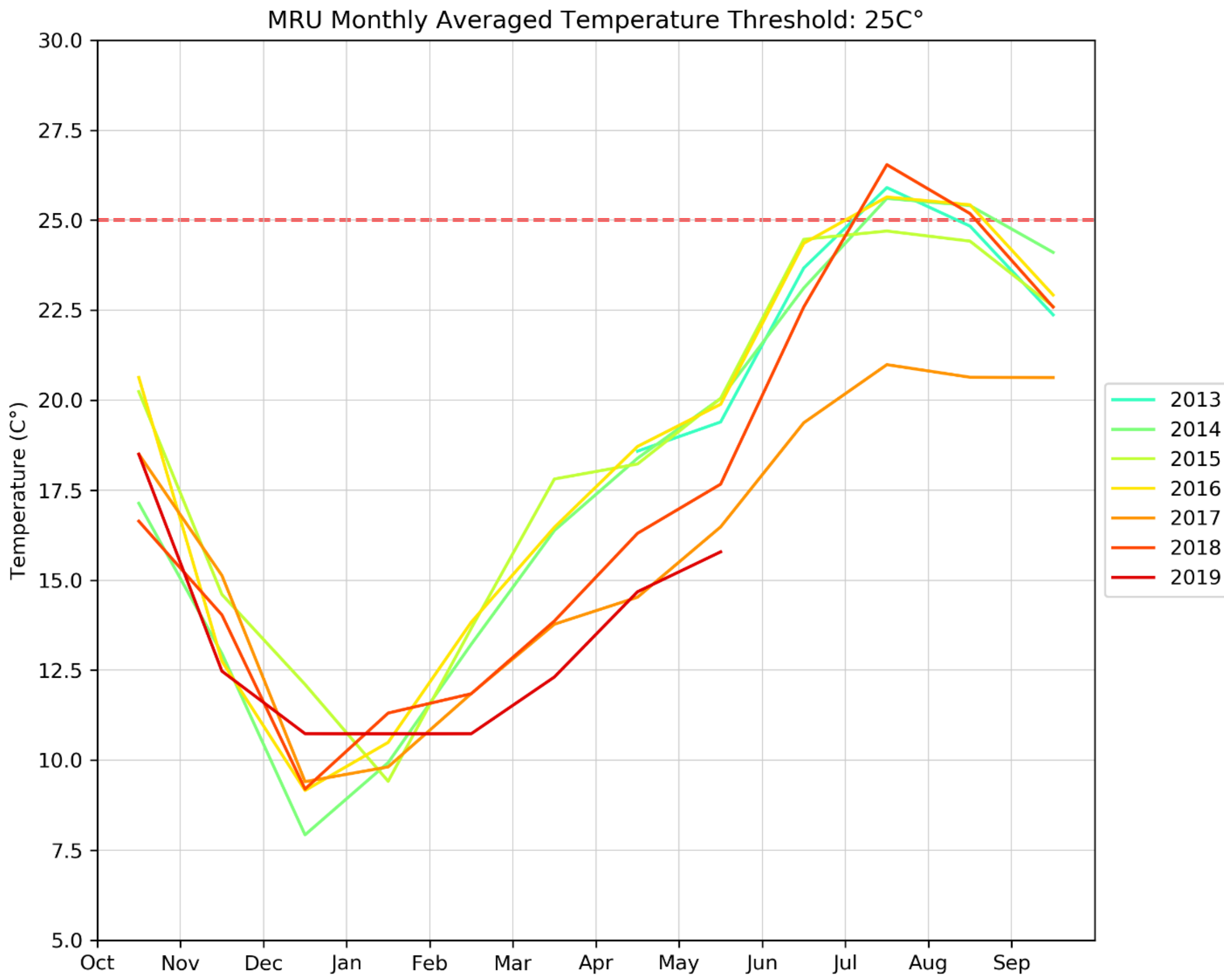

Figure 65. Monthly Average Temperature for the Period of Record at Station MRU – Middle River at Undine Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

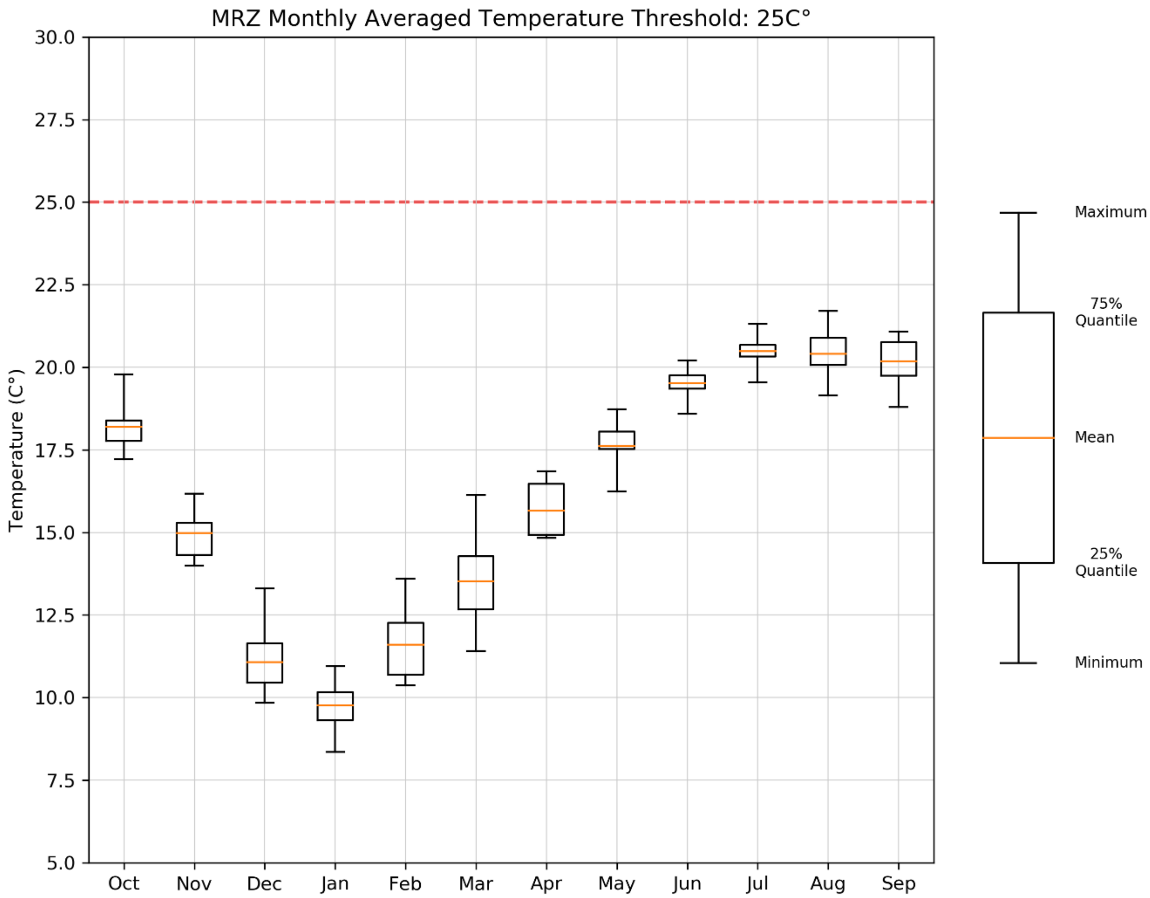

Figure 66. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MRZ – Martinez

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

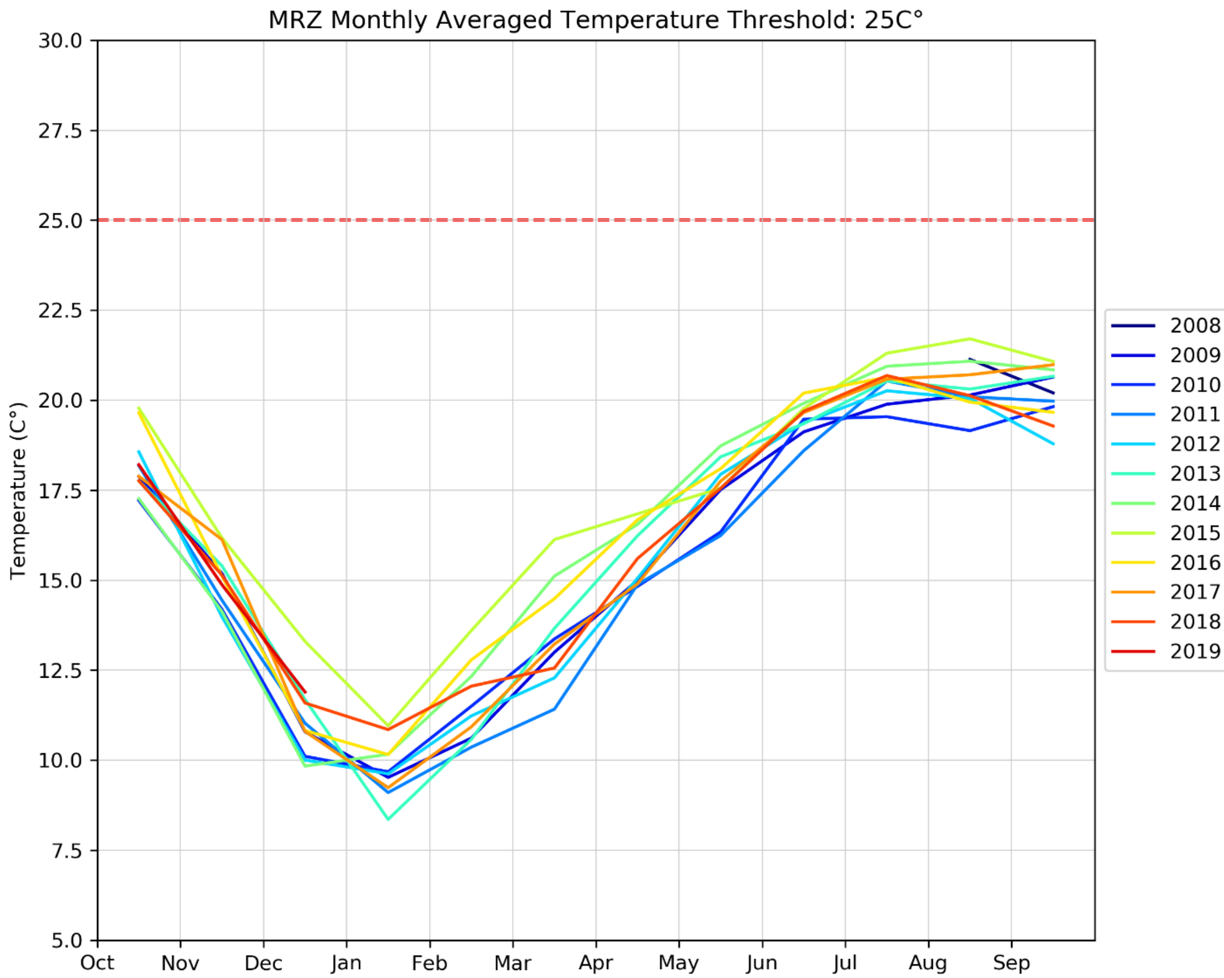

Figure 67. Monthly Average Temperature for the Period of Record at Station MRZ – Martinez

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

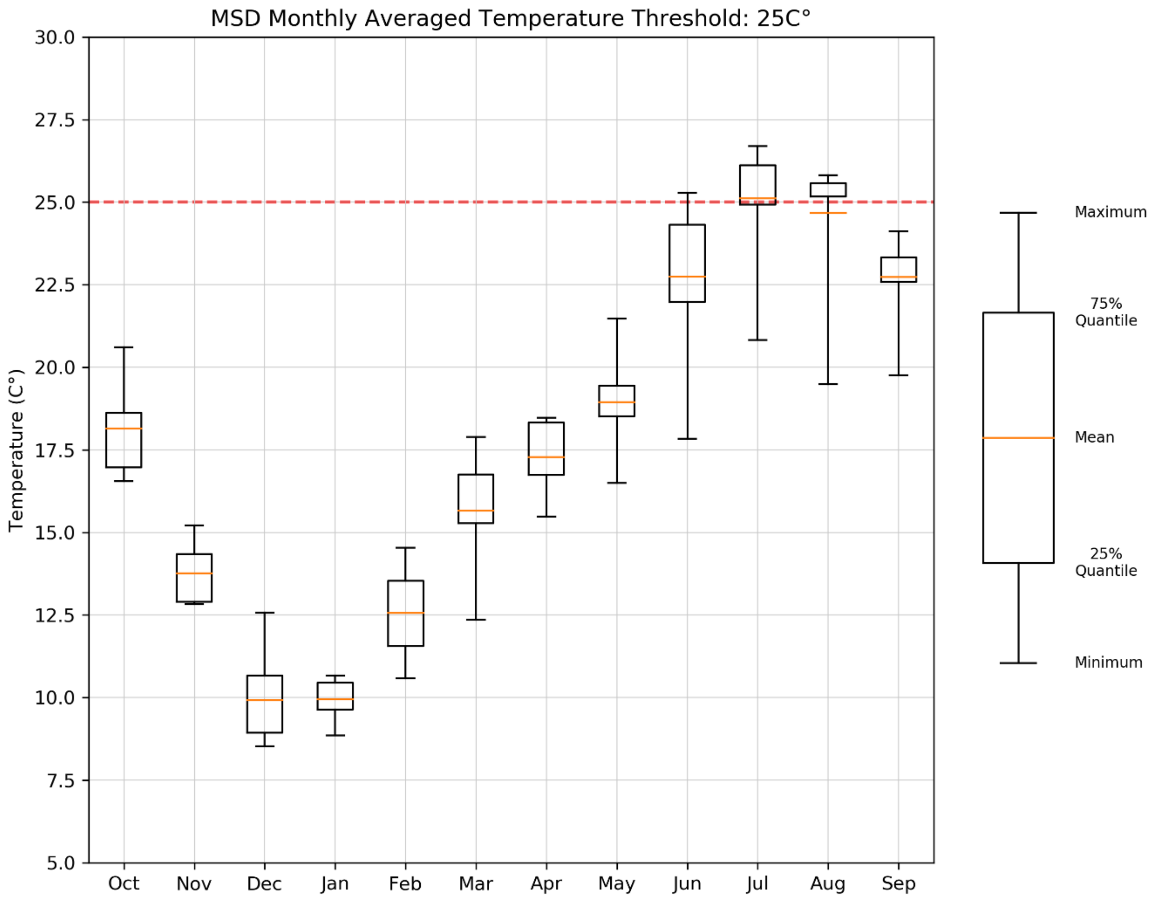

Figure 68. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MSD – San Joaquin River at Mossdale Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

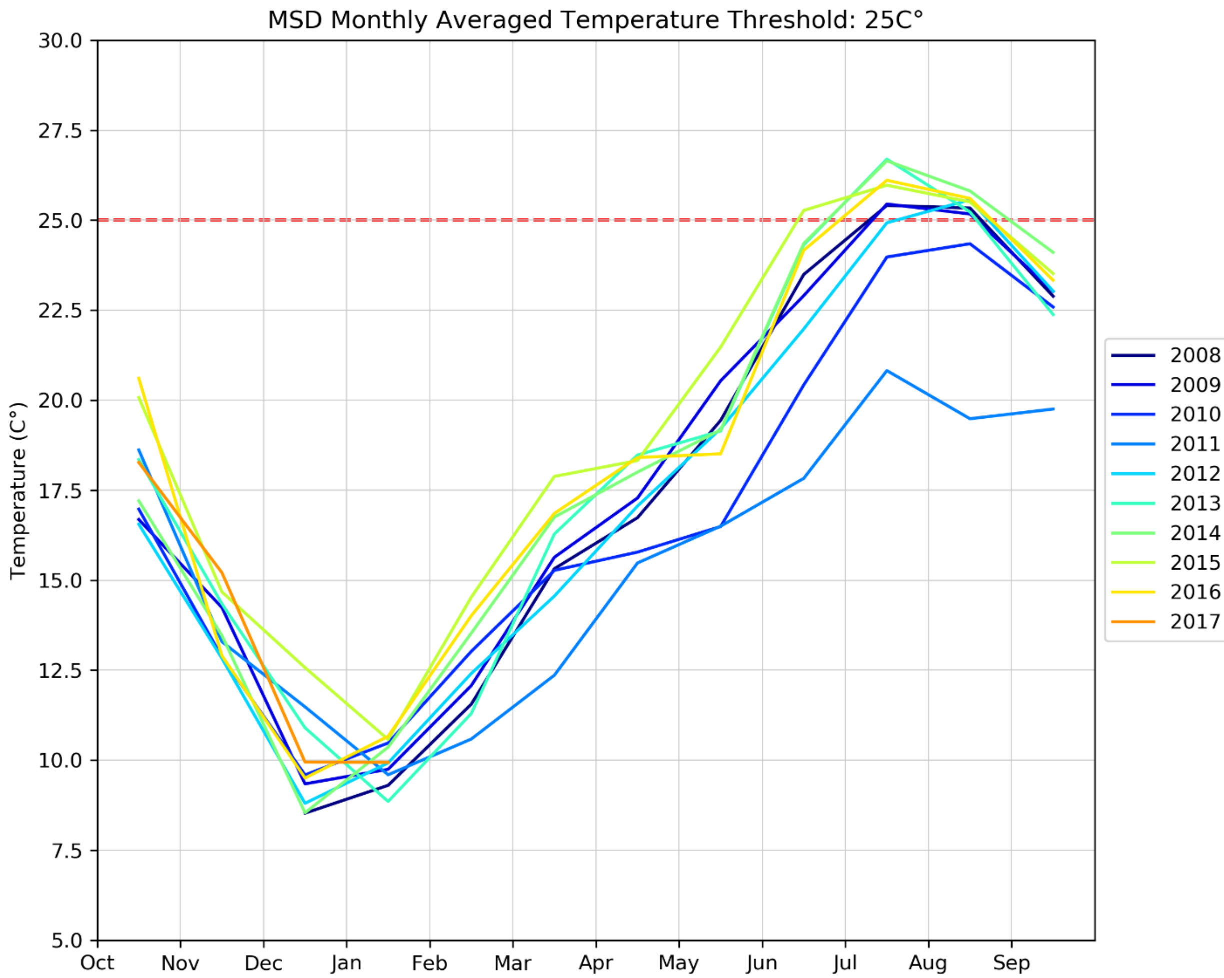

Figure 69. Monthly Average Temperature for the Period of Record at Station MSD – San Joaquin River at Mossdale Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

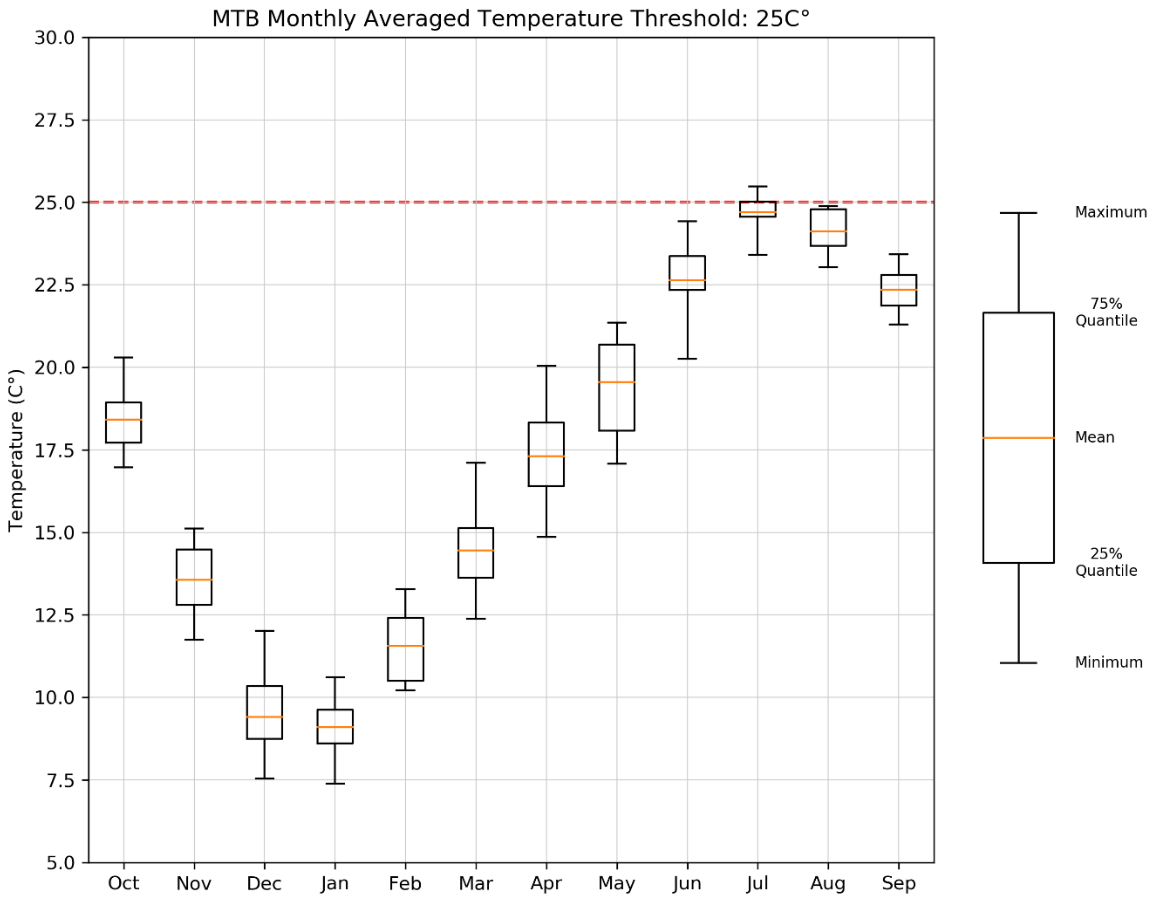

Figure 70. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station MTB – Middle River at Tracy Boulevard

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

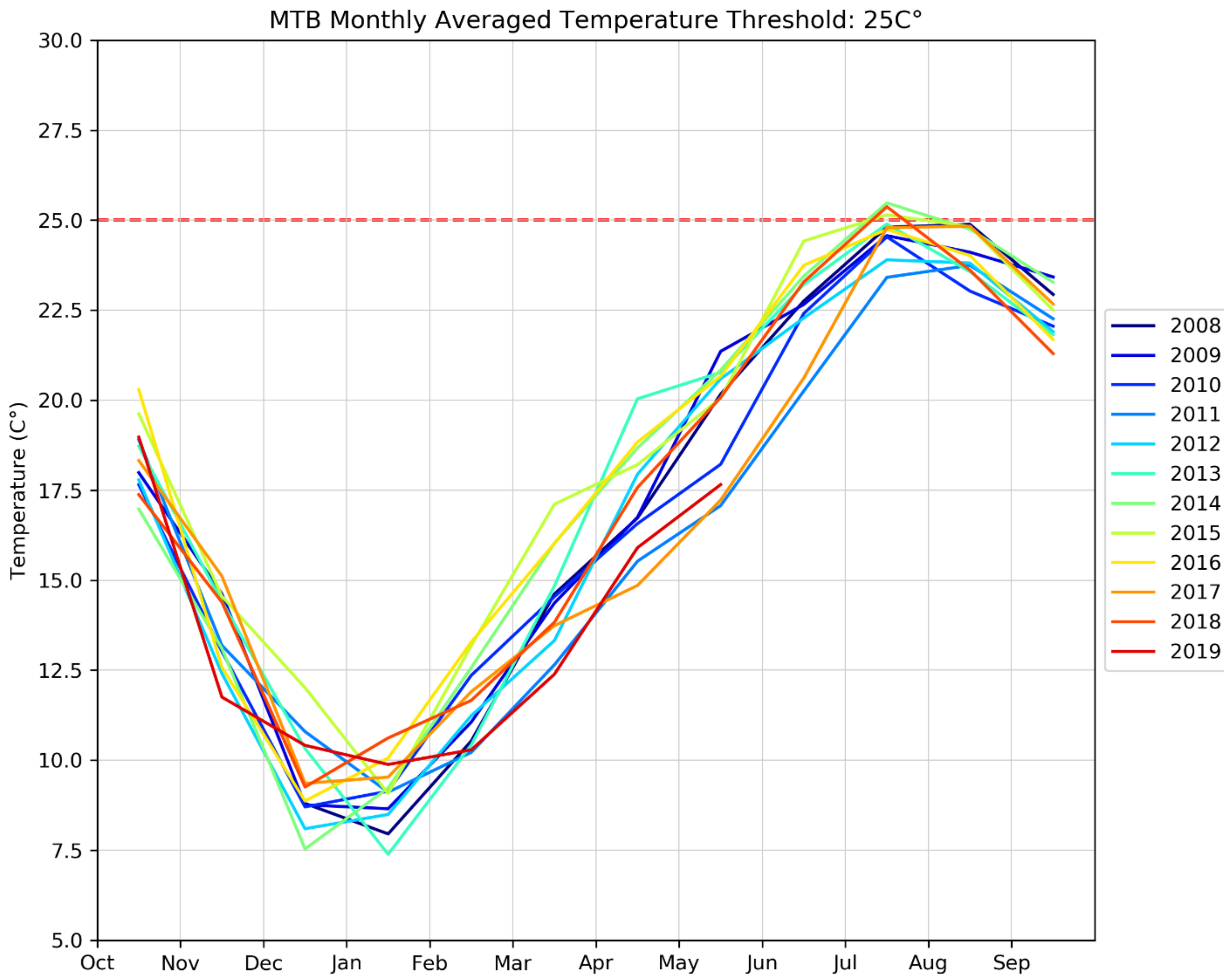

Figure 71. Monthly Average Temperature for the Period of Record at Station MTB – Middle River at Tracy Boulevard

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

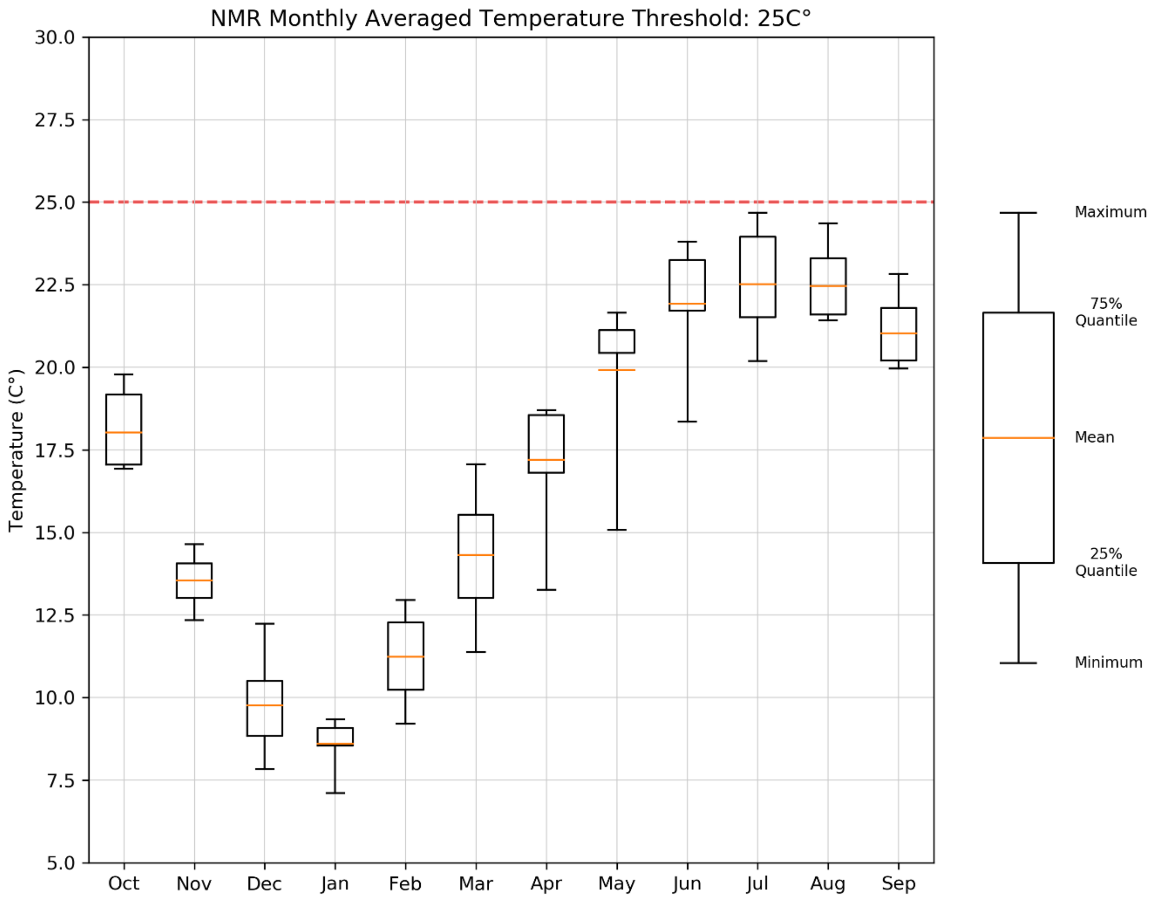

Figure 72. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station NMR – North Mokelumne River at West Walnut Grove Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

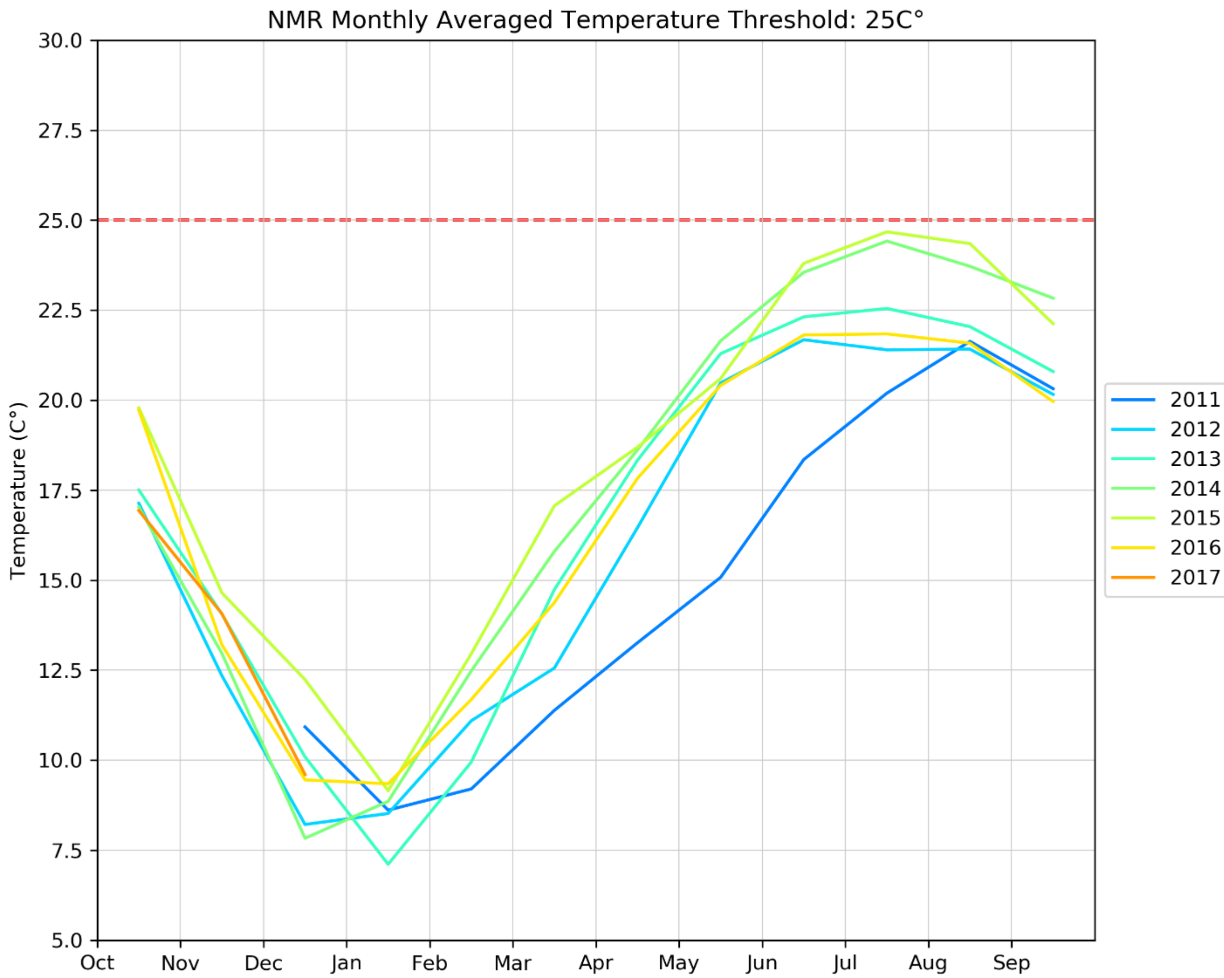

Figure 73. Monthly Average Temperature for the Period of Record at Station NMR – North Mokelumne River at West Walnut Grove Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

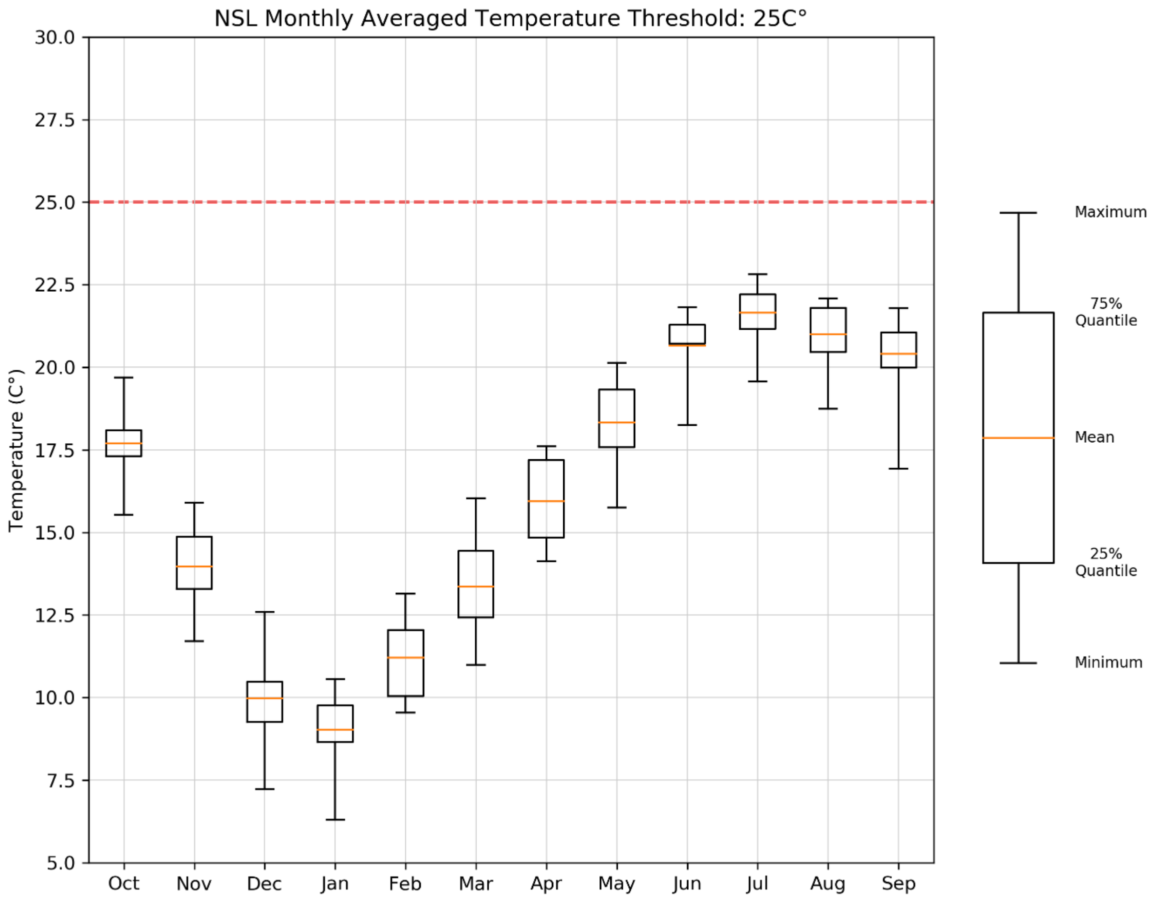

Figure 74. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station NSL – Montezuma Slough at National Steel

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

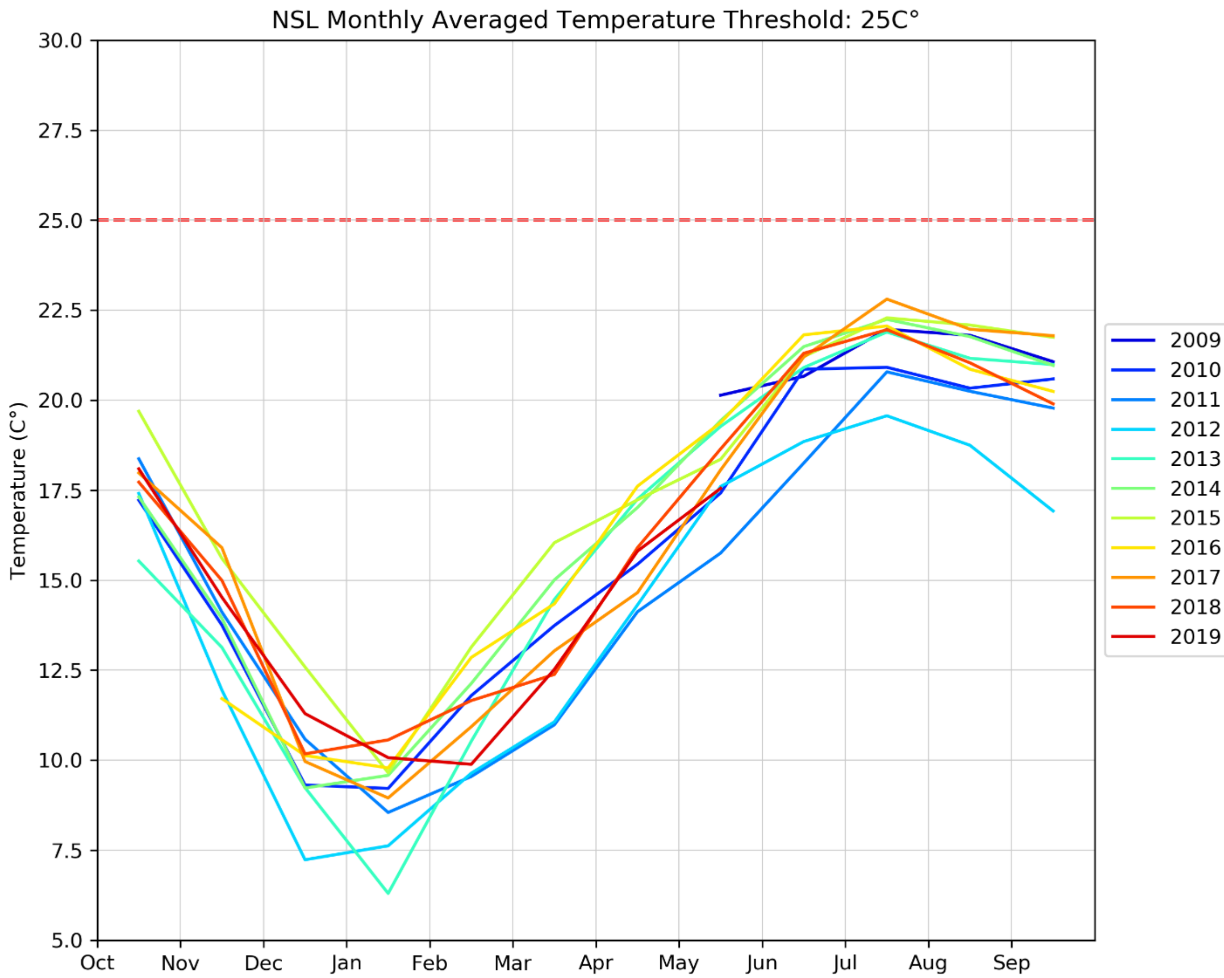

Figure 75. Monthly Average Temperature for the Period of Record at Station NSL – Montezuma Slough at National Steel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

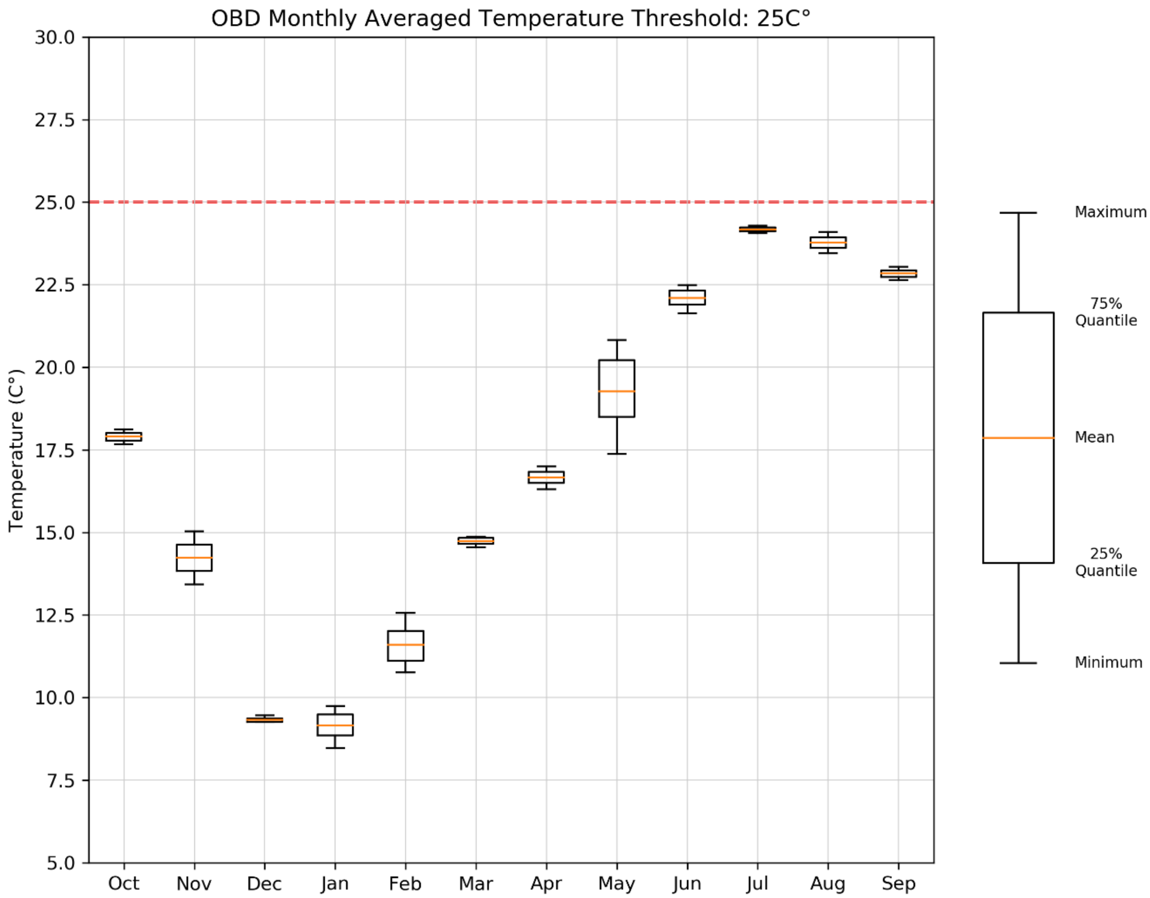

Figure 76. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OBD – Old River Near DMC Below Dam

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

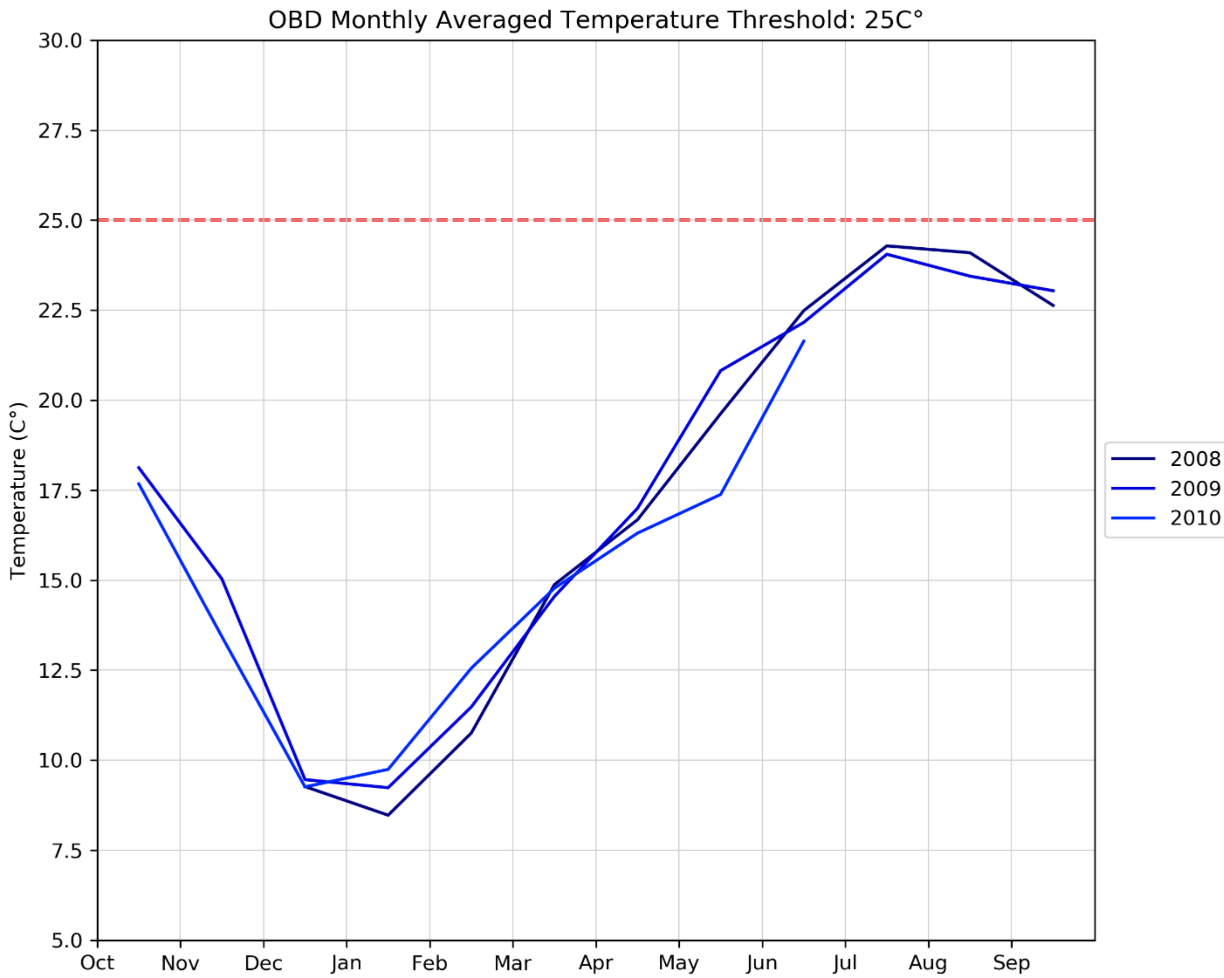

Figure 77. Monthly Average Temperature for the Period of Record at Station OBD – Old River Near DMC Below Dam

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

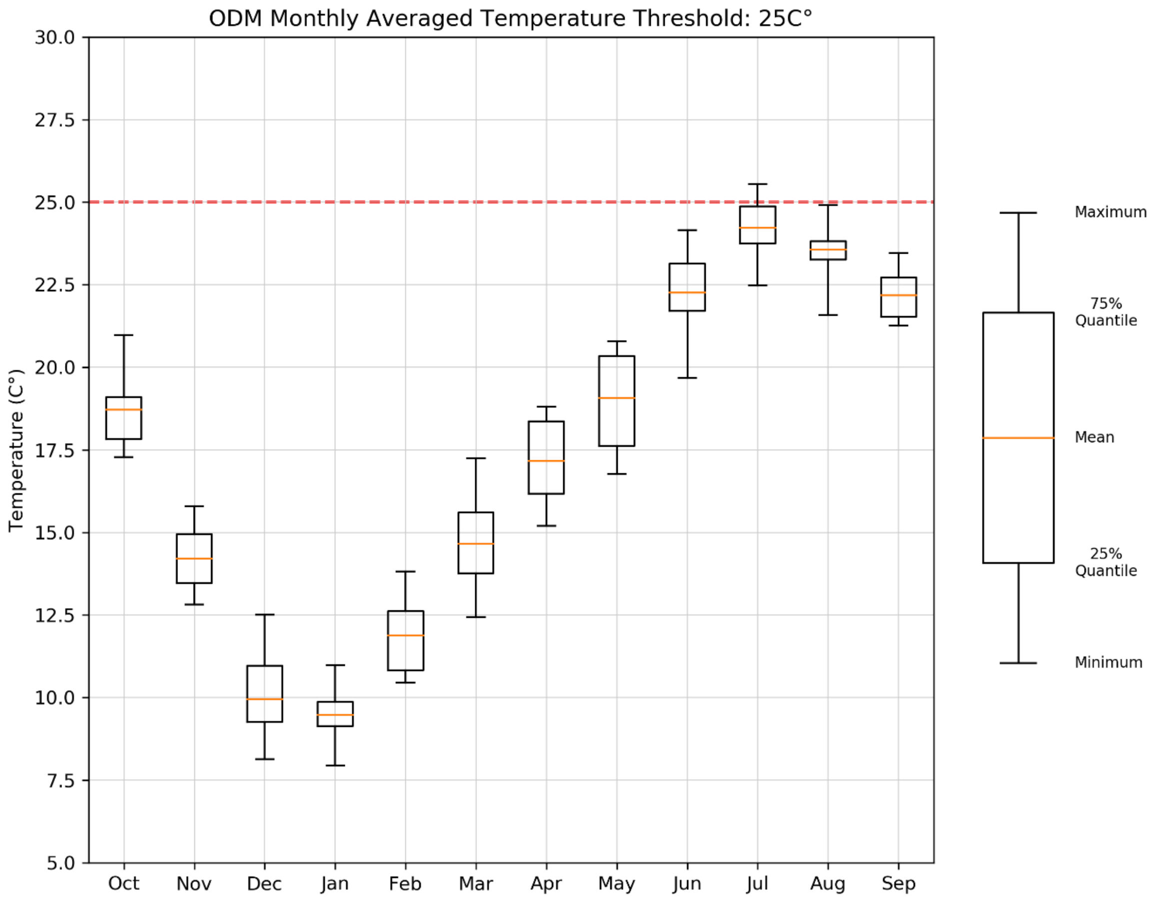

Figure 78. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ODM – Old River at Delta Mendota Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

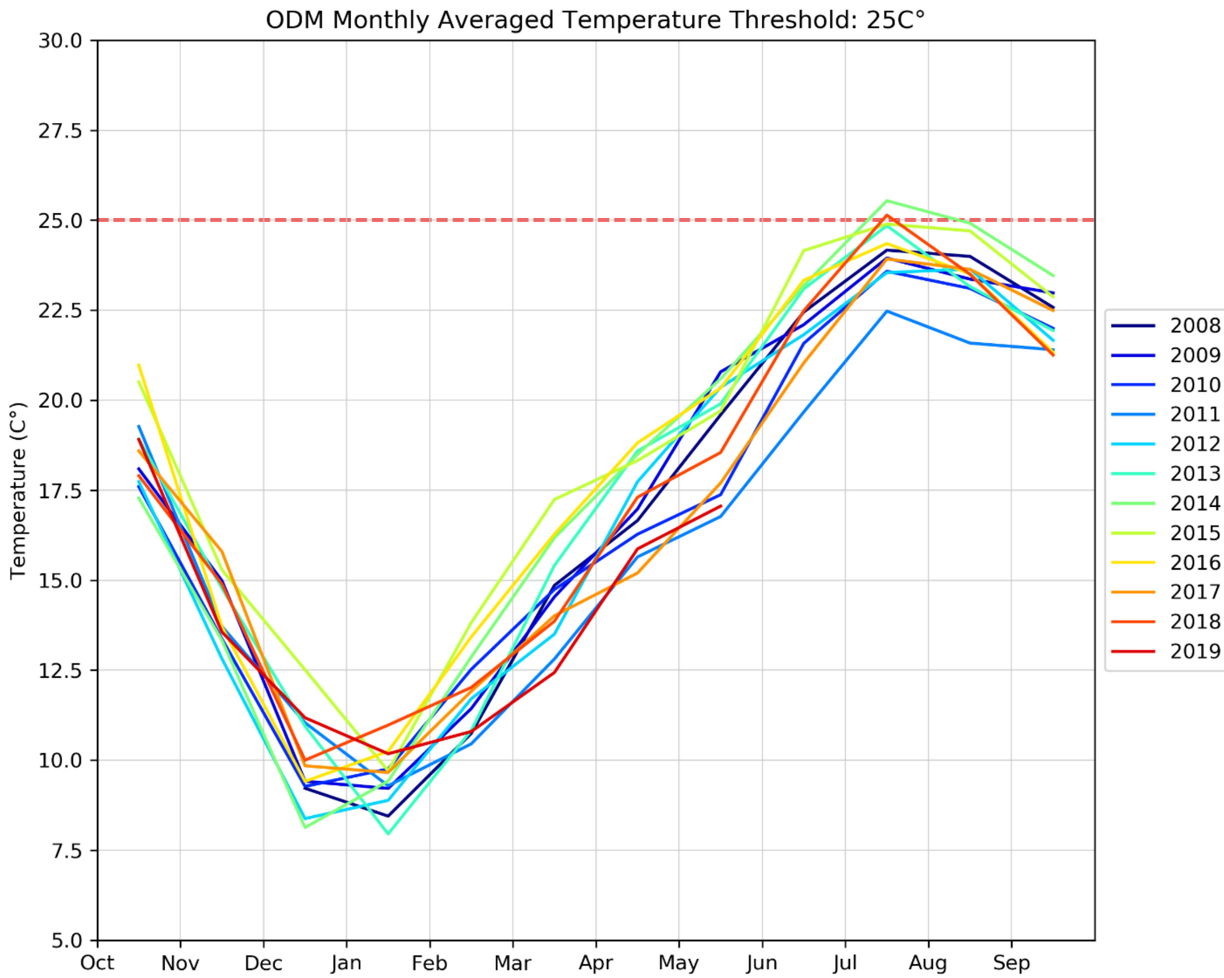

Figure 79. Monthly Average Temperature for the Period of Record at Station ODM - Old River at Delta Mendota Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

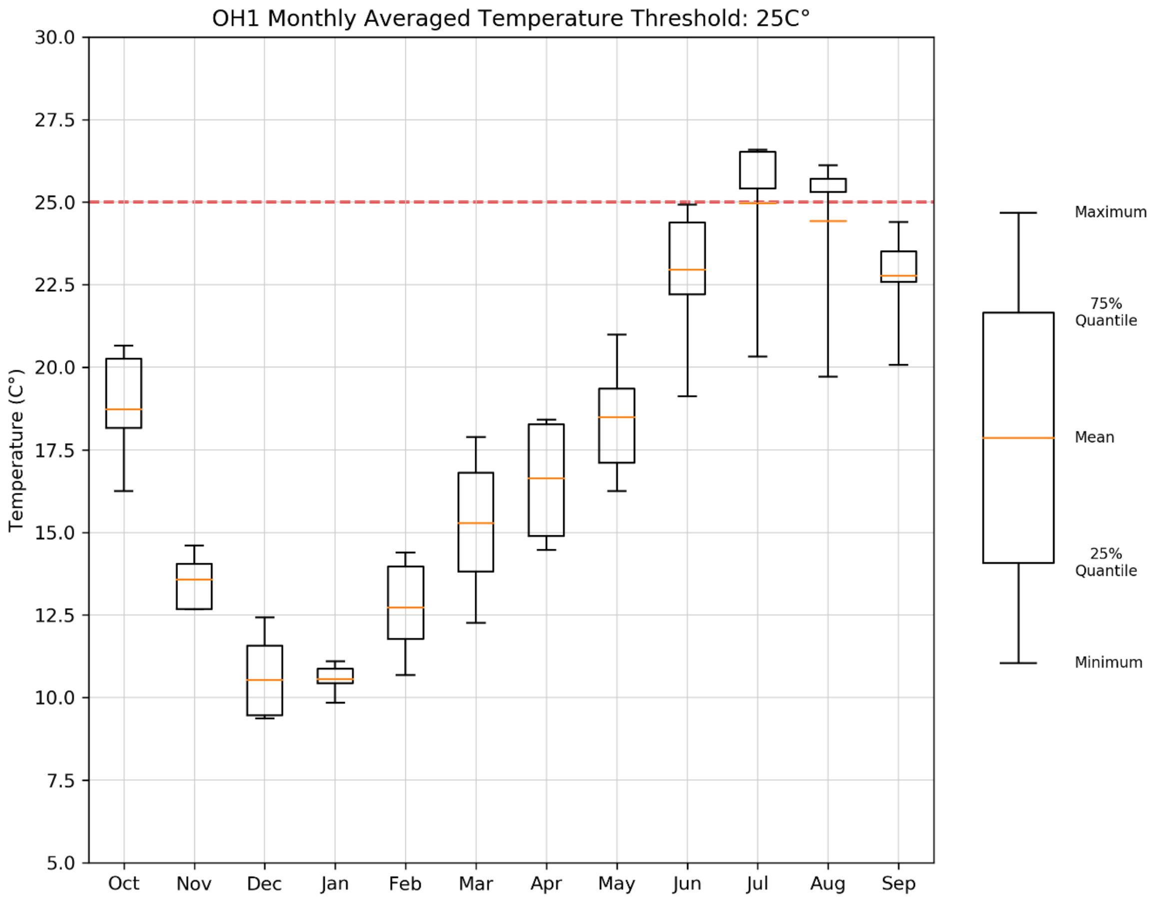

Figure 80. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OH1 - Old River at Head

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

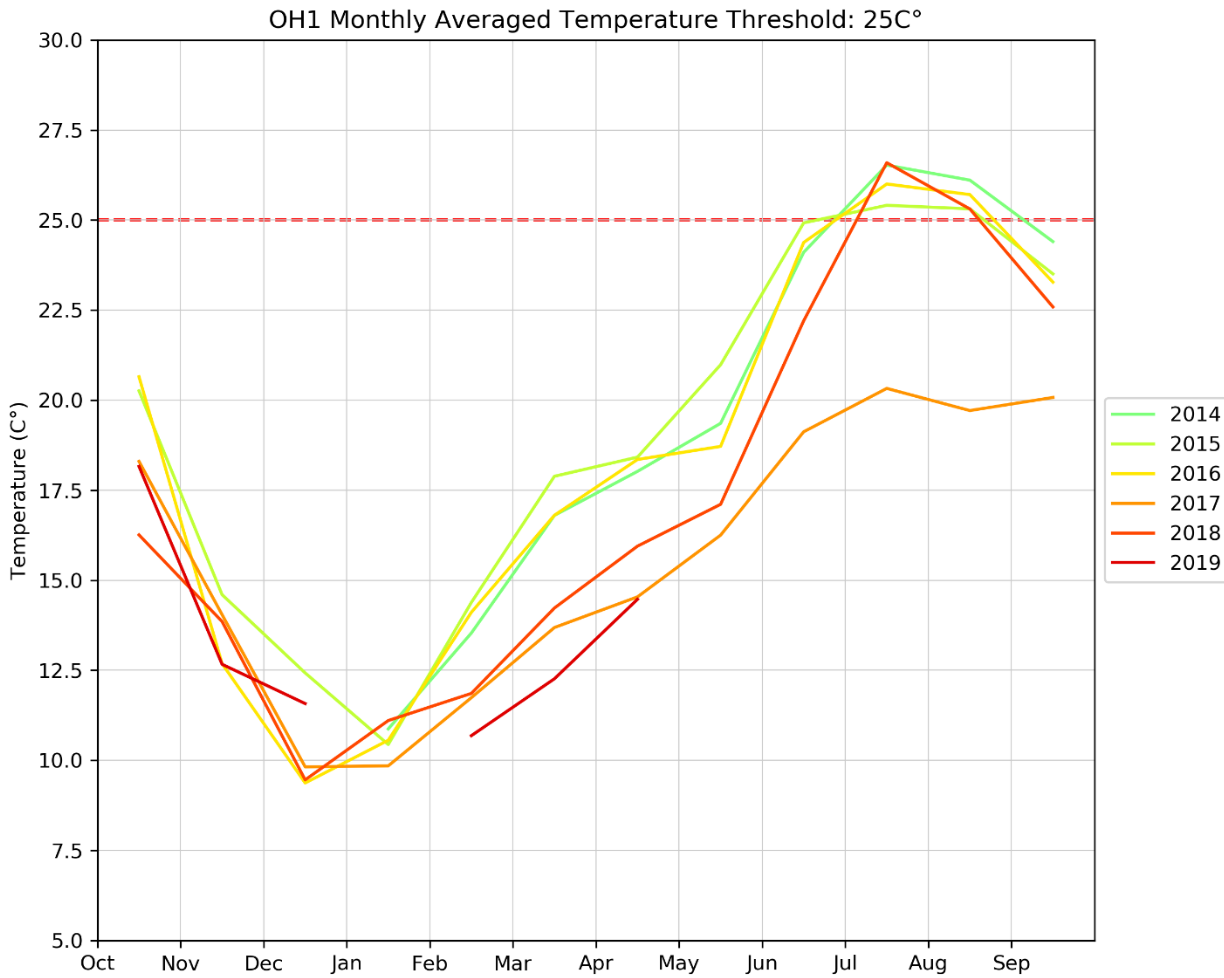

Figure 81. Monthly Average Temperature for the Period of Record at Station OH1 – Old River at Head

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

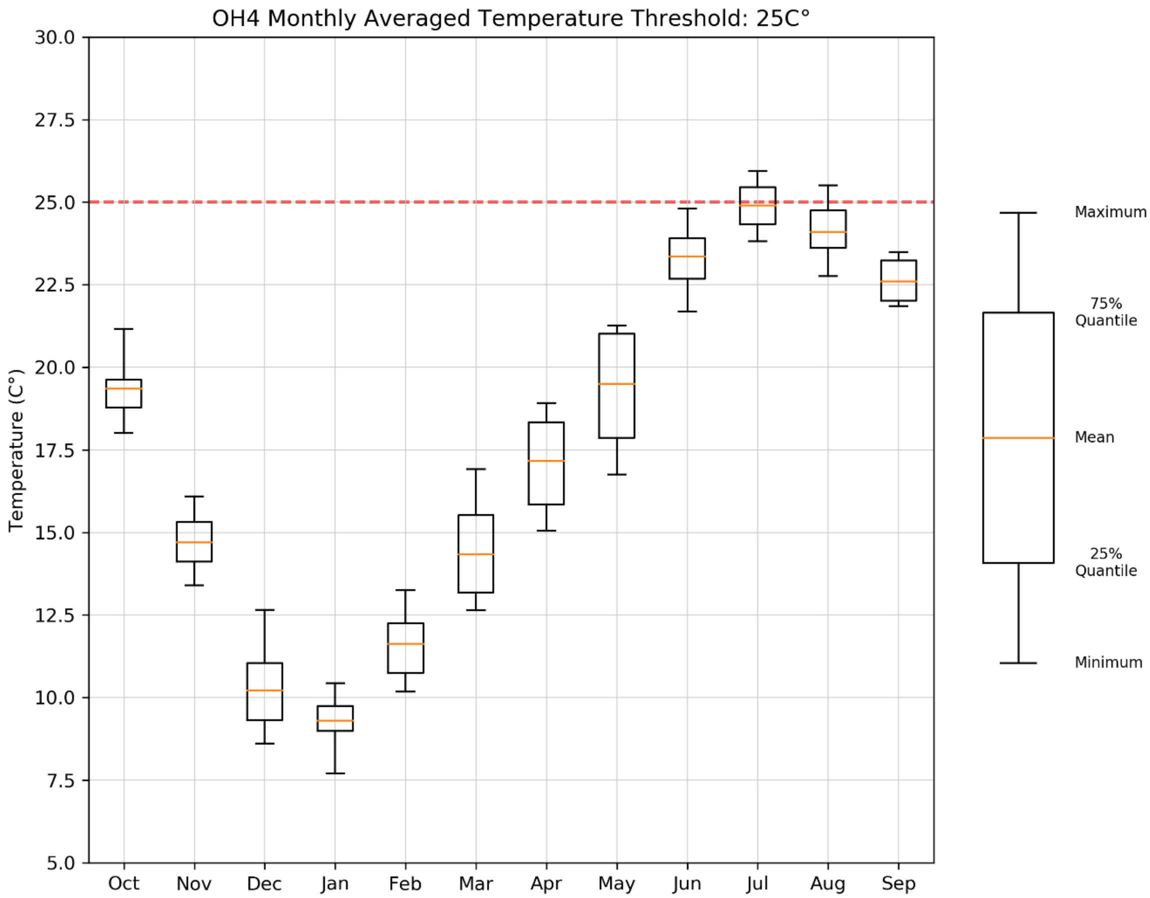

Figure 82. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OH4 - Old River at Highway 4

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

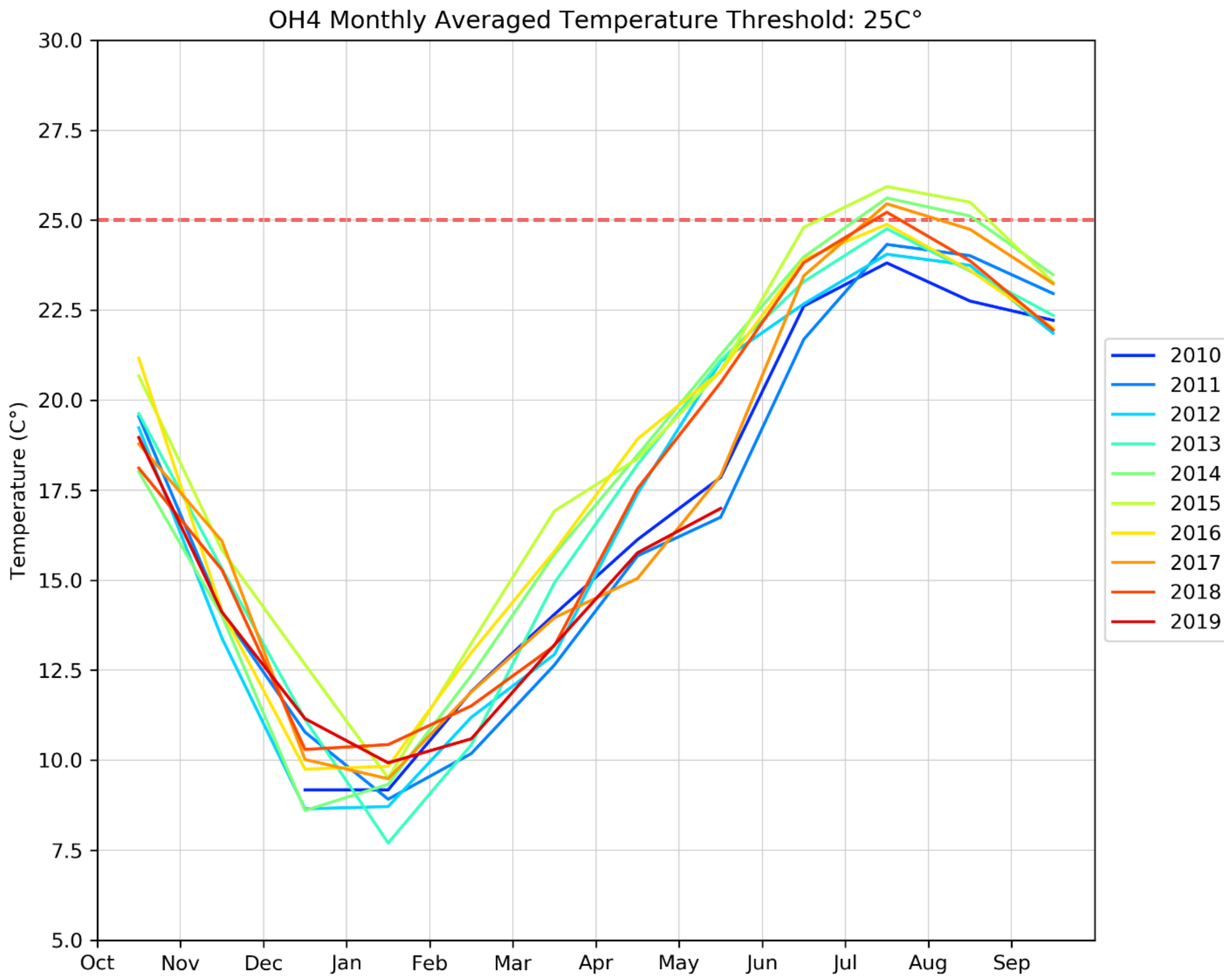

Figure 83. Monthly Average Temperature for the Period of Record at Station OH4 – Old River at Highway 4

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

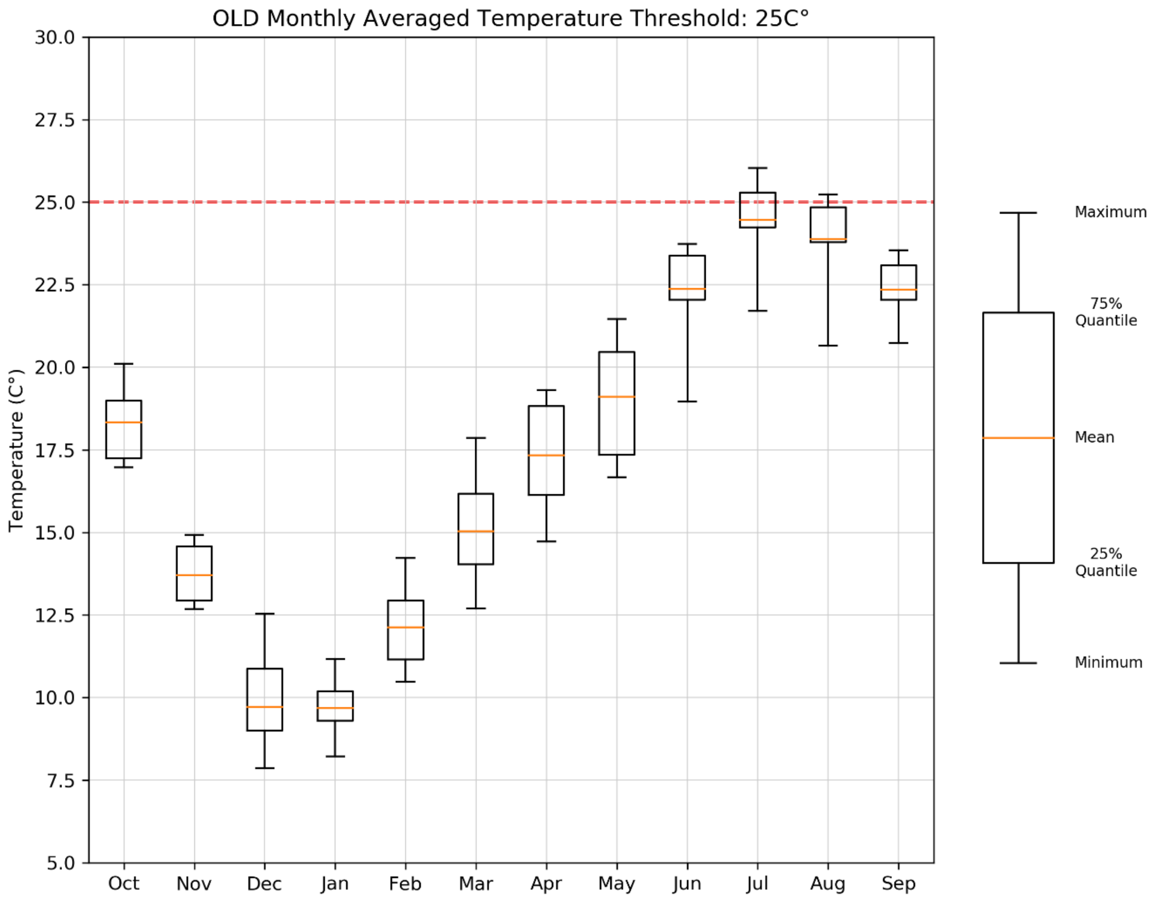

Figure 84. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OLD – Old River Near Tracy

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

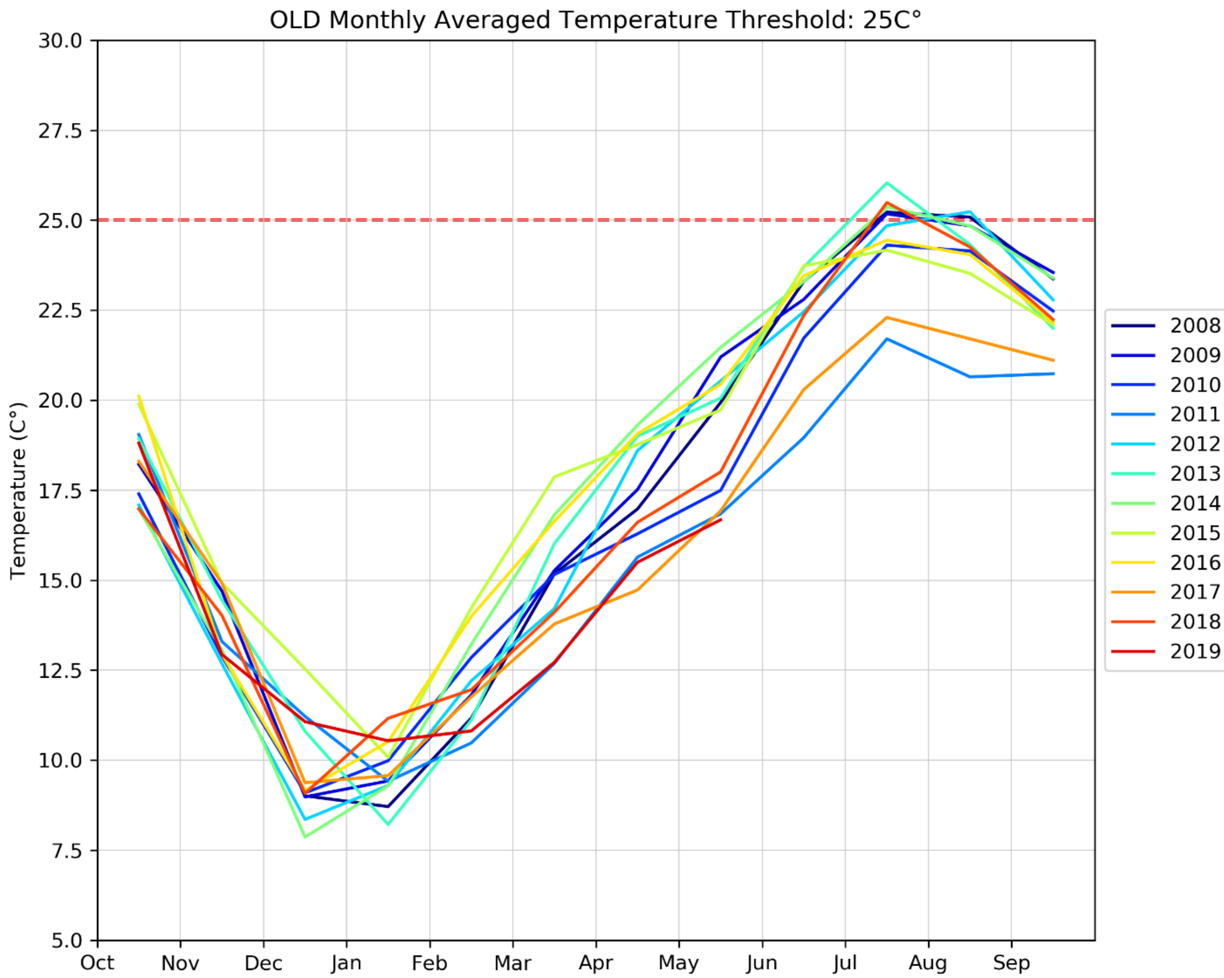

Figure 85. Monthly Average Temperature for the Period of Record at Station OLD – Old River Near Tracy

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

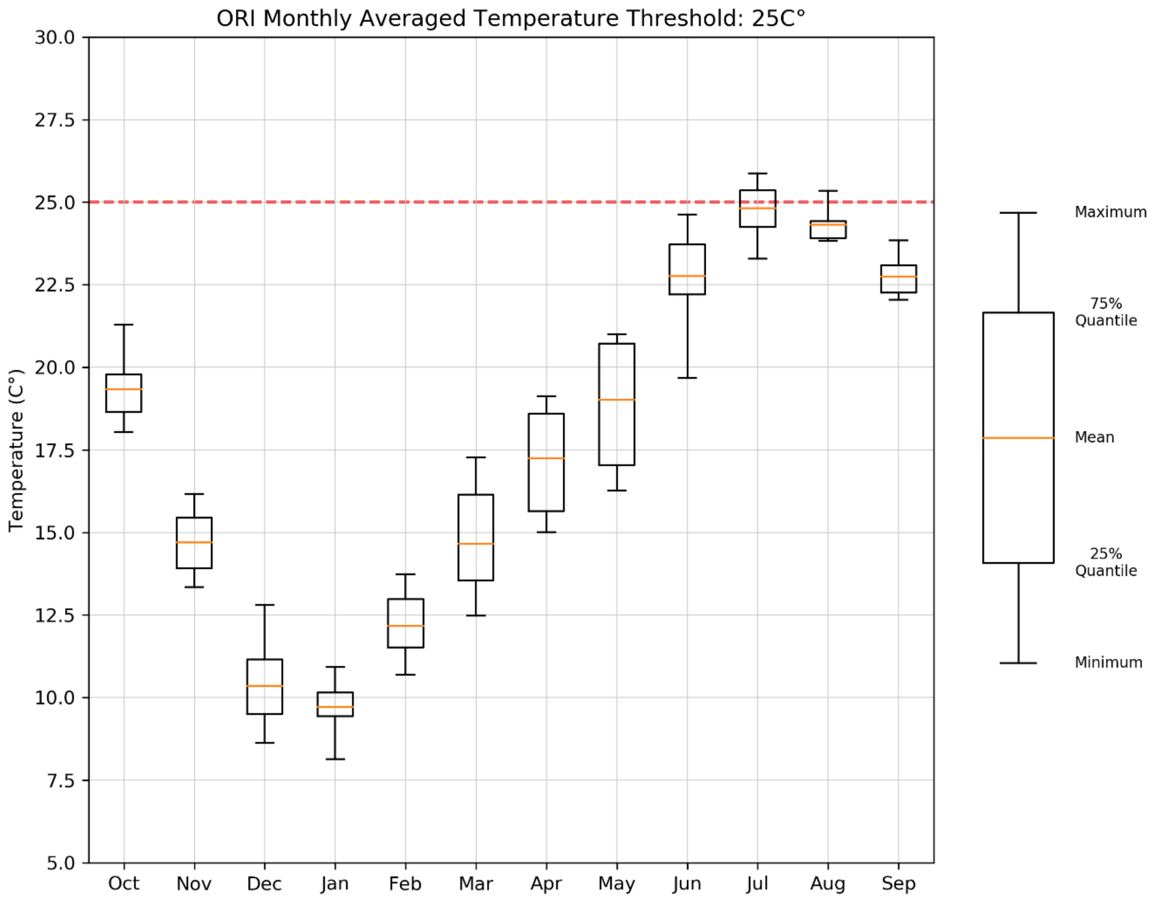

Figure 86. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ORI – Old River at Clifton Court Intake

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

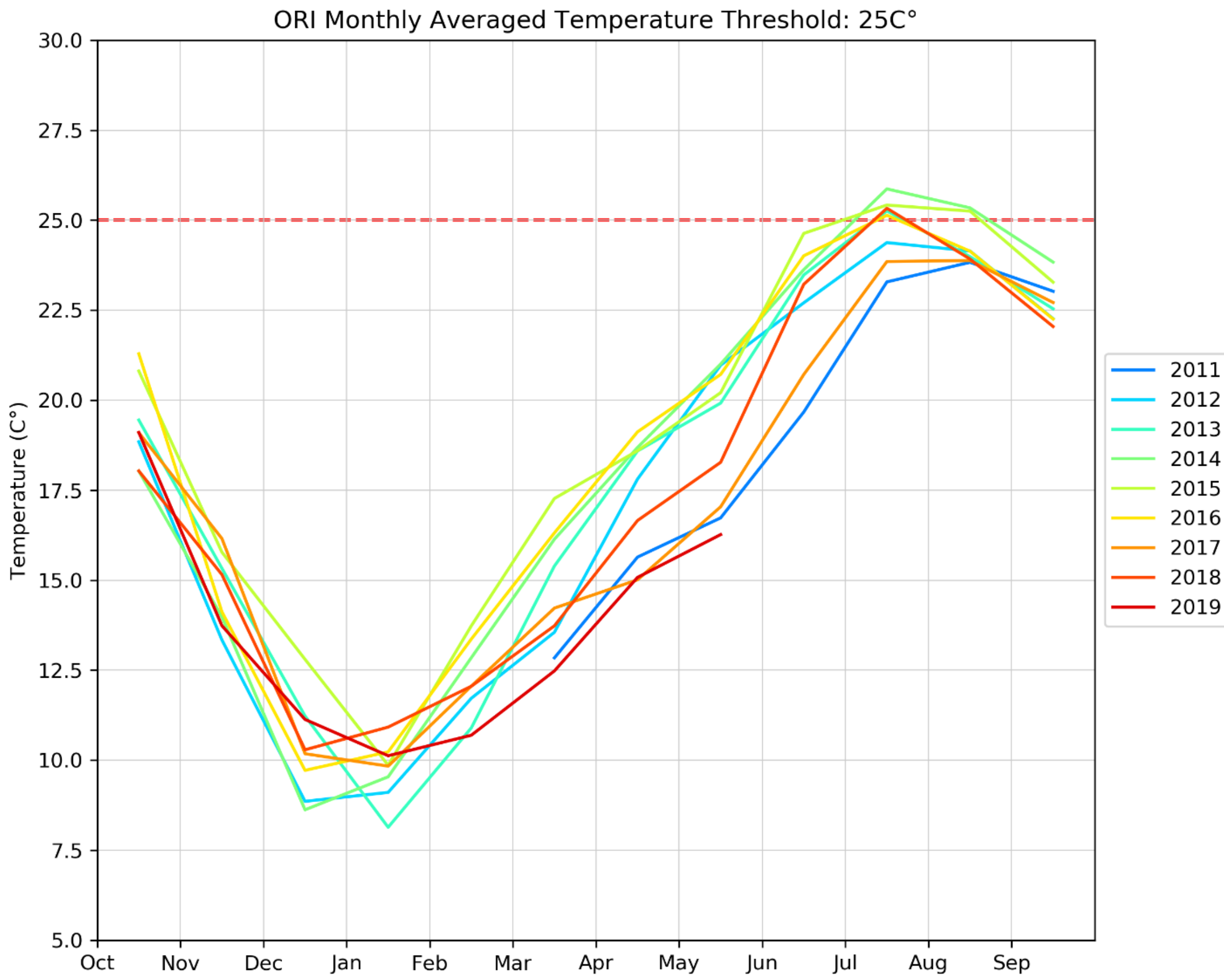

Figure 87. Monthly Average Temperature for the Period of Record at Station ORI – Old River at Clifton Court Intake

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

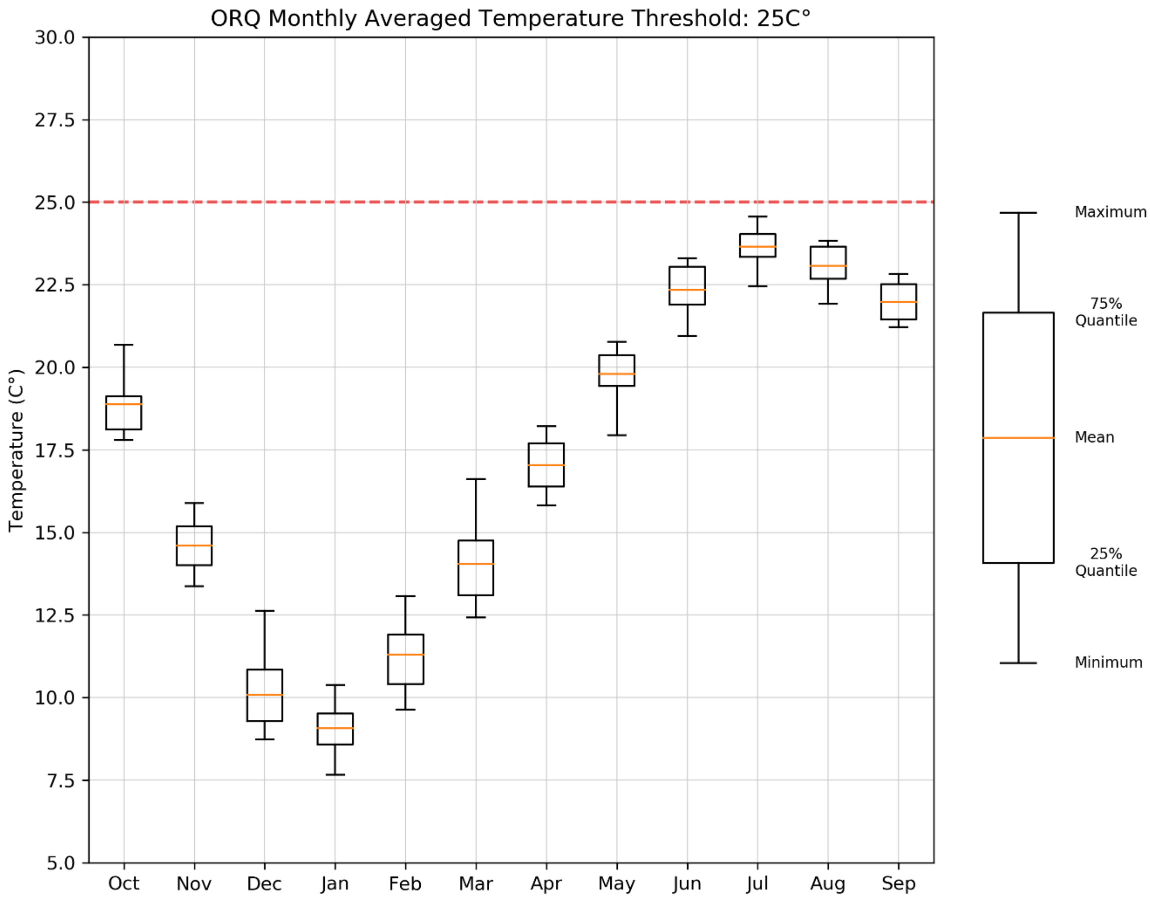

Figure 88. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ORQ – Old River at Quimby Island near Bethel Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

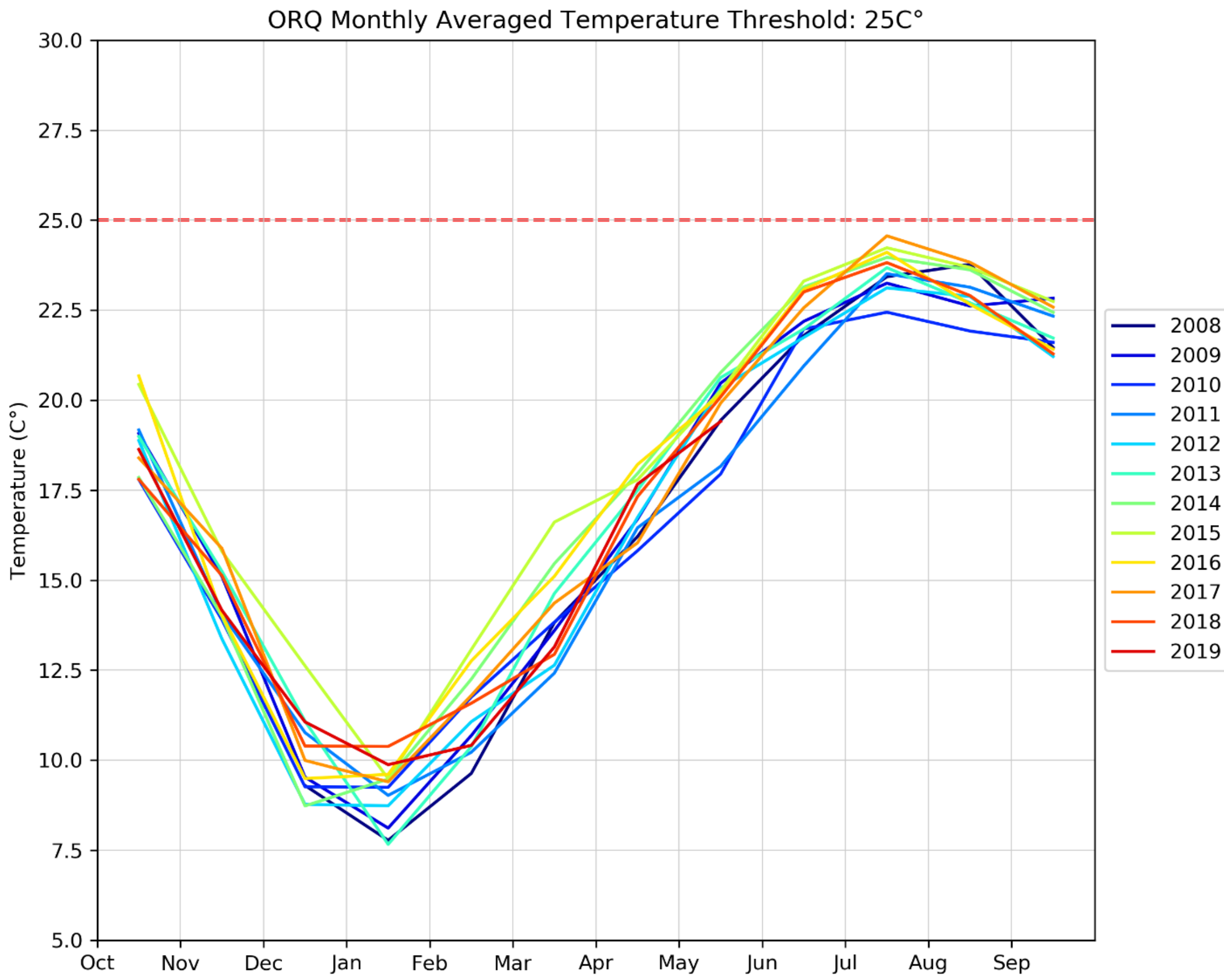

Figure 89. Monthly Average Temperature for the Period of Record at Station ORQ – Old River at Quimby Island near Bethel Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

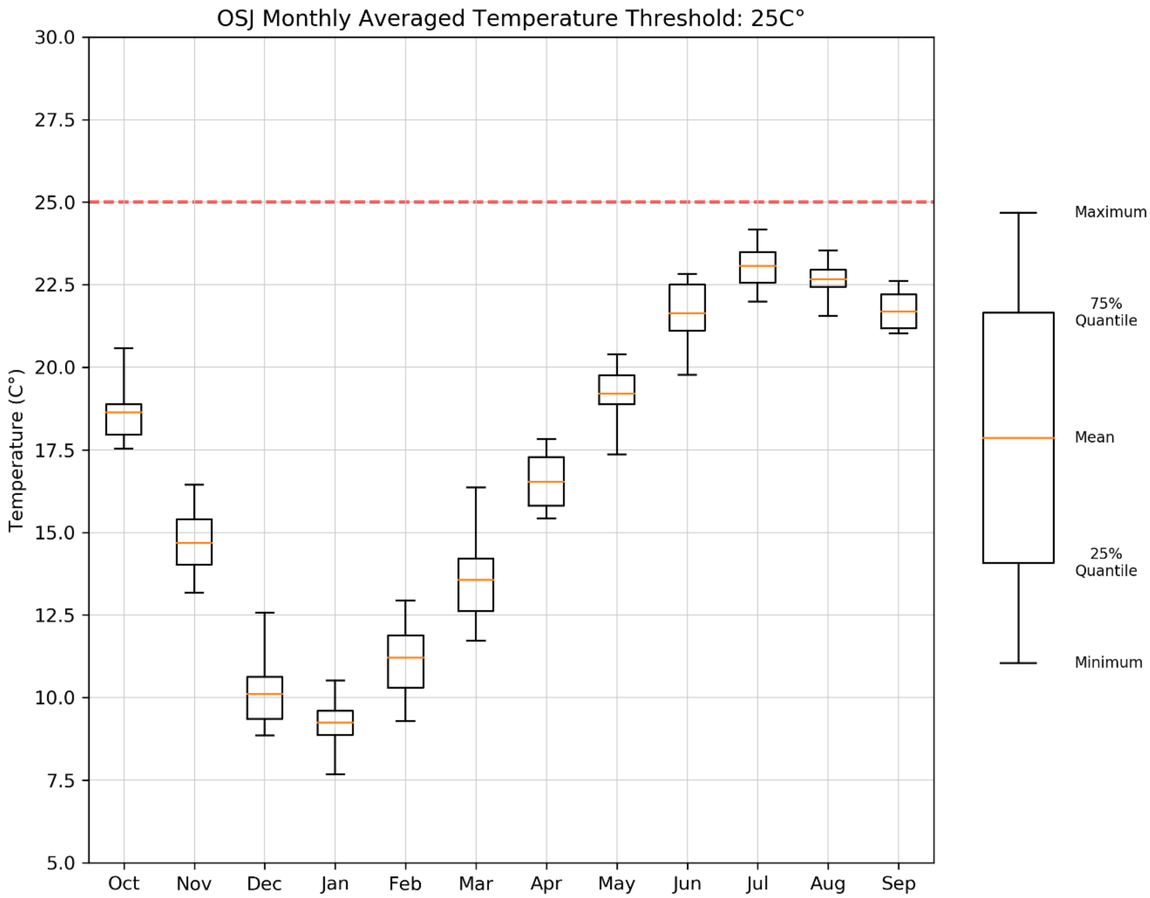

Figure 90. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station OSJ – Old River at Frank's Tract near Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

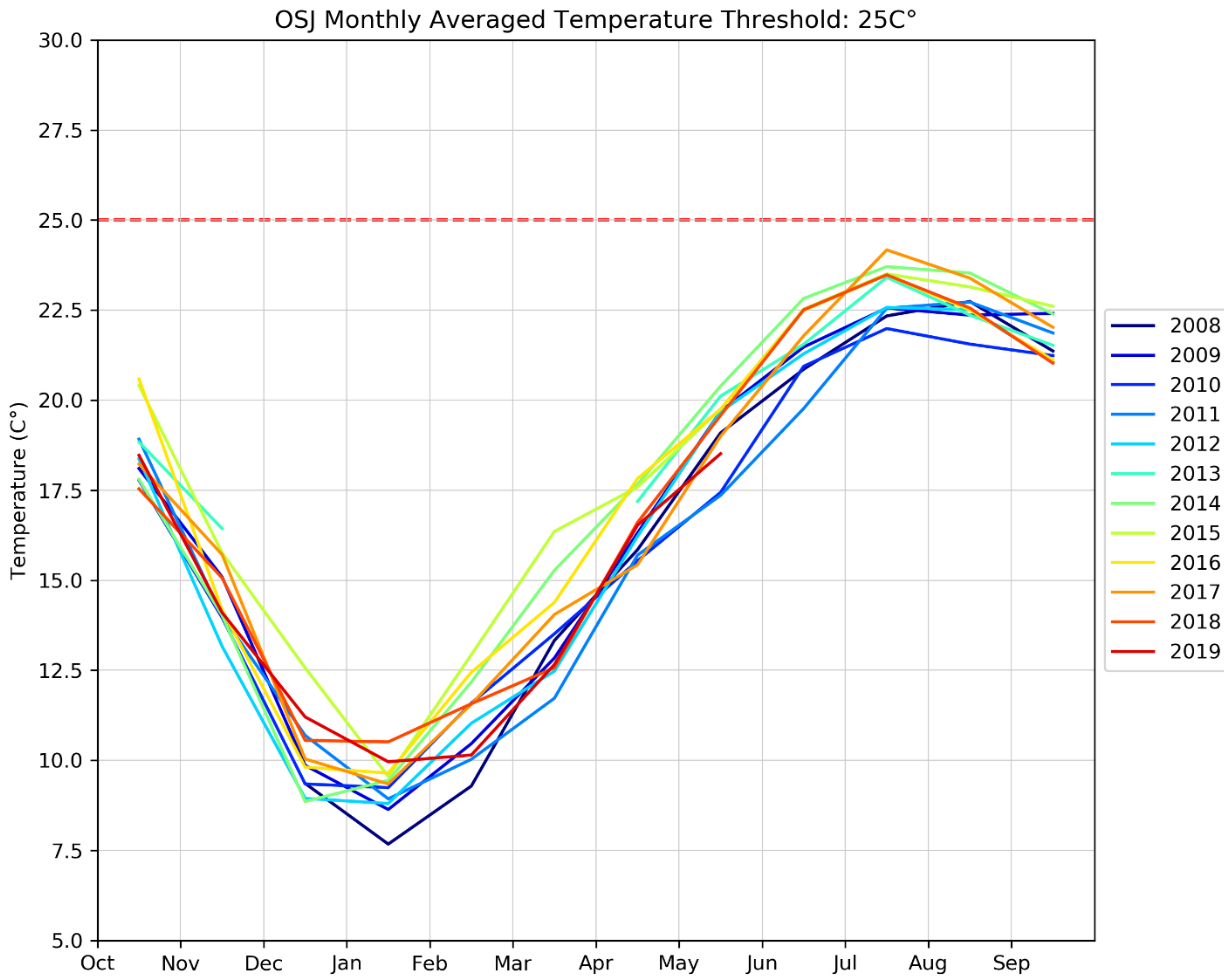

Figure 91. Monthly Average Temperature for the Period of Record at Station OSJ – Old River at Frank's Tract near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

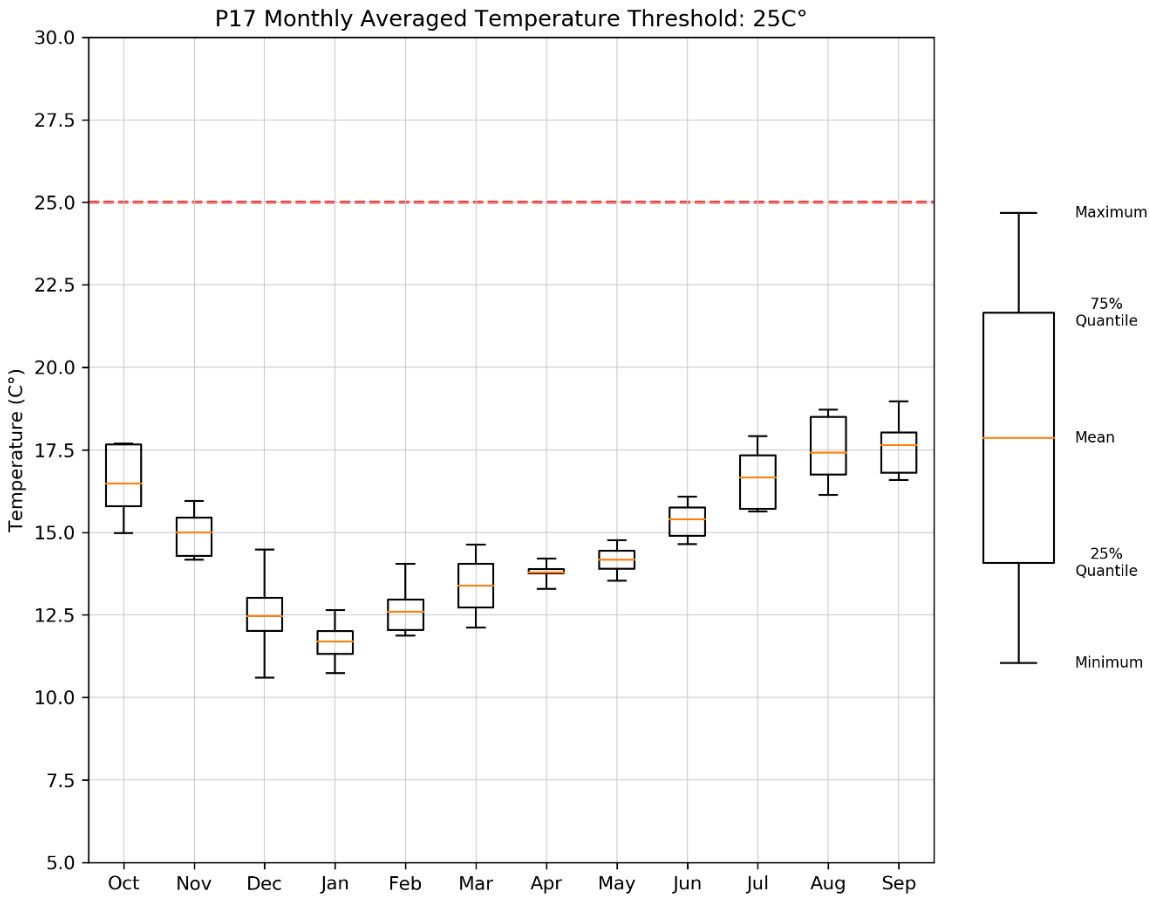

Figure 92. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station P17 – Pier 17

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

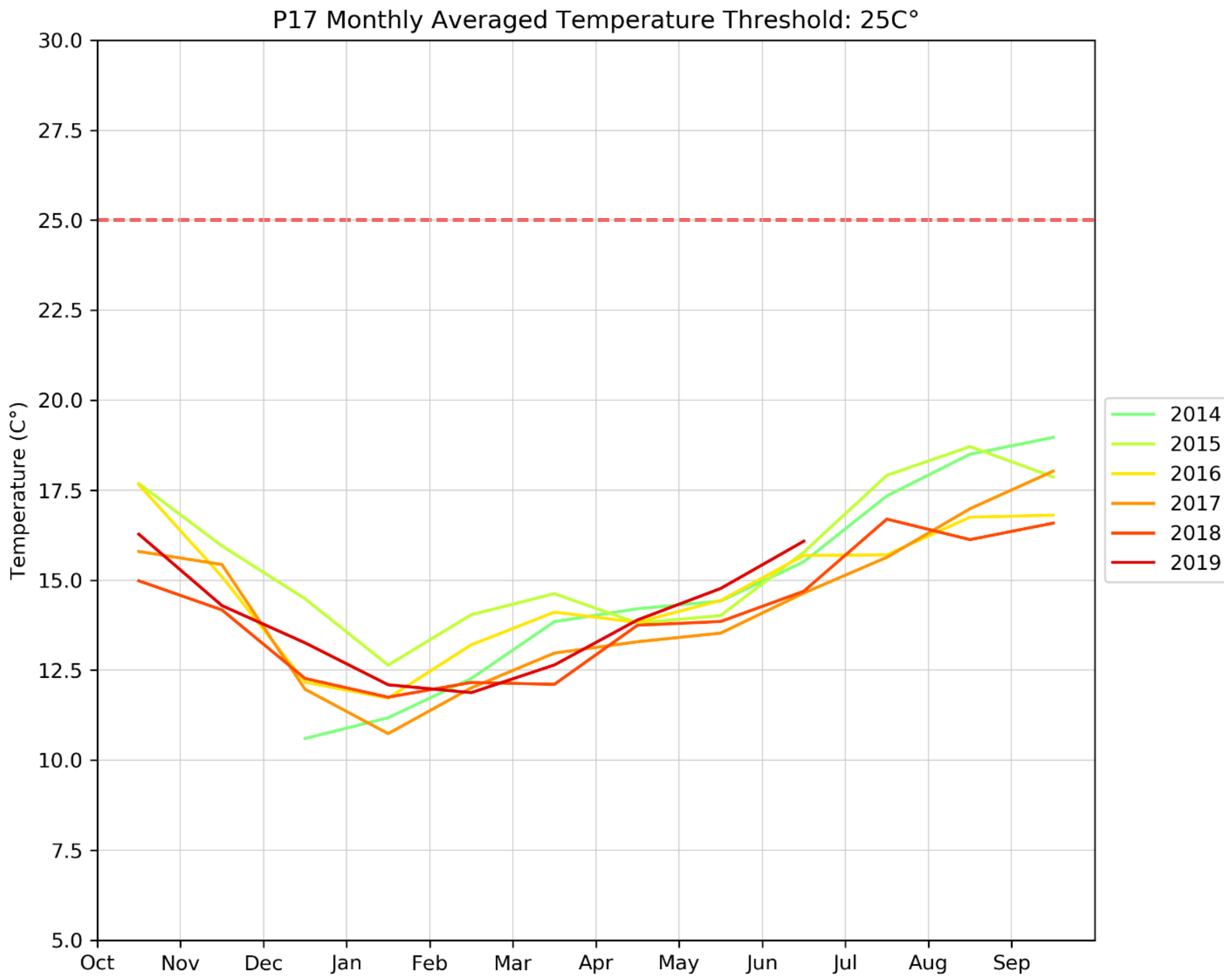

Figure 93. Monthly Average Temperature for the Period of Record at Station P17 – Pier 17

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

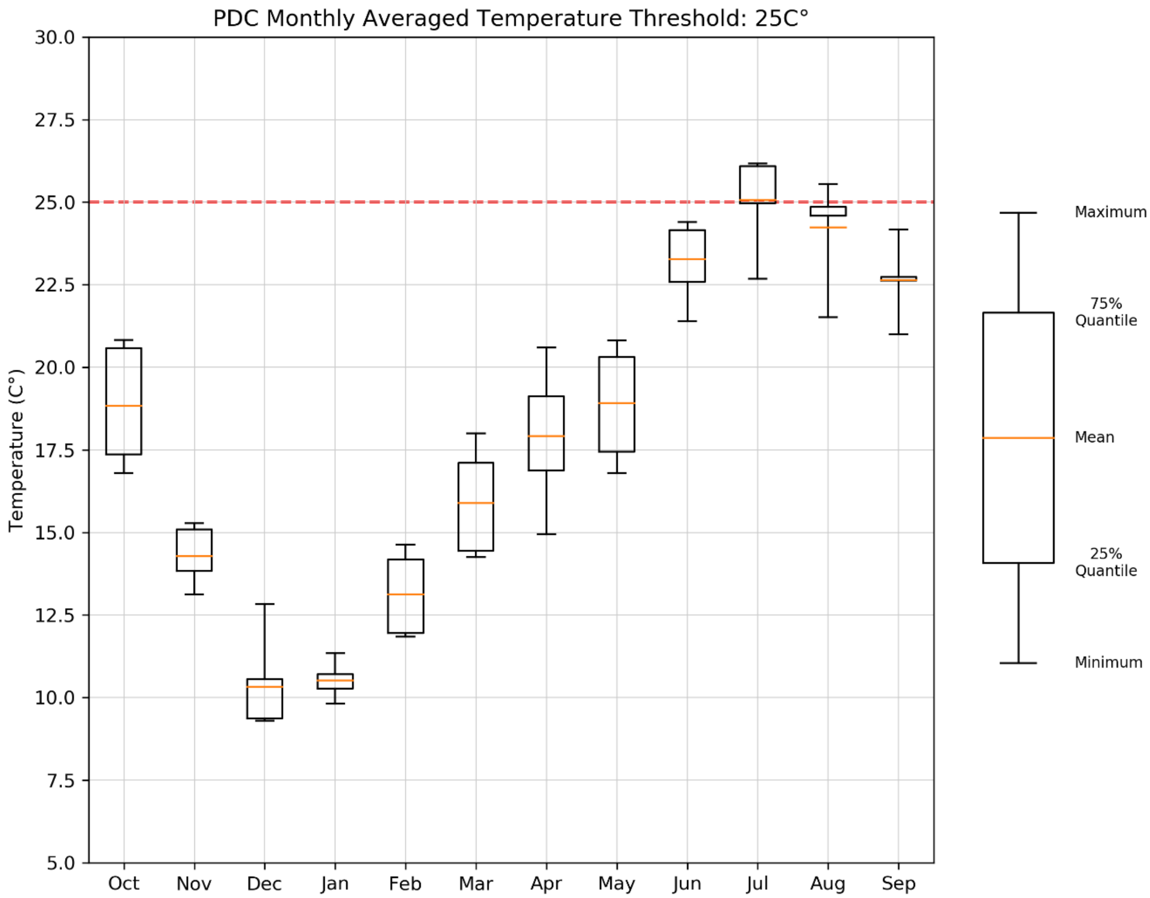

Figure 94. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station PDC – Paradise Cut

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

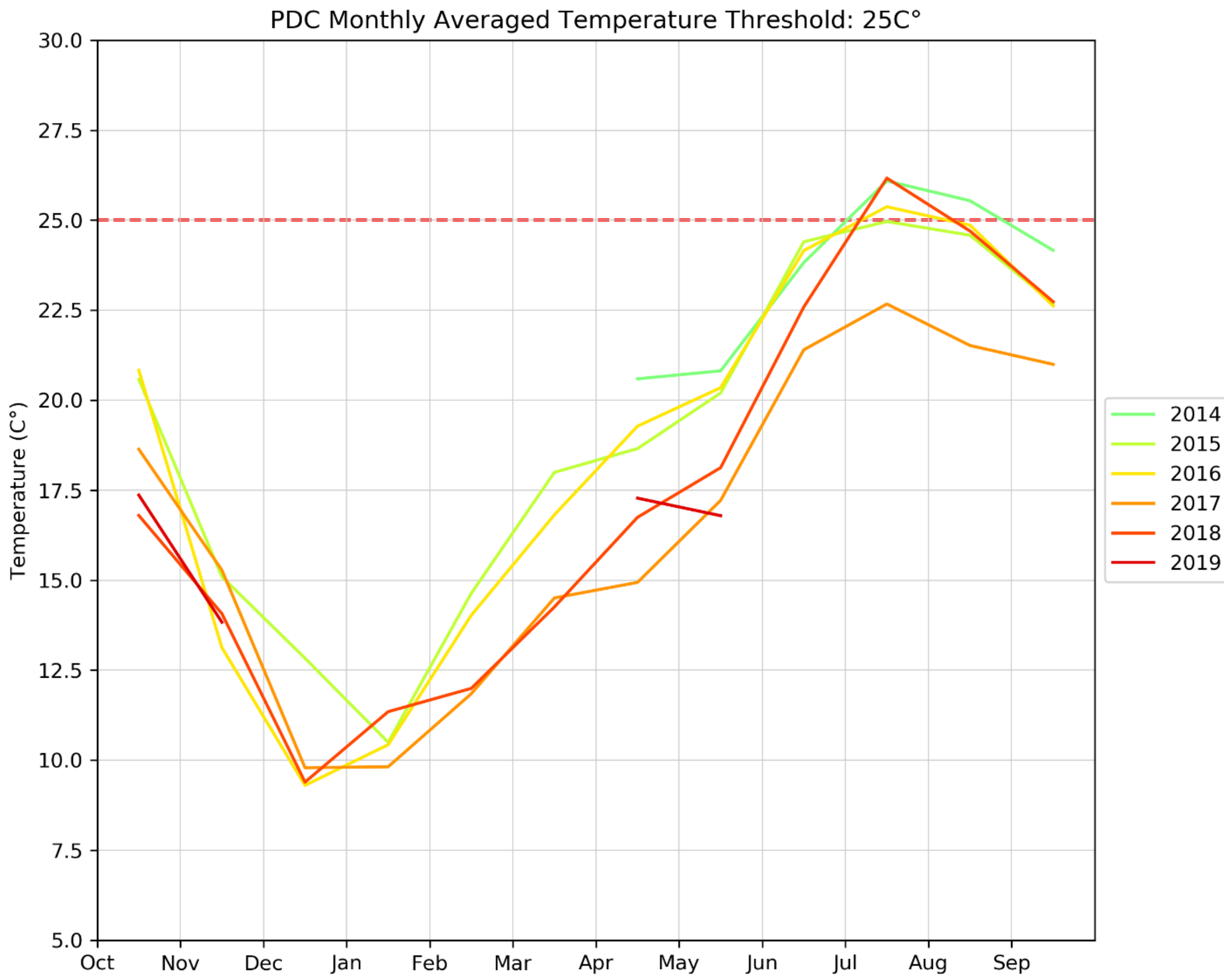

Figure 95. Monthly Average Temperature for the Period Of Record at Station PDC – Paradise Cut

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

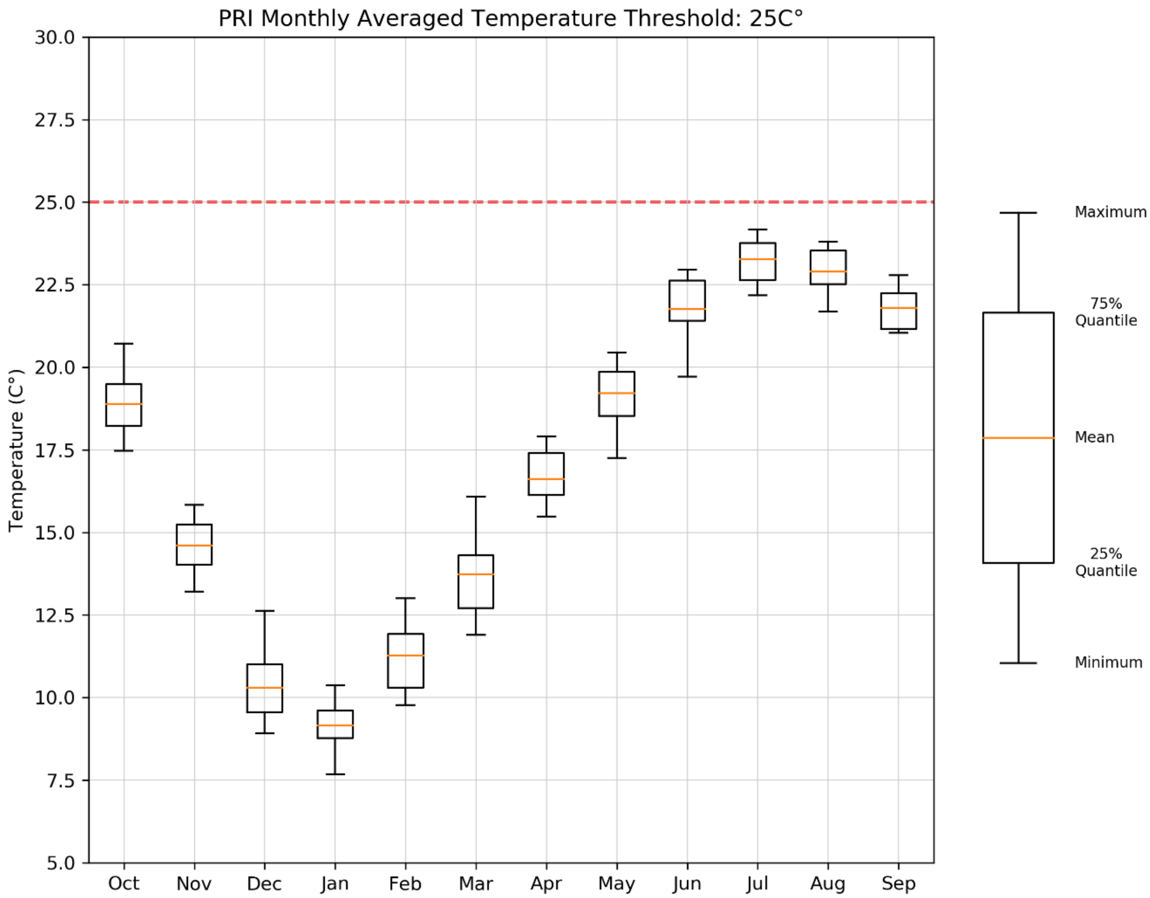

Figure 96. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station PRI – San Joaquin River at Prisoners Point near Terminus

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

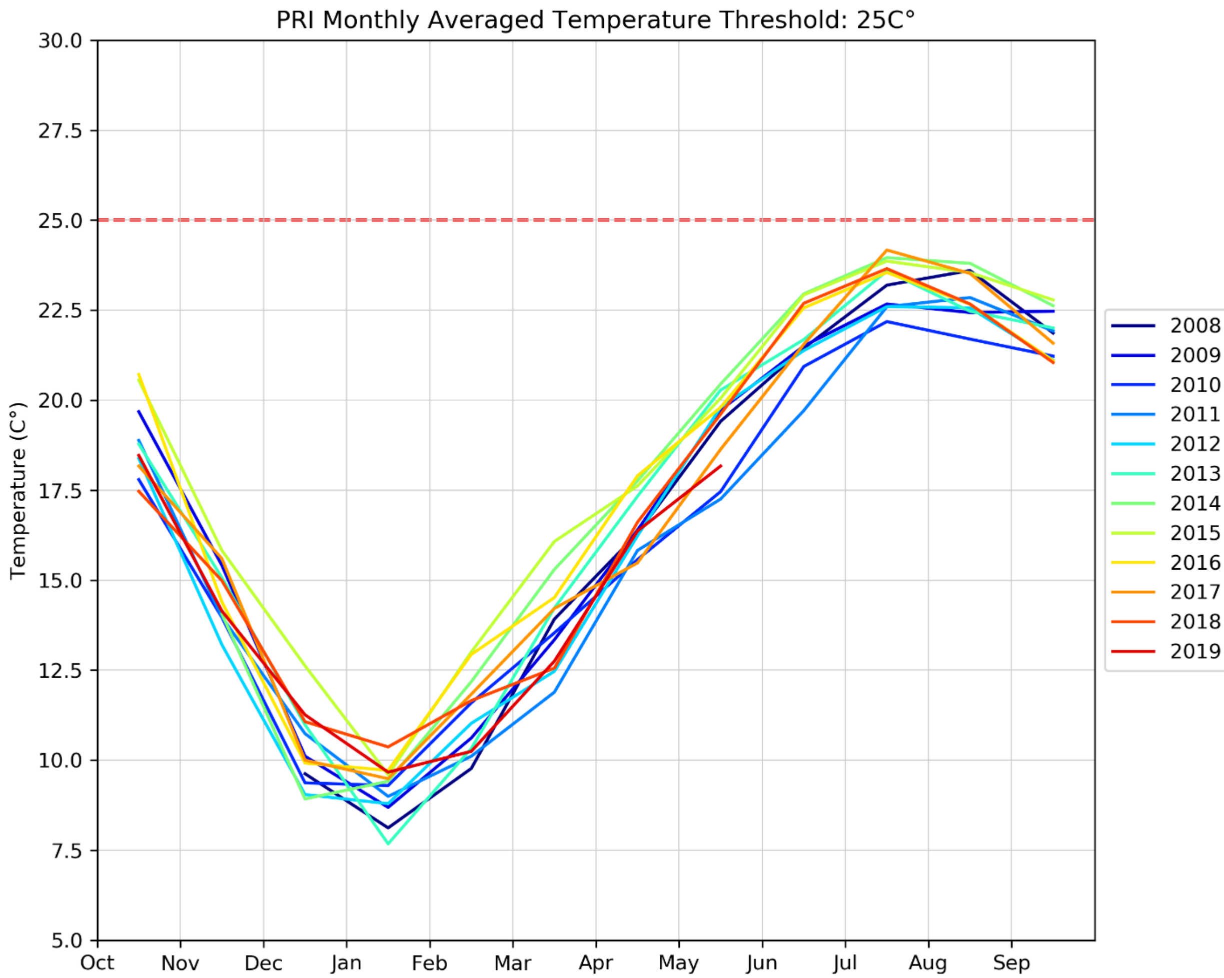

Figure 97. Monthly Average Temperature for the Period of Record at Station PRI – San Joaquin River at Prisoners Point Near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

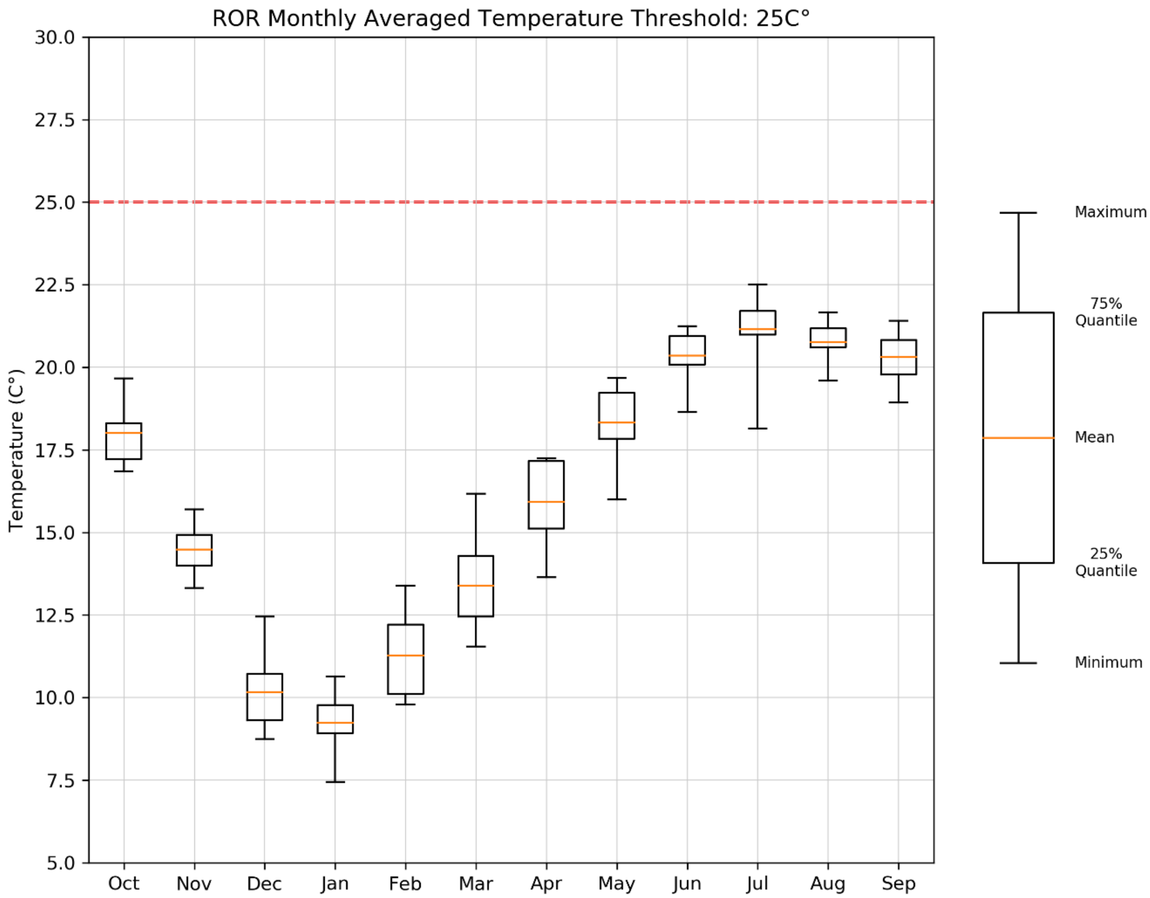

Figure 98. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station ROR – Roaring River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

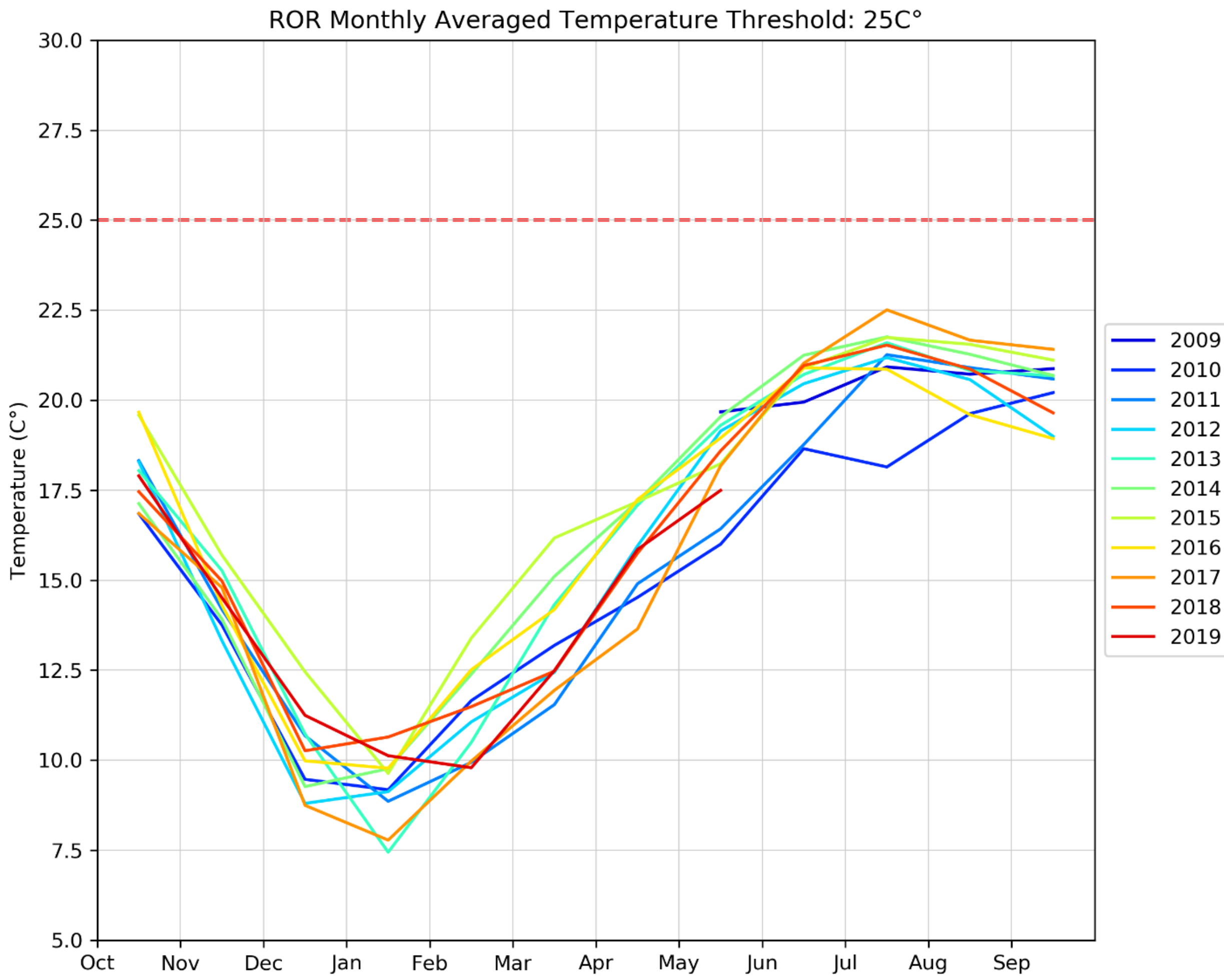

Figure 99. Monthly Average Temperature for the Period of Record at Station ROR – Roaring River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

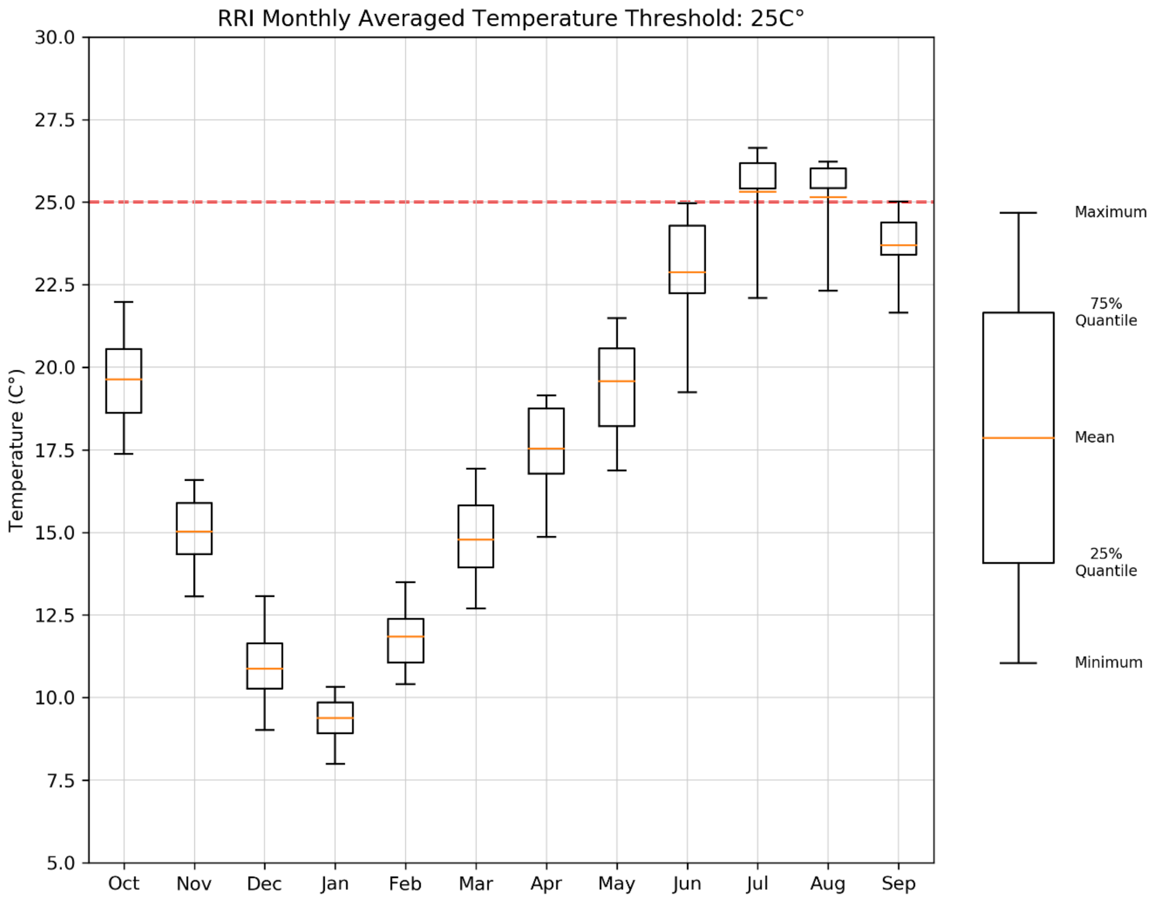

Figure 100. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RRI – Rough and Ready Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

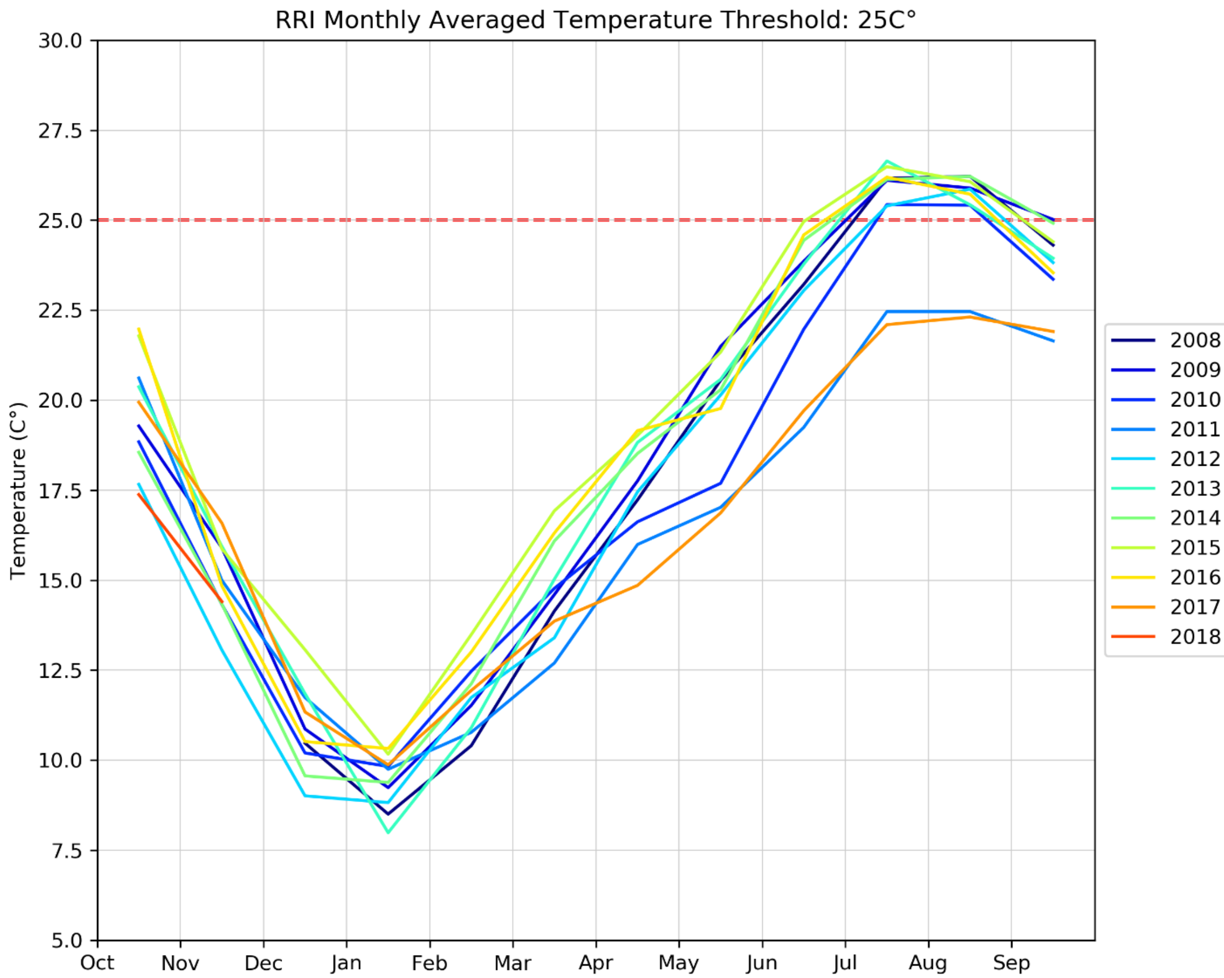

Figure 101. Monthly Average Temperature for the Period of Record at Station RRI – Rough and Ready Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

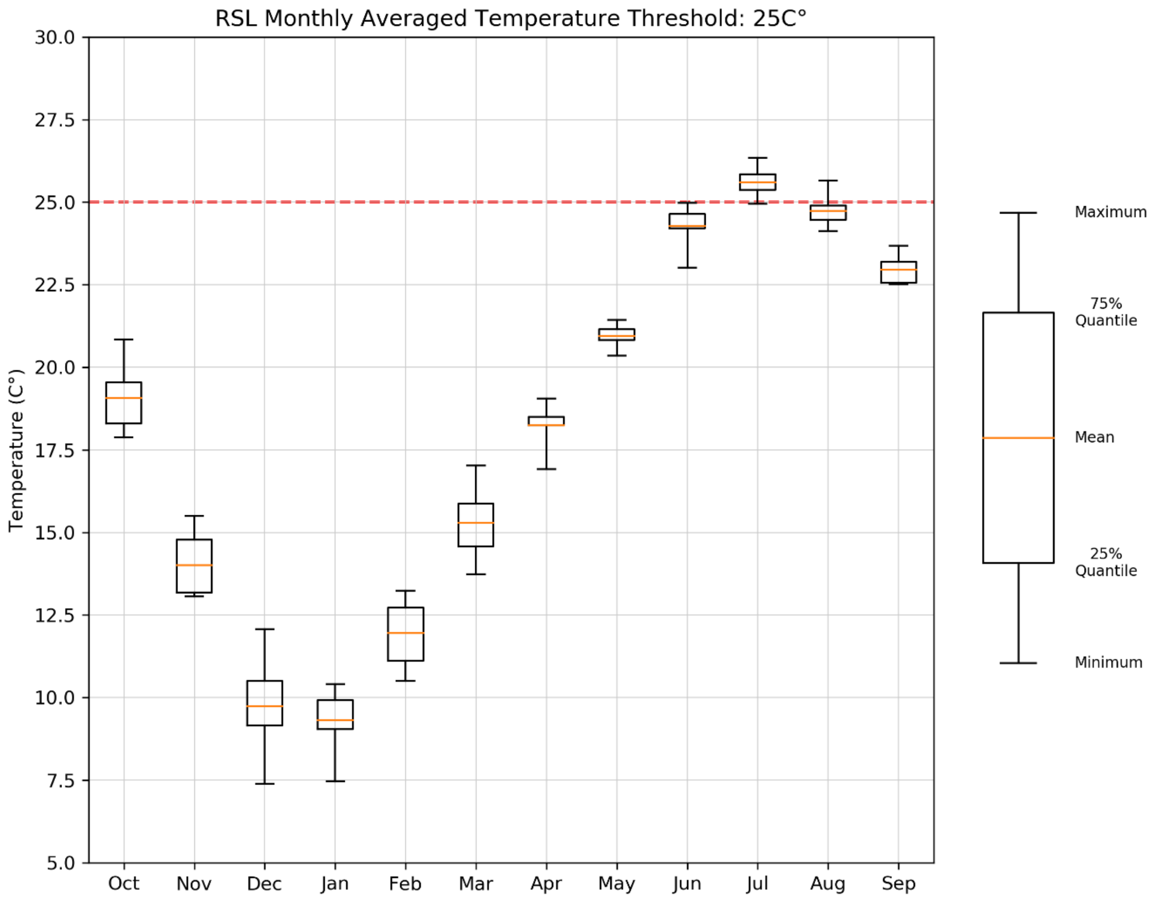

Figure 102. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RSL – Rock Slough Above Contra Costa Canal

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

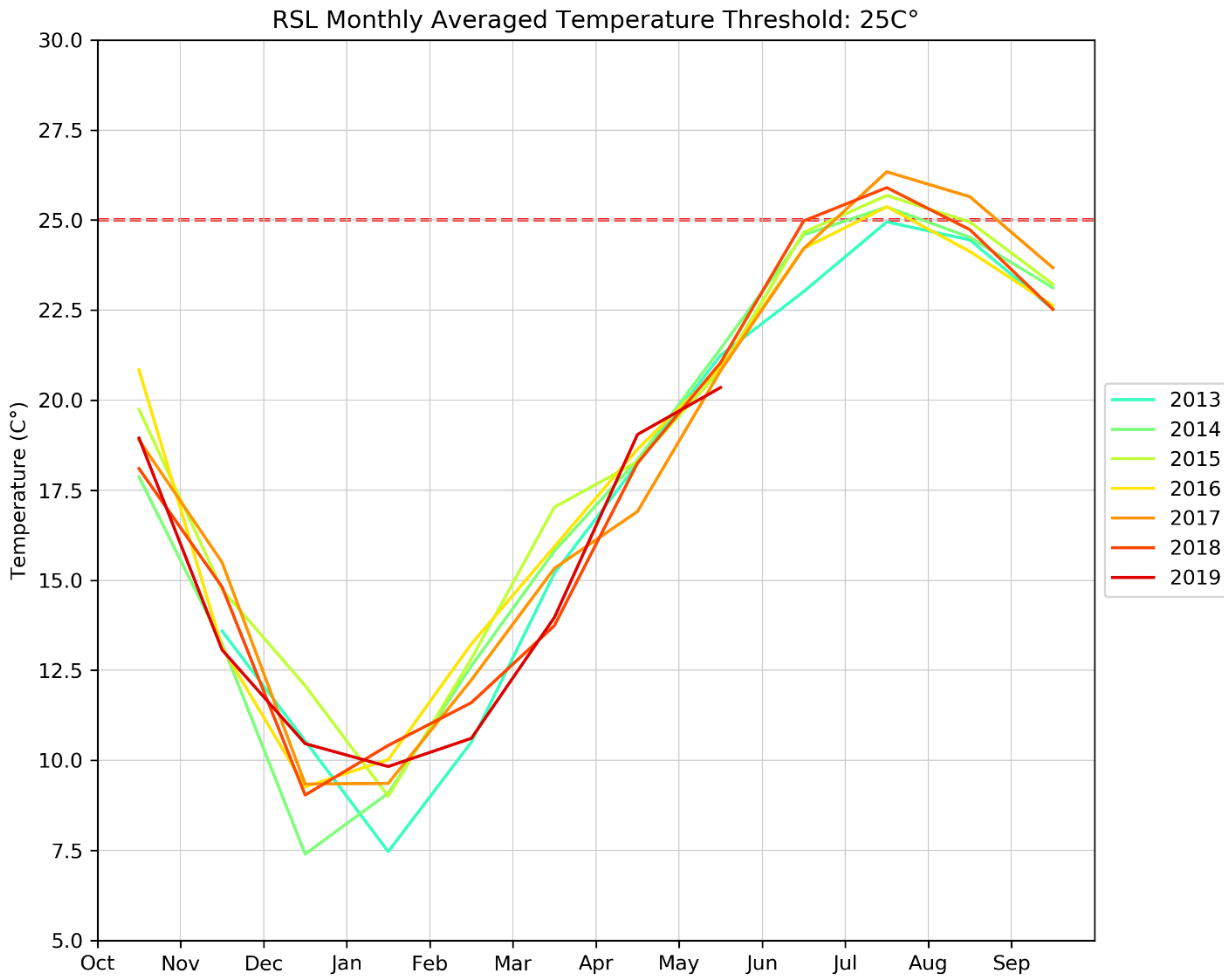

Figure 103. Monthly Average Temperature for the Period of Record at Station RSL - Rock Slough above Contra Costa Canal

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

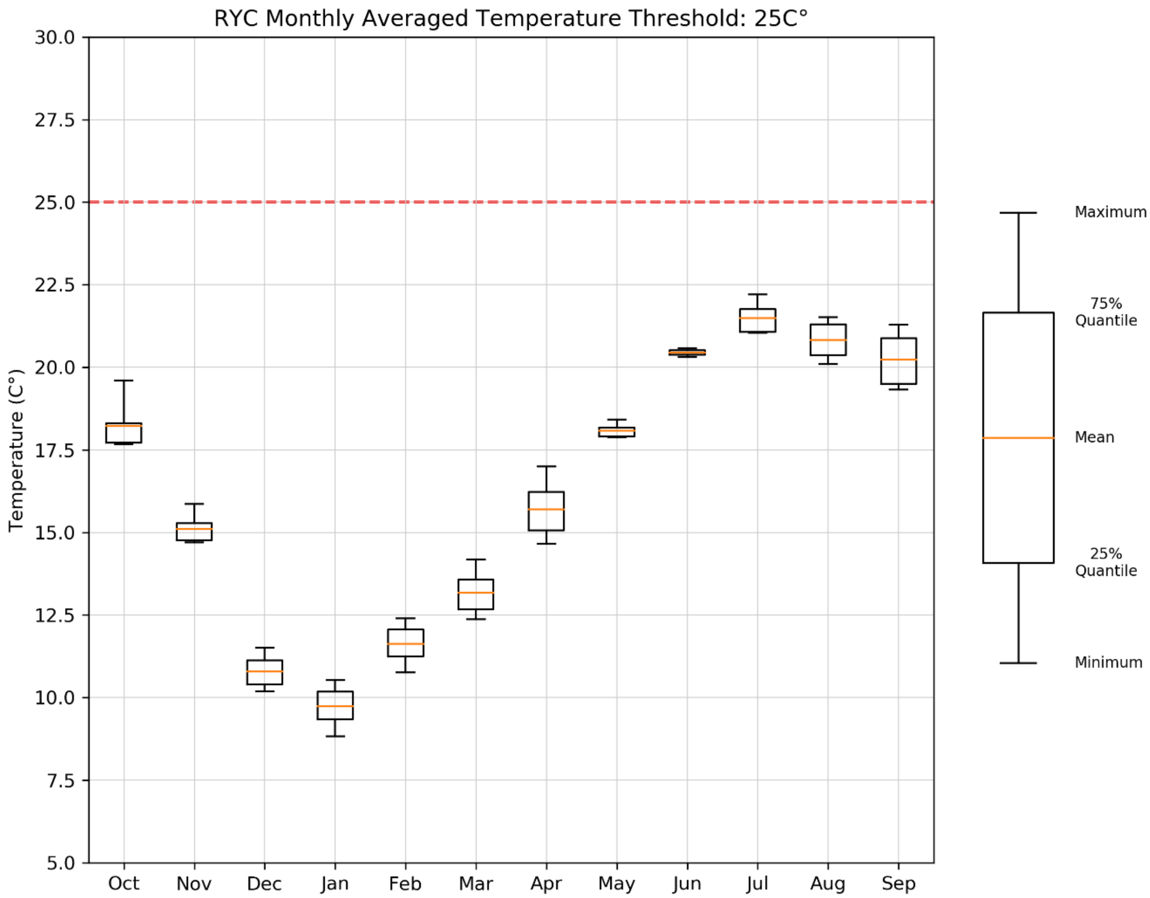

Figure 104. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RYC - Suisun Bay Cutoff near Ryer

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

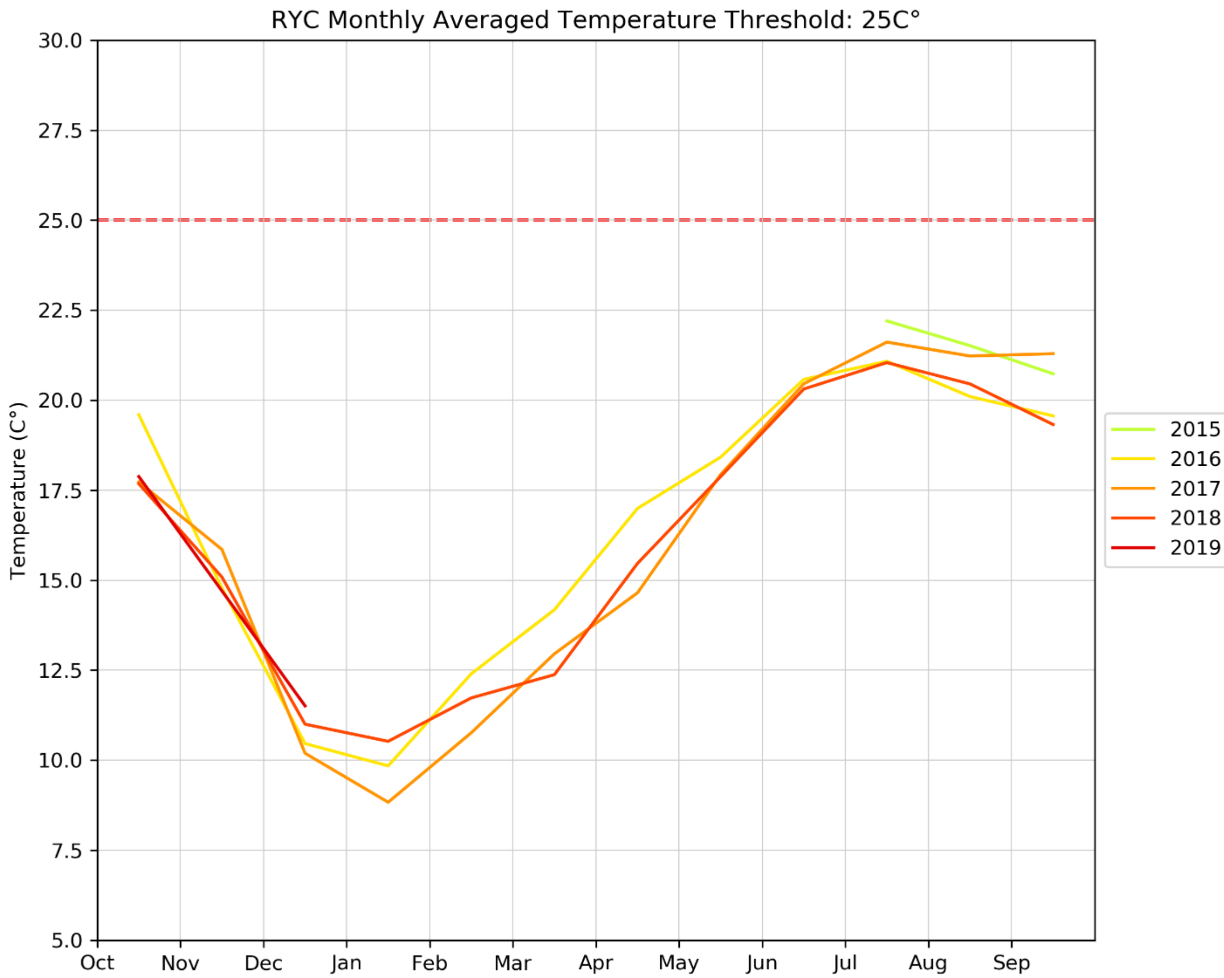

Figure 105. Monthly Average Temperature for the Period of Record at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

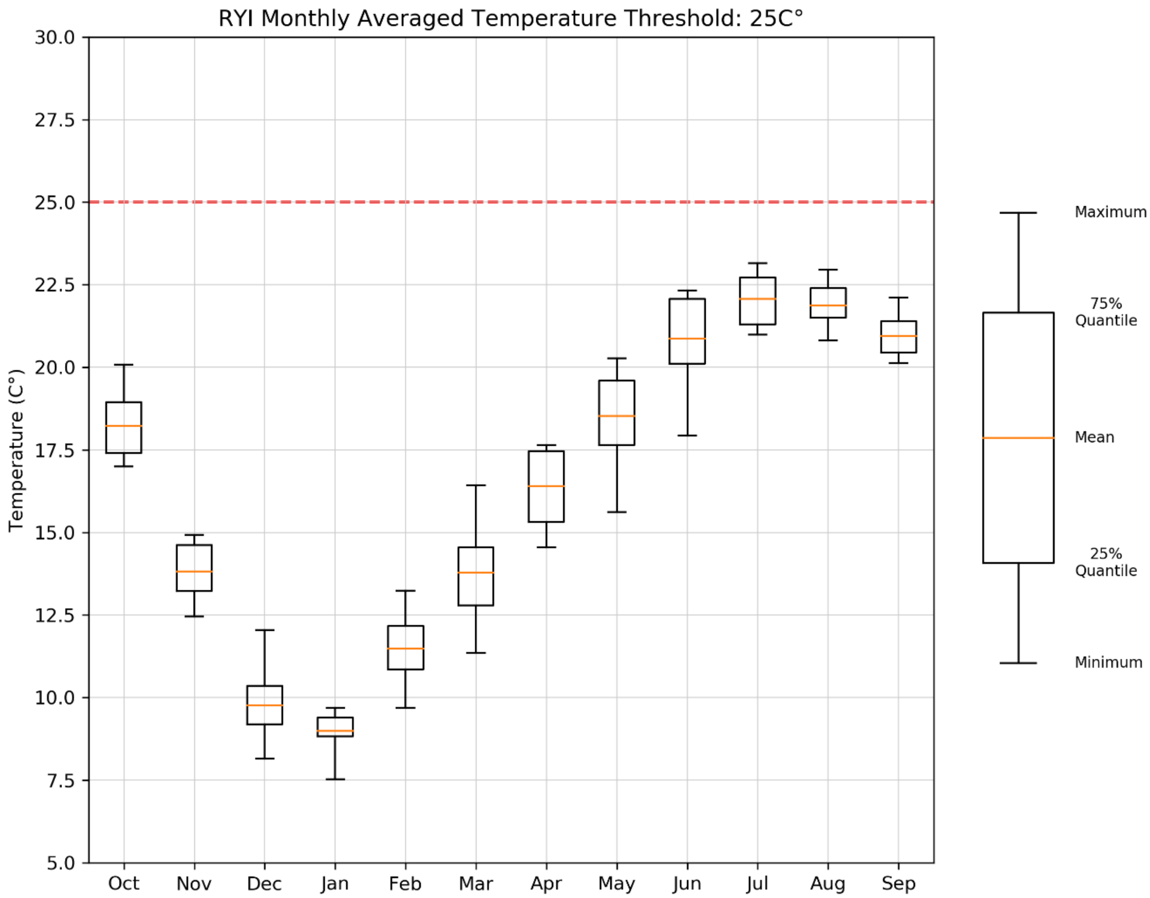

Figure 106. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station RYI – Cache Slough at Ryer Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

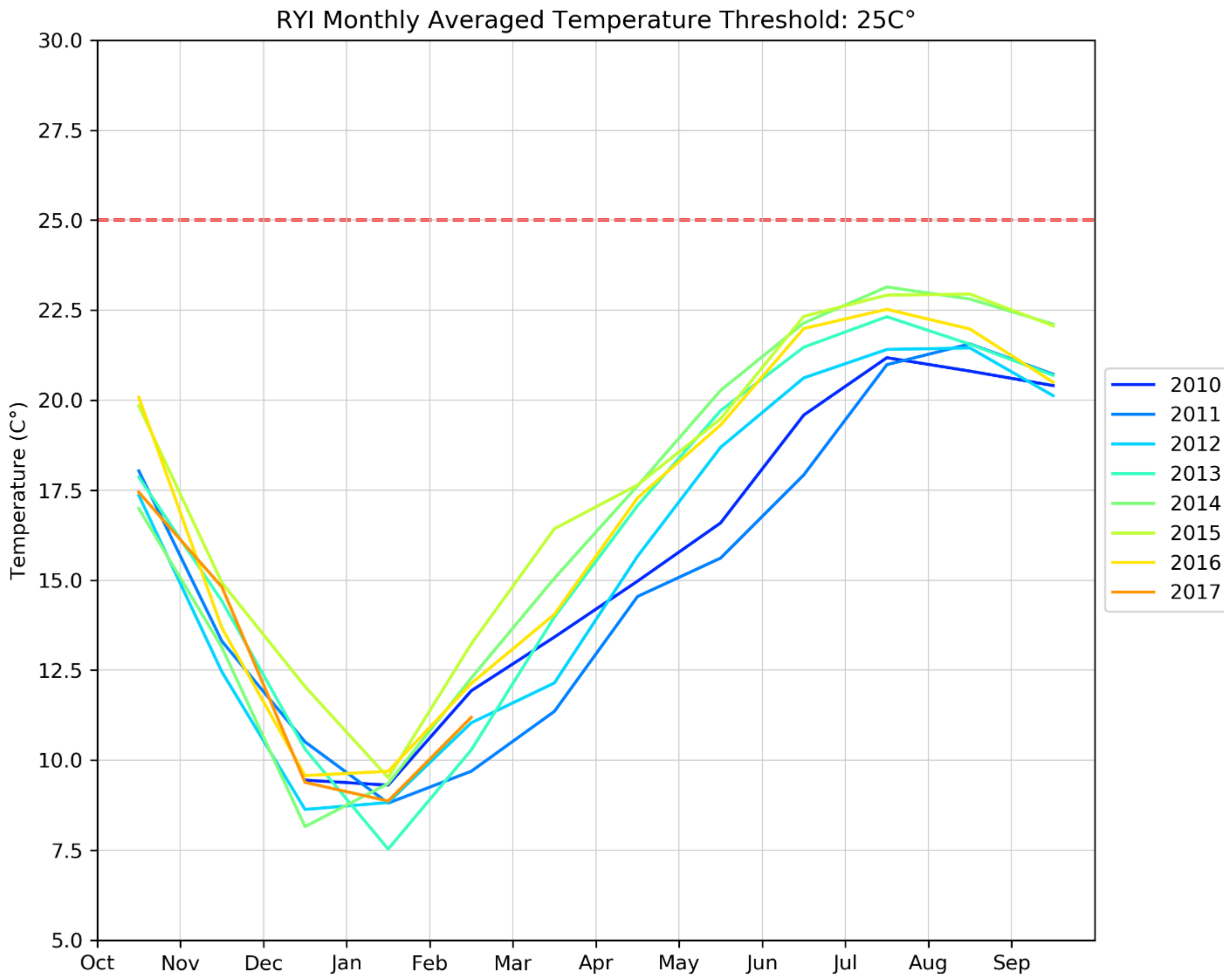

Figure 107. Monthly Average Temperature for the Period of Record at Station RYI – Cache Slough at Ryer Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

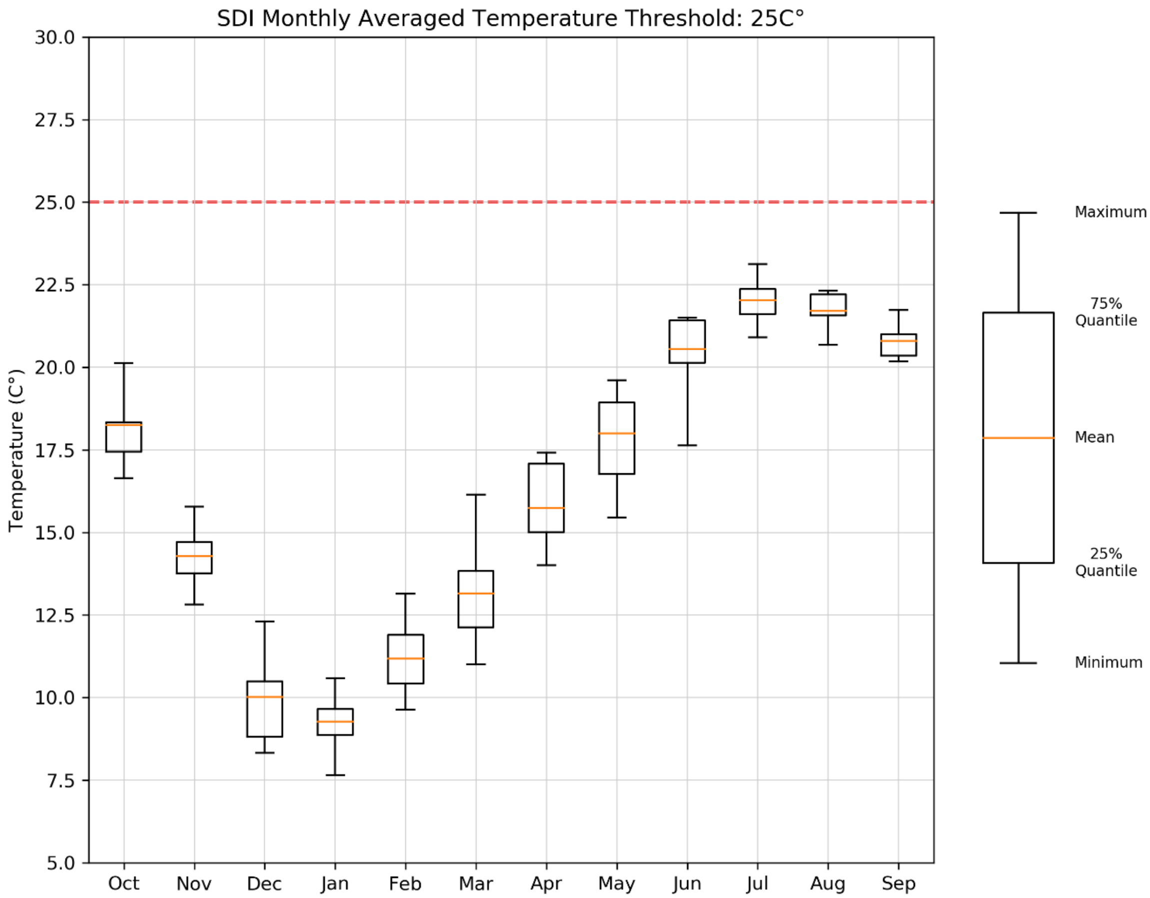

Figure 108. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SDI – Sacramento River at Decker Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

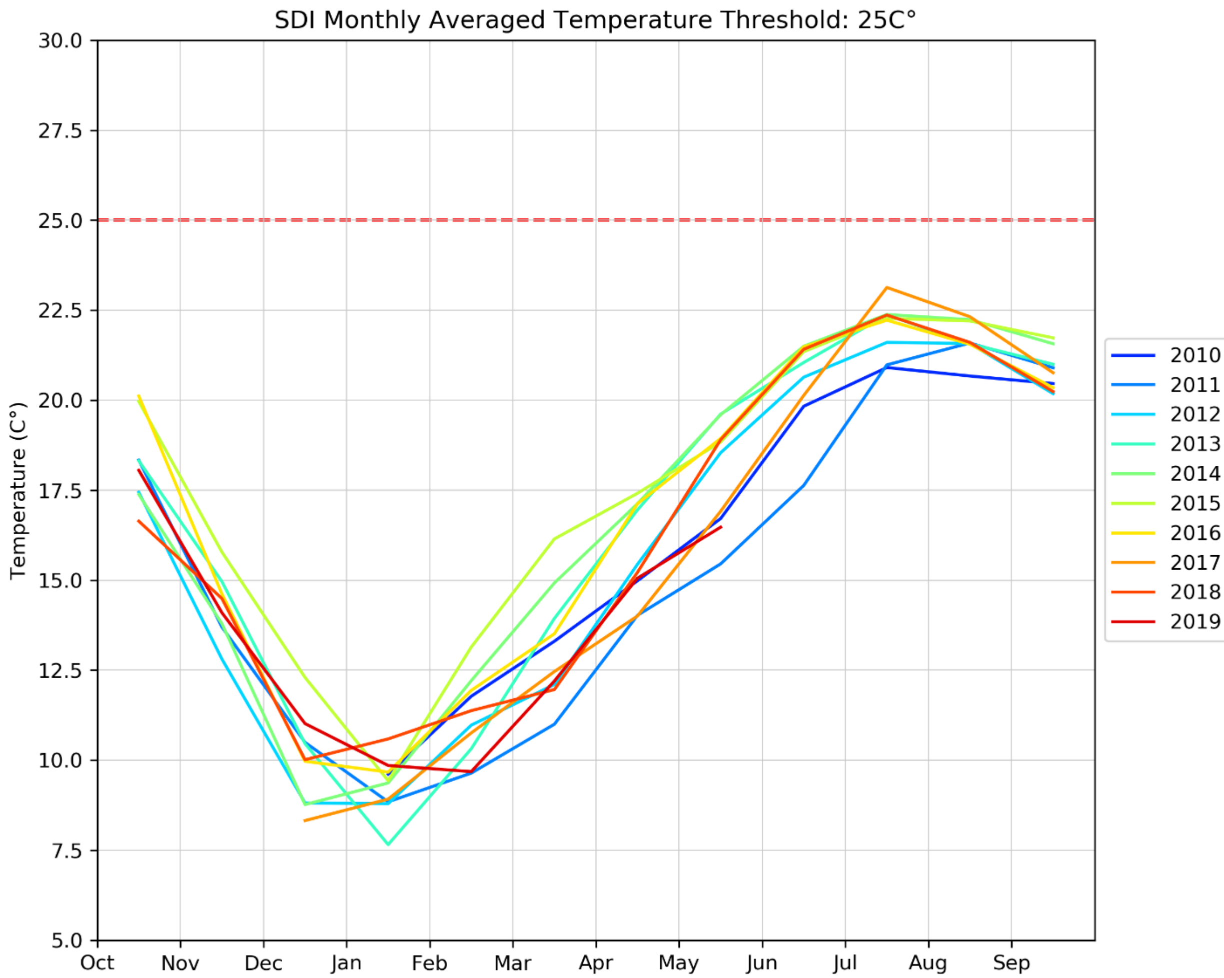

Figure 109. Monthly Average Temperature for the Period of Record at Station SDI – Sacramento River at Decker Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

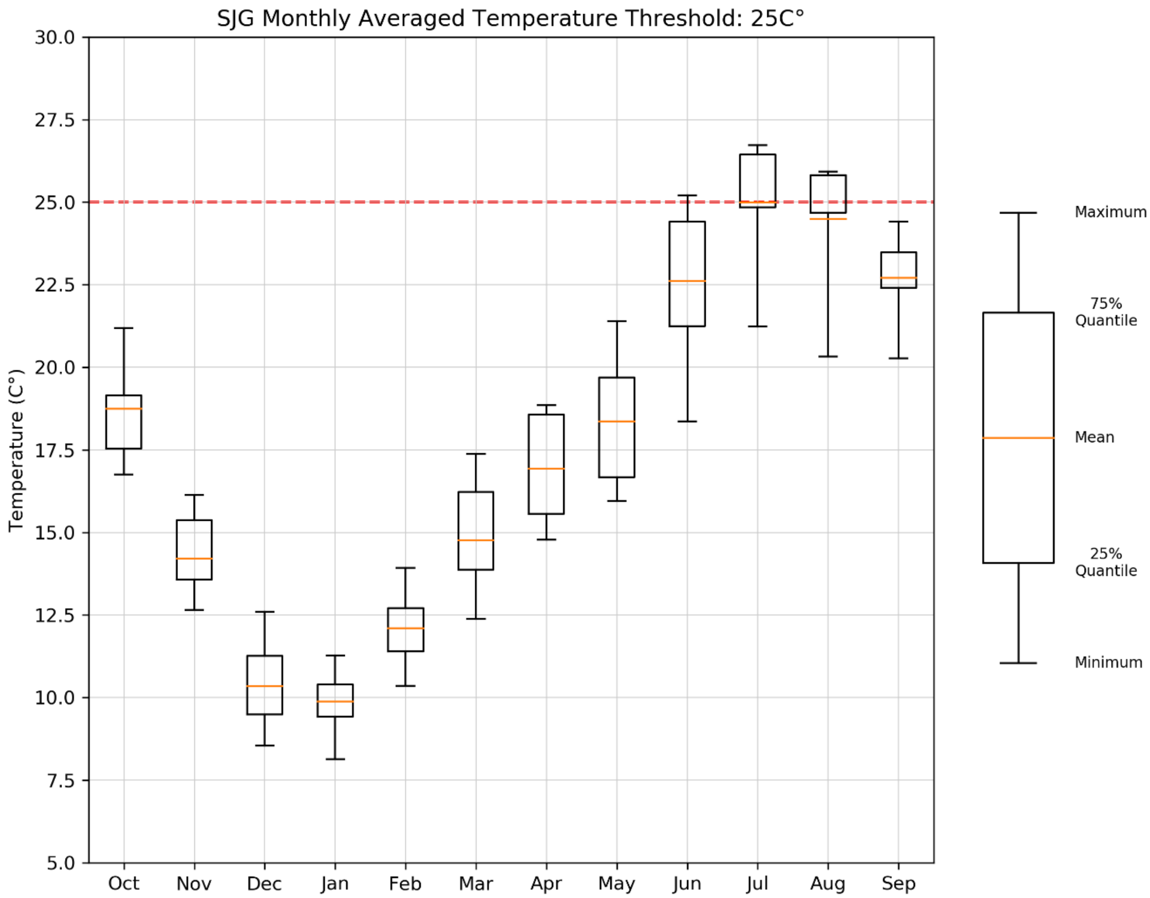

Figure 110. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SJG – San Joaquin River at Garwood Bridge

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

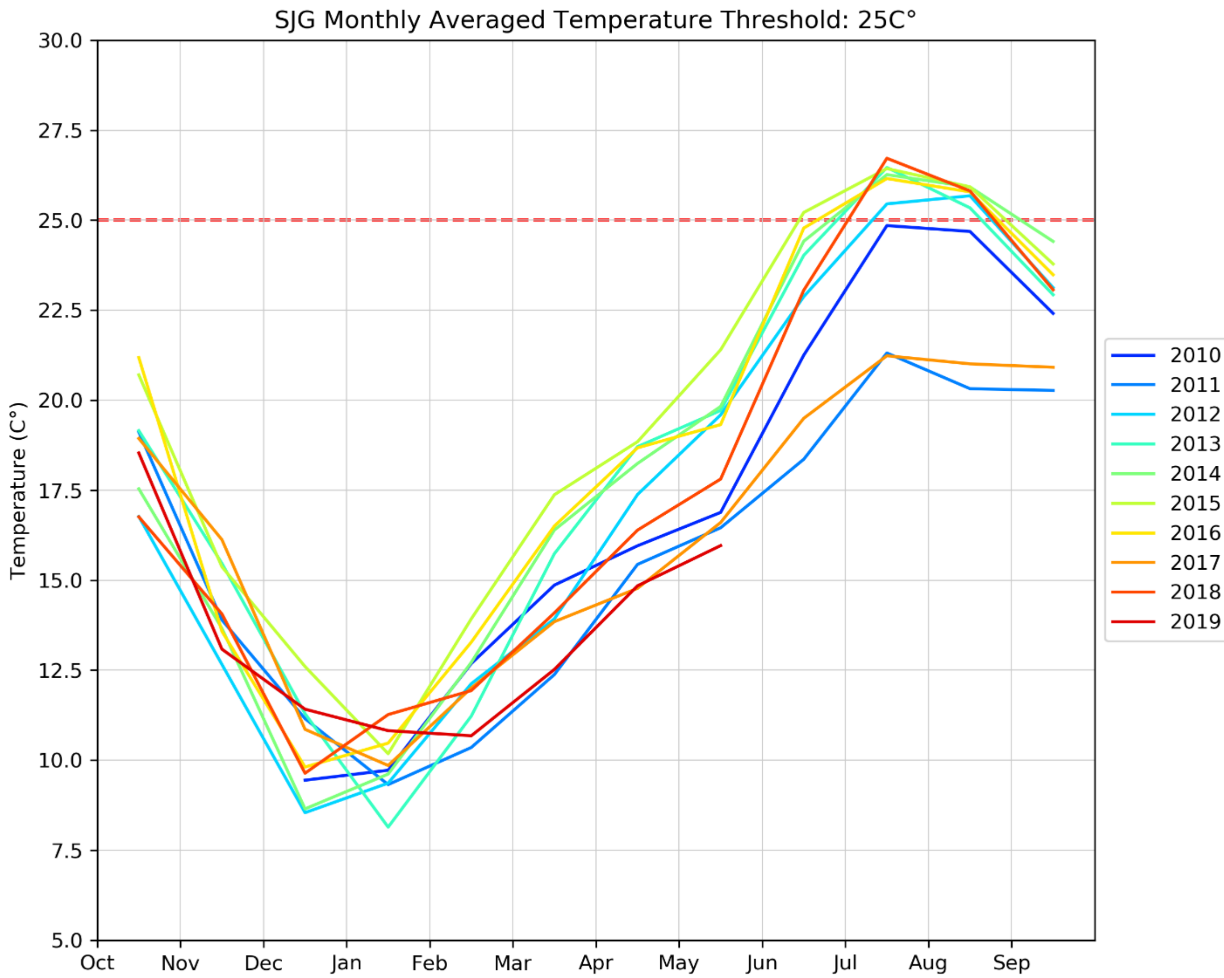

Figure 111. Monthly Average Temperature for the Period of Record at Station SJG – San Joaquin River at Garwood Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

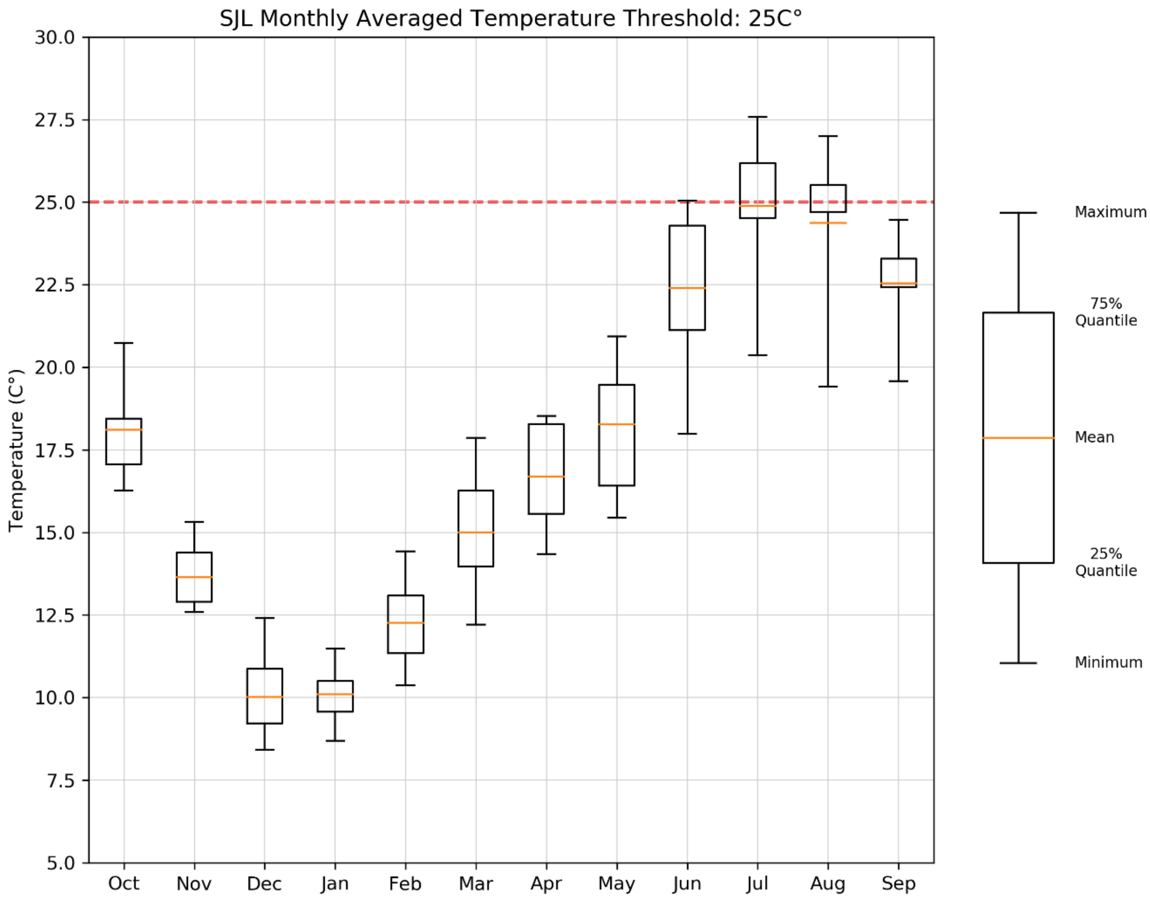

Figure 112. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SJL – San Joaquin River below Old River near Lathrop

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

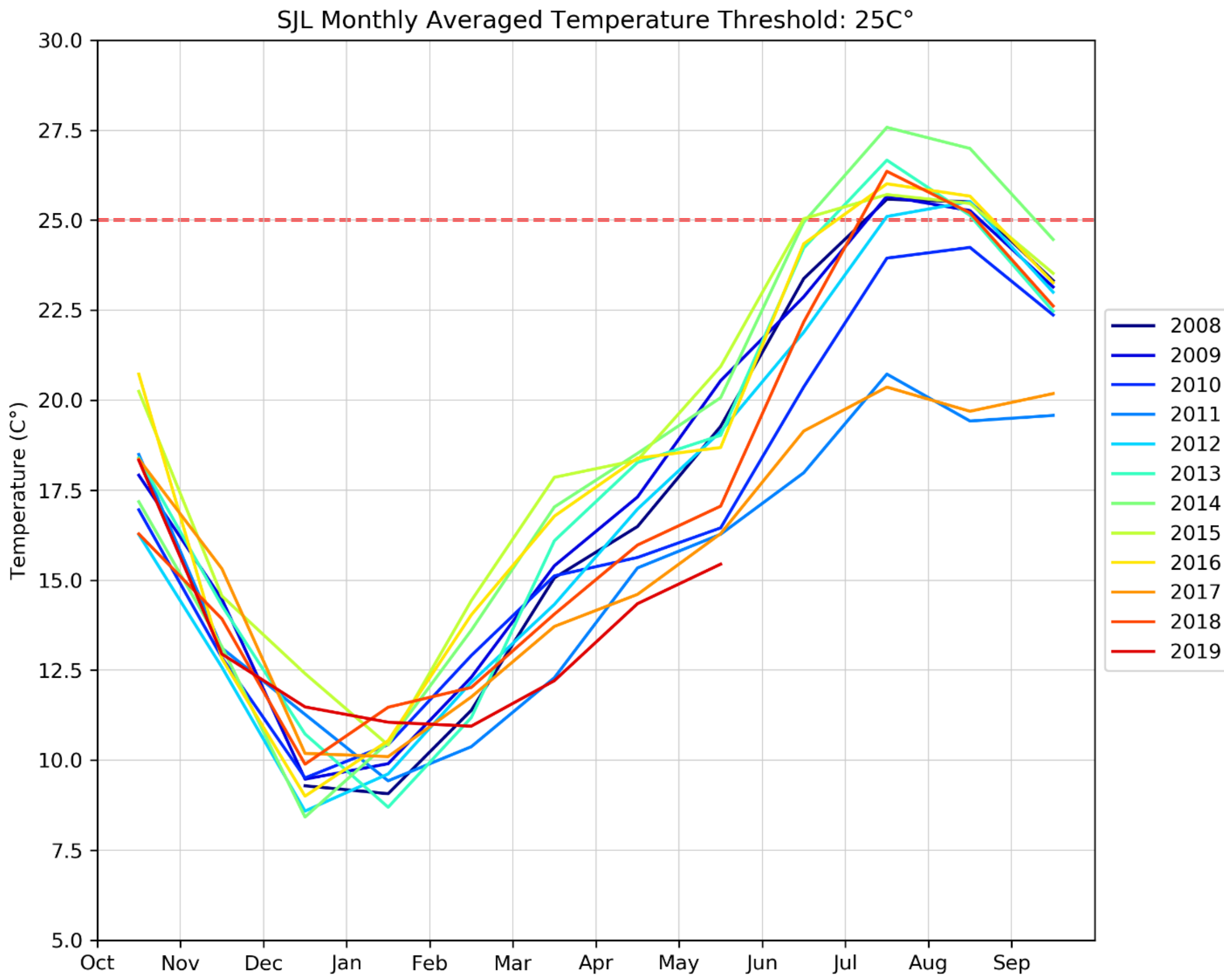

Figure 113. Monthly Average Temperature for the Period of Record at Station SJL – San Joaquin River below Old River near Lathrop

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

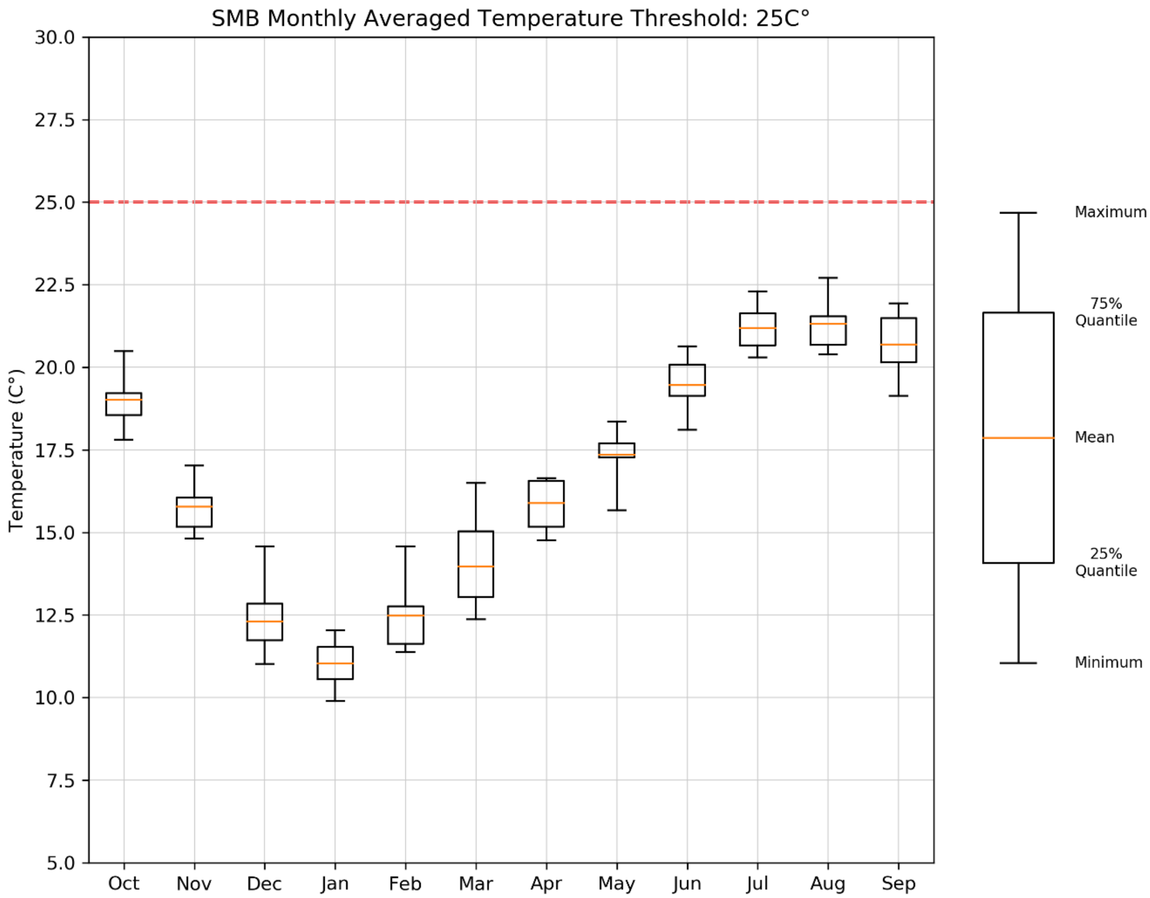

Figure 114. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SMB – Santa Margarita Booster

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

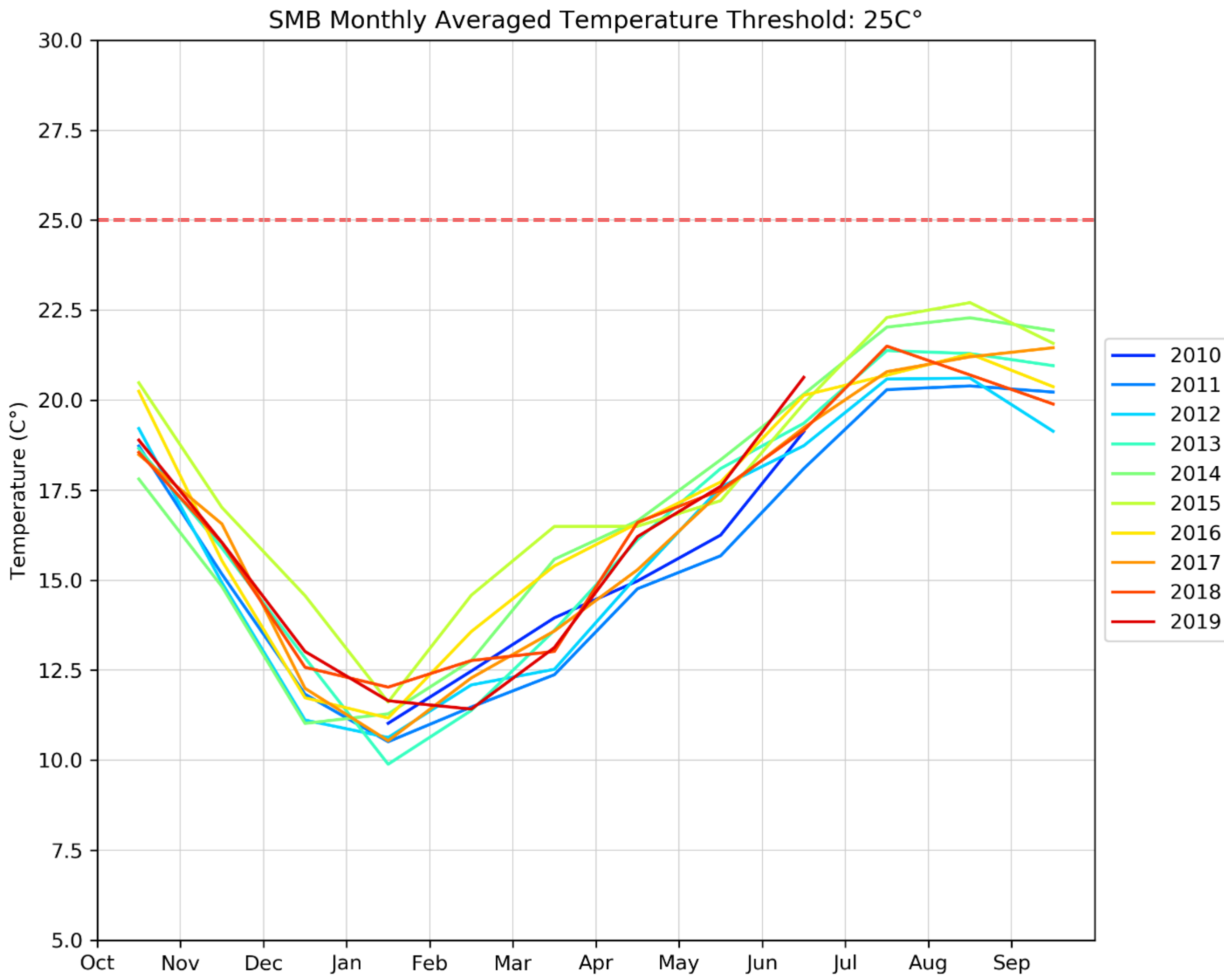

Figure 115. Monthly Average Temperature for the Period of Record at Station SMB – Santa Margarita Booster

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

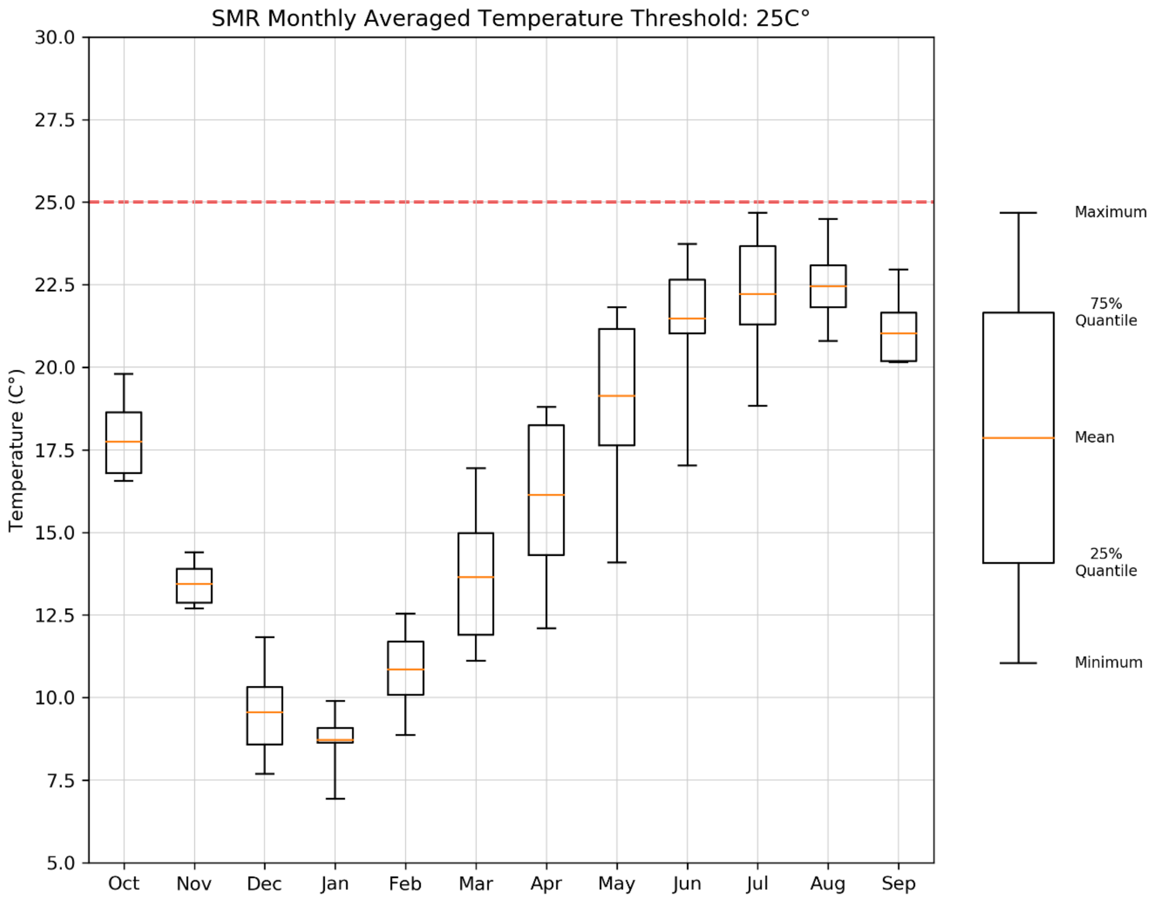

Figure 116. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SMR – South Mokelumne River at West Walnut Grove Road

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

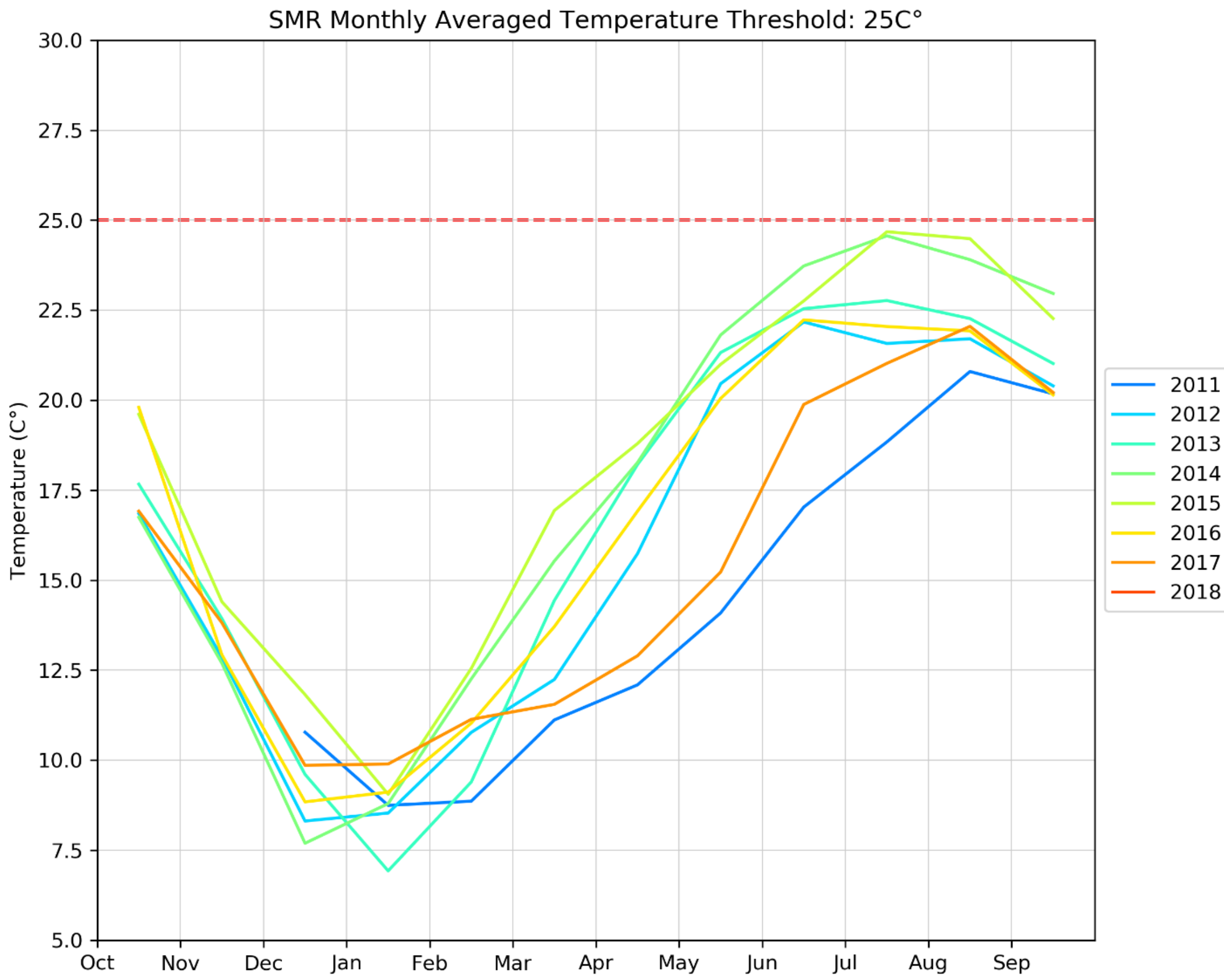

Figure 117. Monthly Average Temperature for the Period of Record at Station SMR – South Mokelumne River at West Walnut Grove Road

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

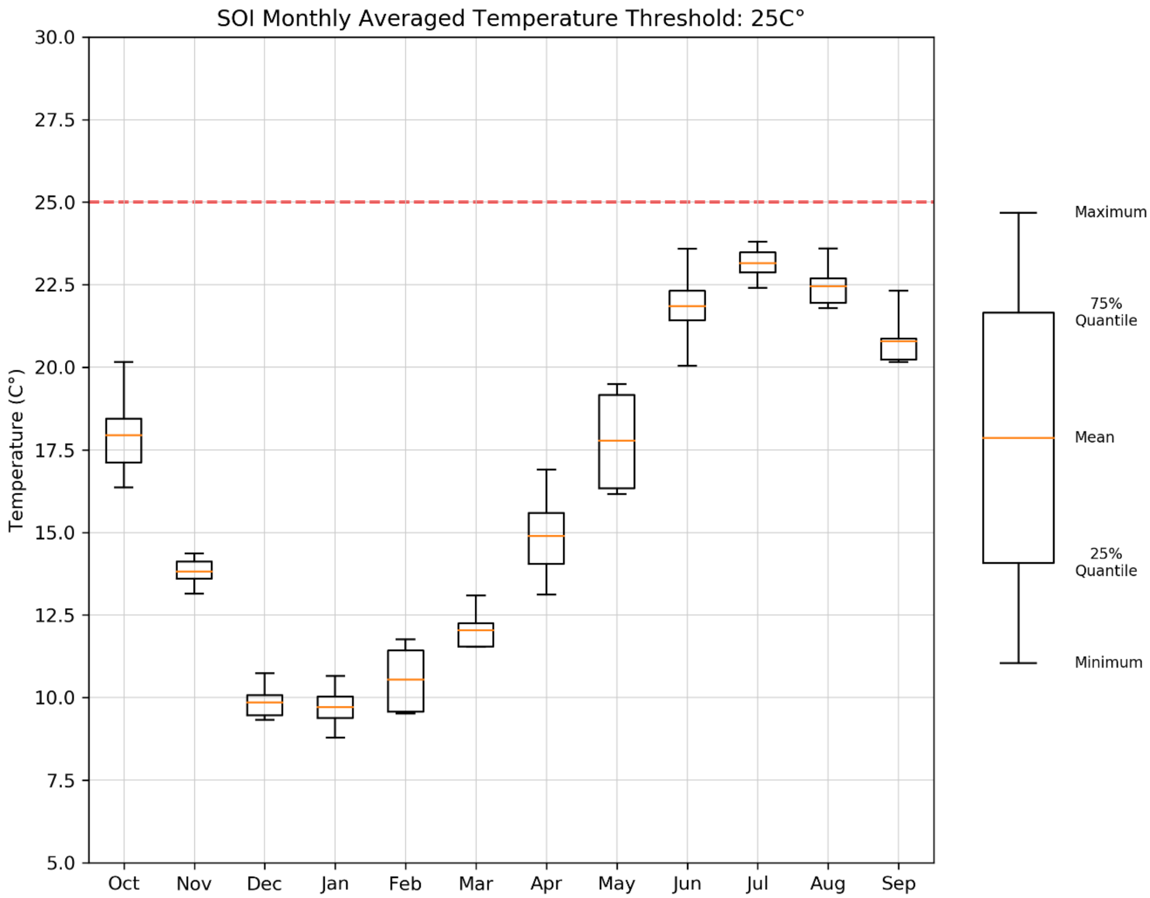

Figure 118 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SOI – Sacramento River Downstream of Isleton

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

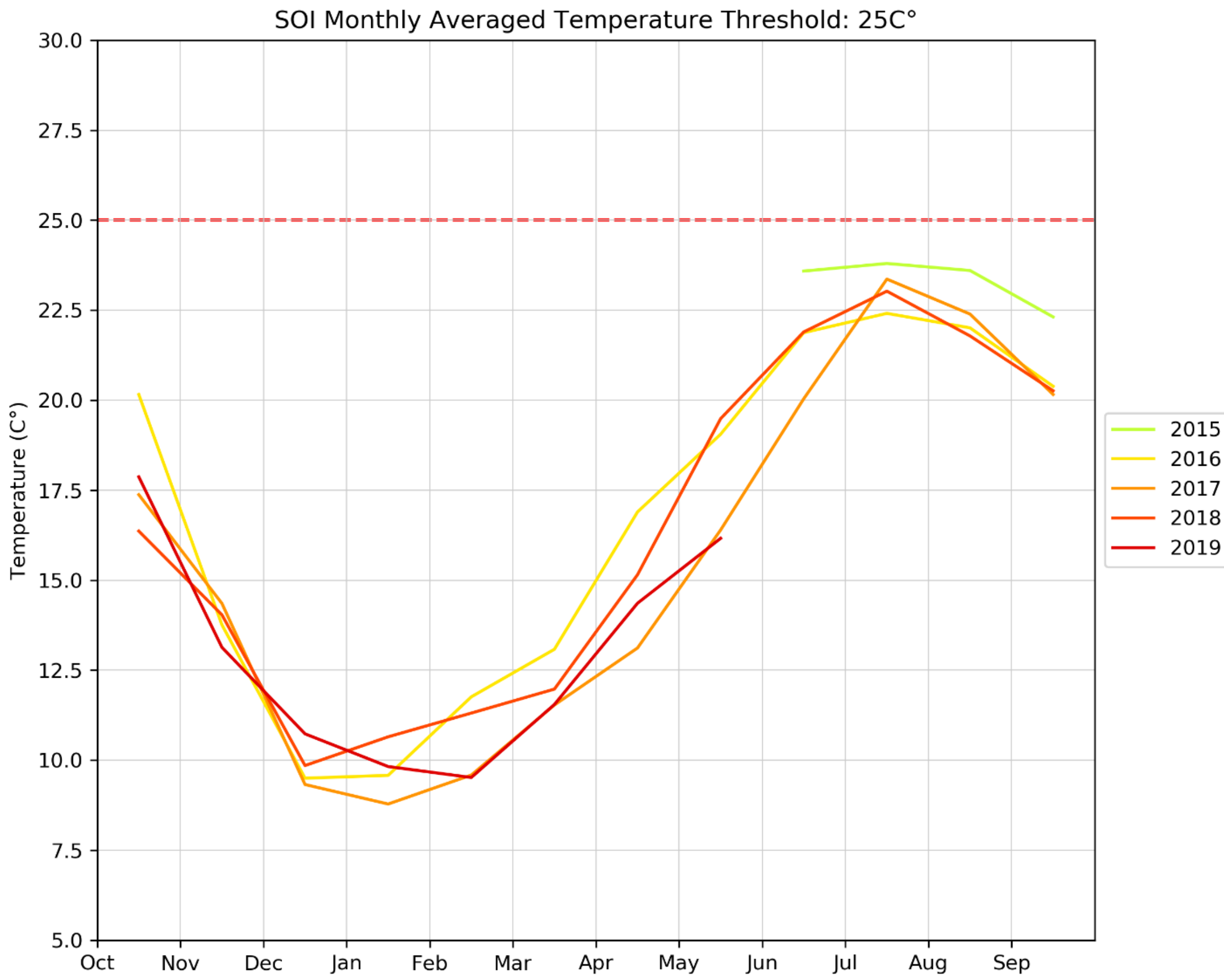

Figure 119. Monthly Average Temperature for the Period of Record at Station SOI – Sacramento River Downstream of Isleton

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

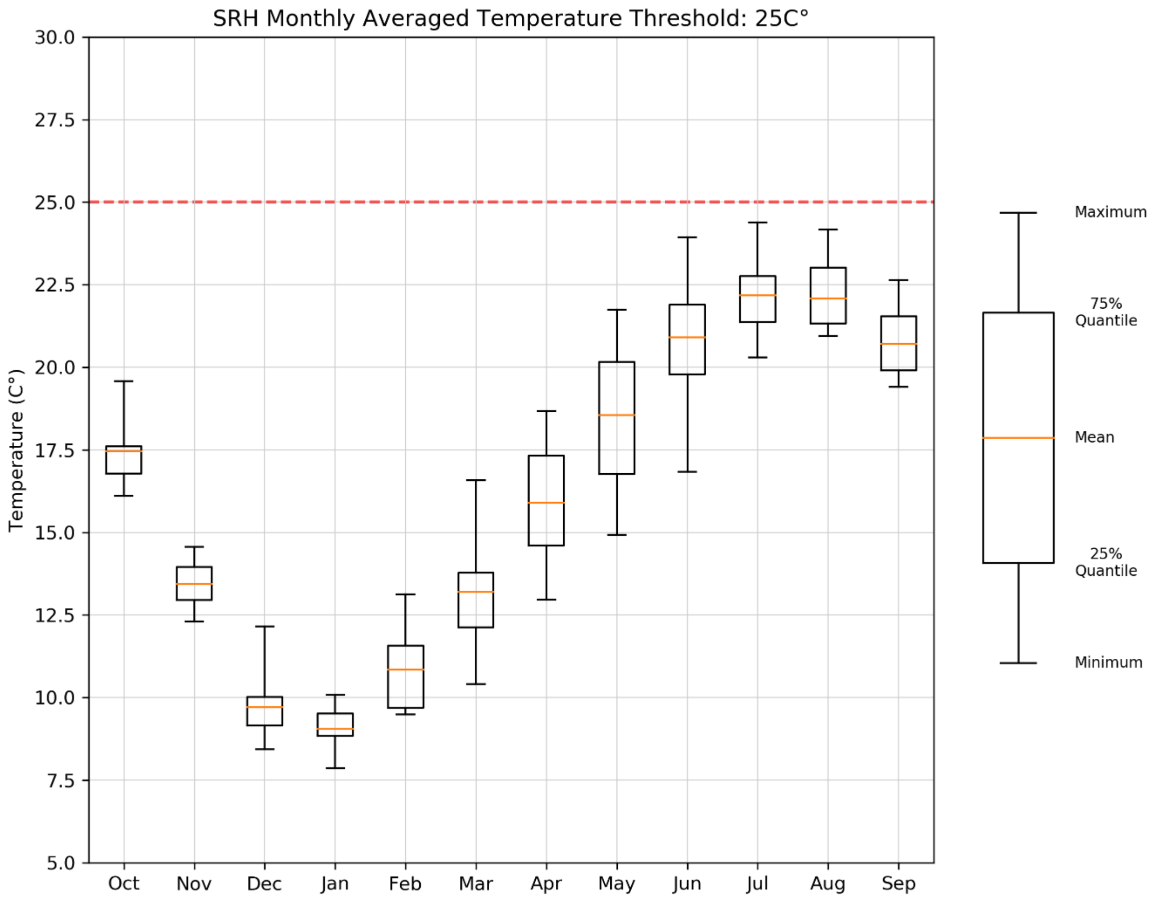

Figure 120. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SRH – Sacramento River at Hood

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

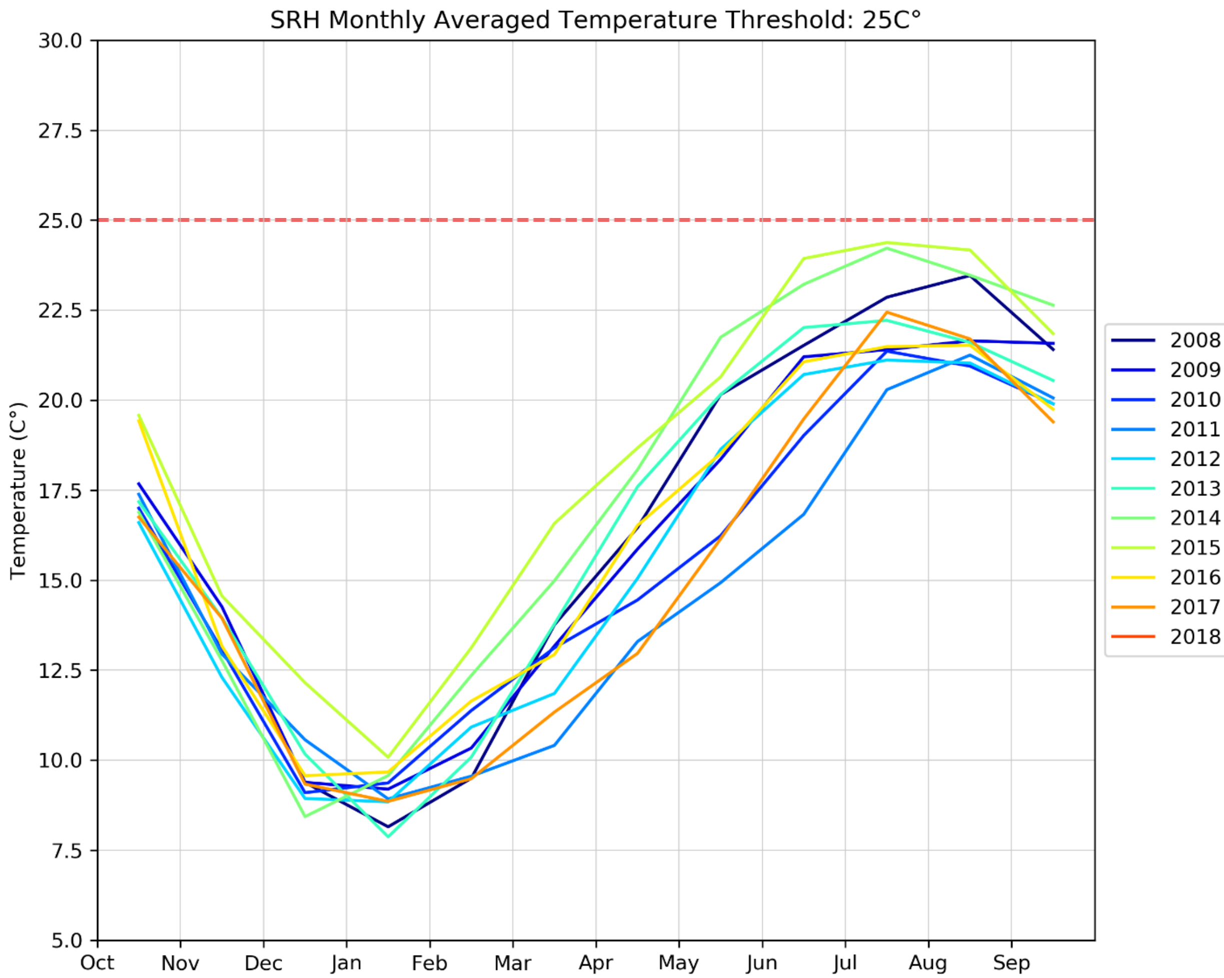

Figure 121. Monthly Average Temperature for the Period of Record at Station SRH – Sacramento River at Hood

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

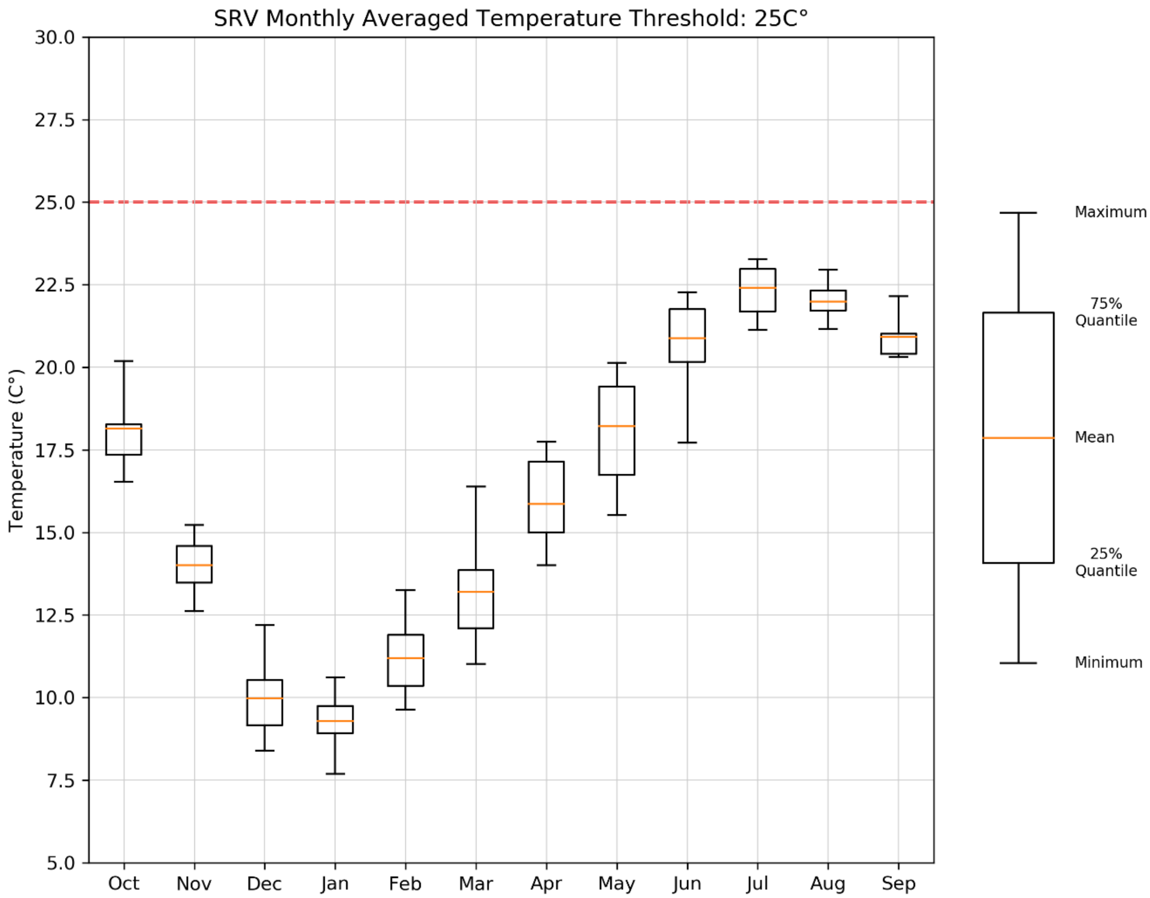

Figure 122. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SRV – Sacramento River at Rio Vista

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

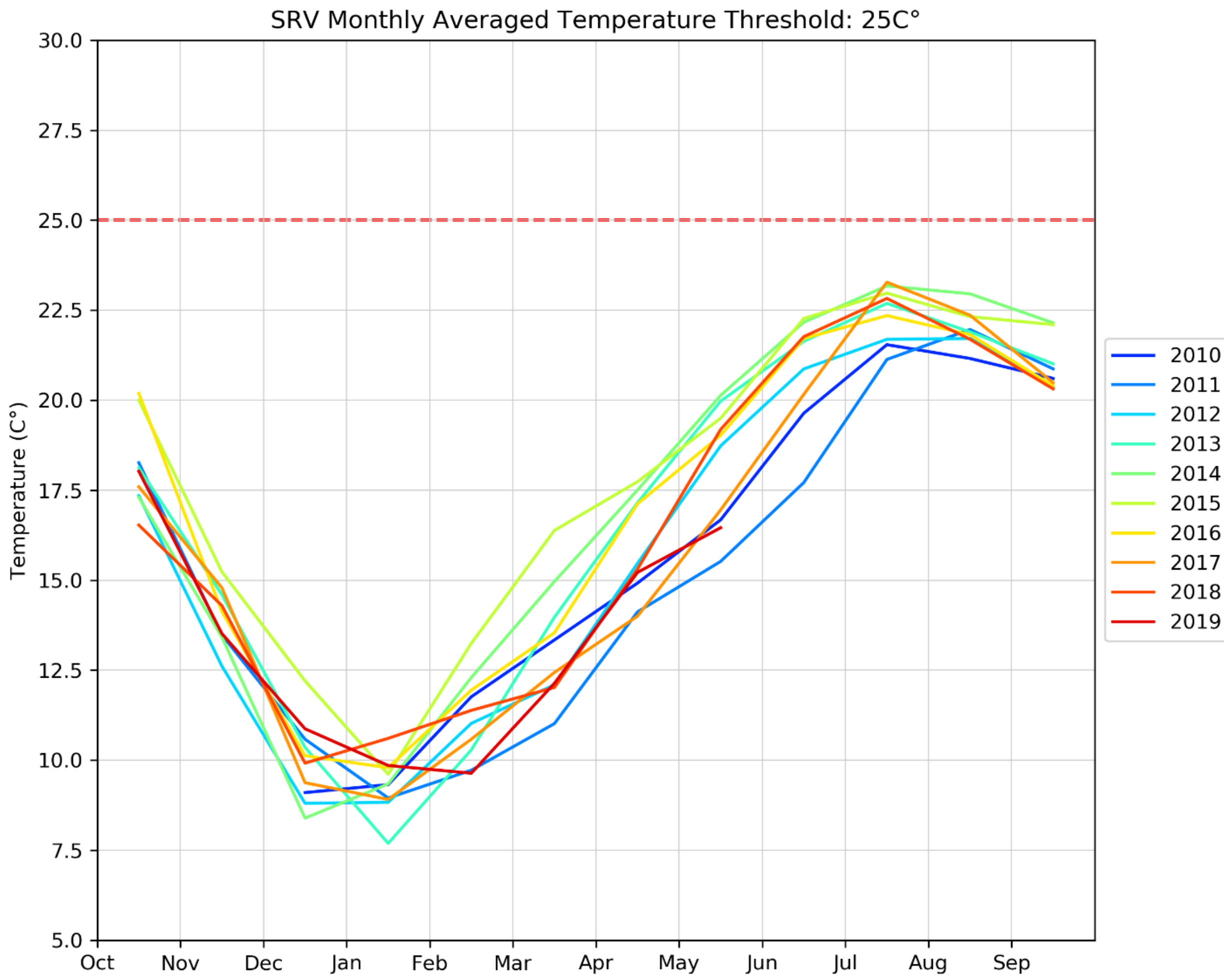

Figure 123. Monthly Average Temperature for the Period of Record at Station SRV – Sacramento River at Rio Vista

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

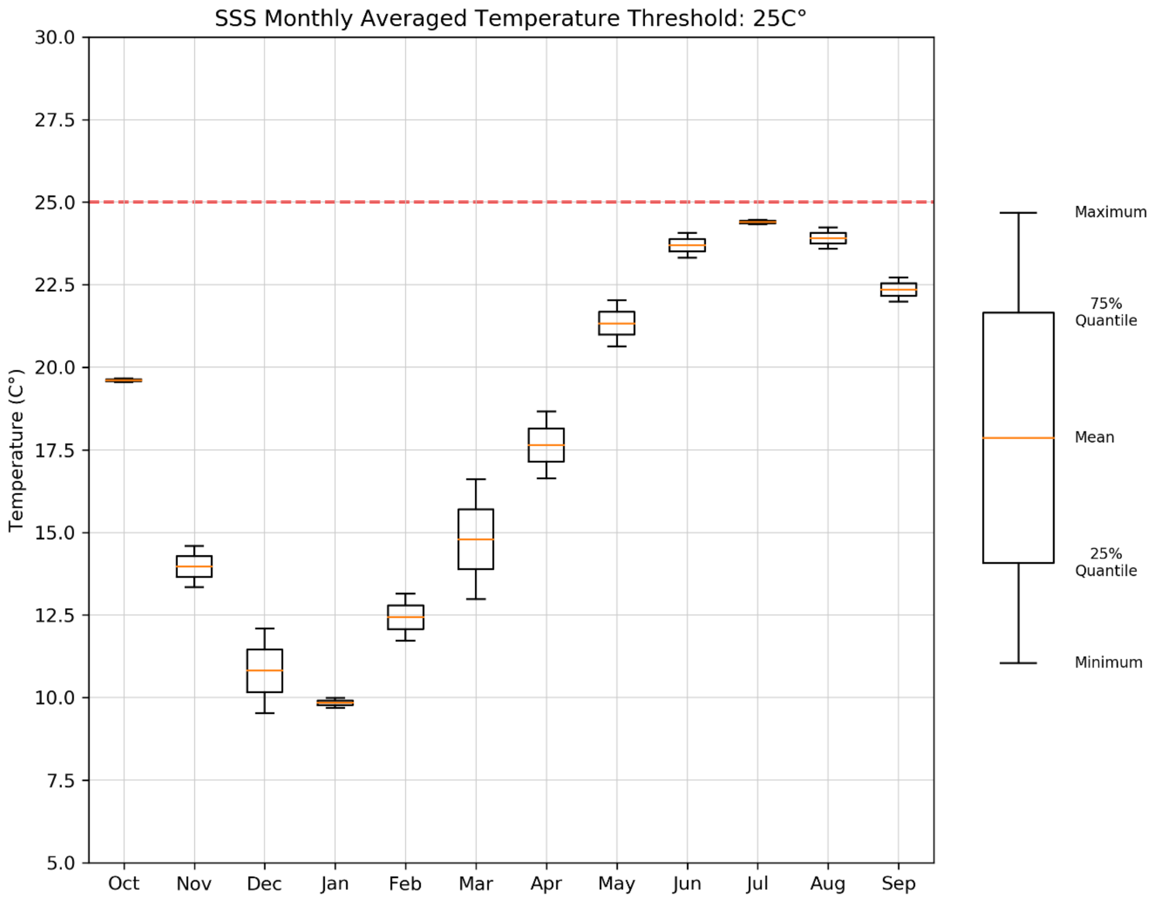

Figure 124. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SSS – Steamboat Slough between Sacramento River and Sutter Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

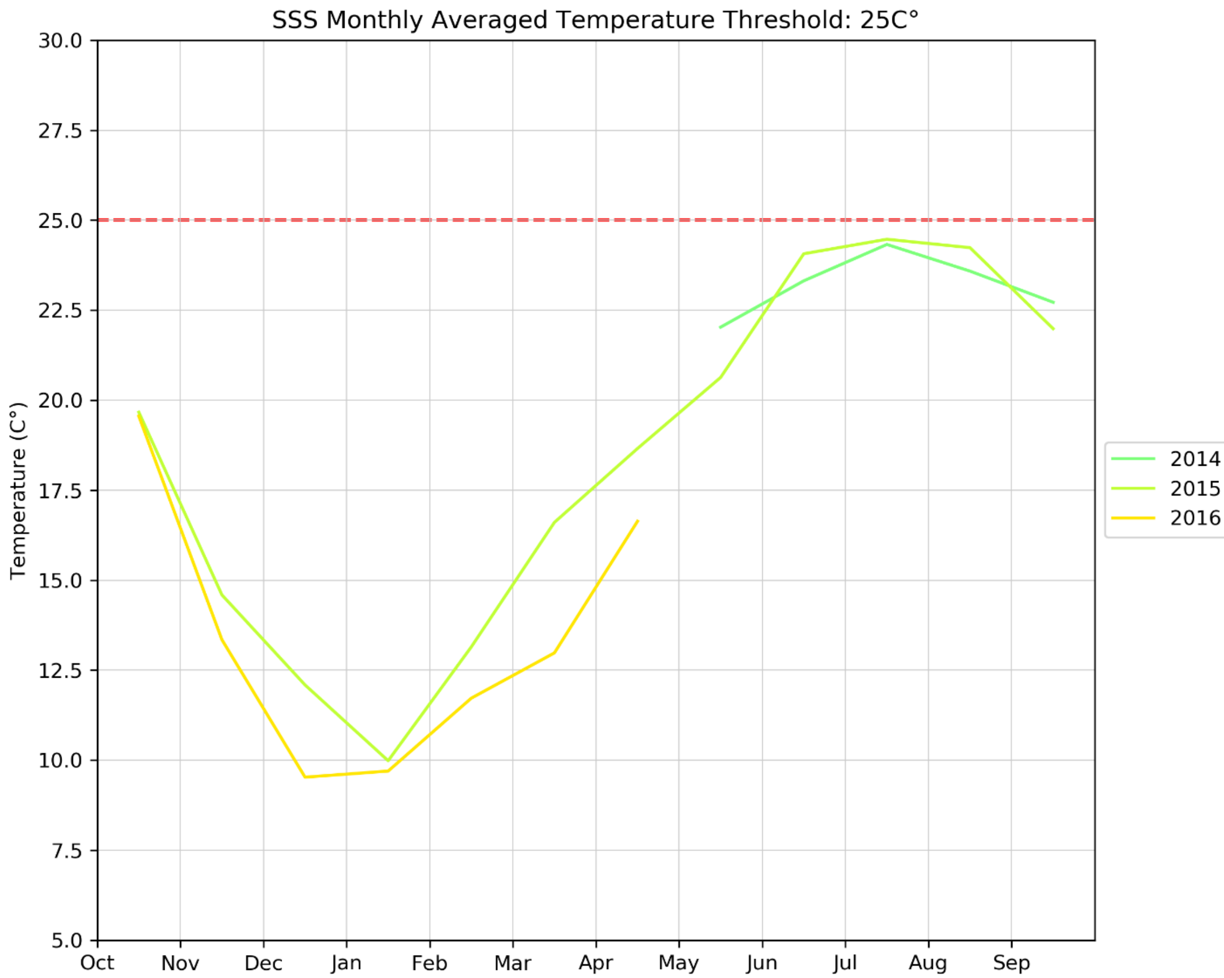

Figure 125. Monthly Average Temperature for the Period of Record at Station SSS – Steamboat Slough between Sacramento River and Sutter Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

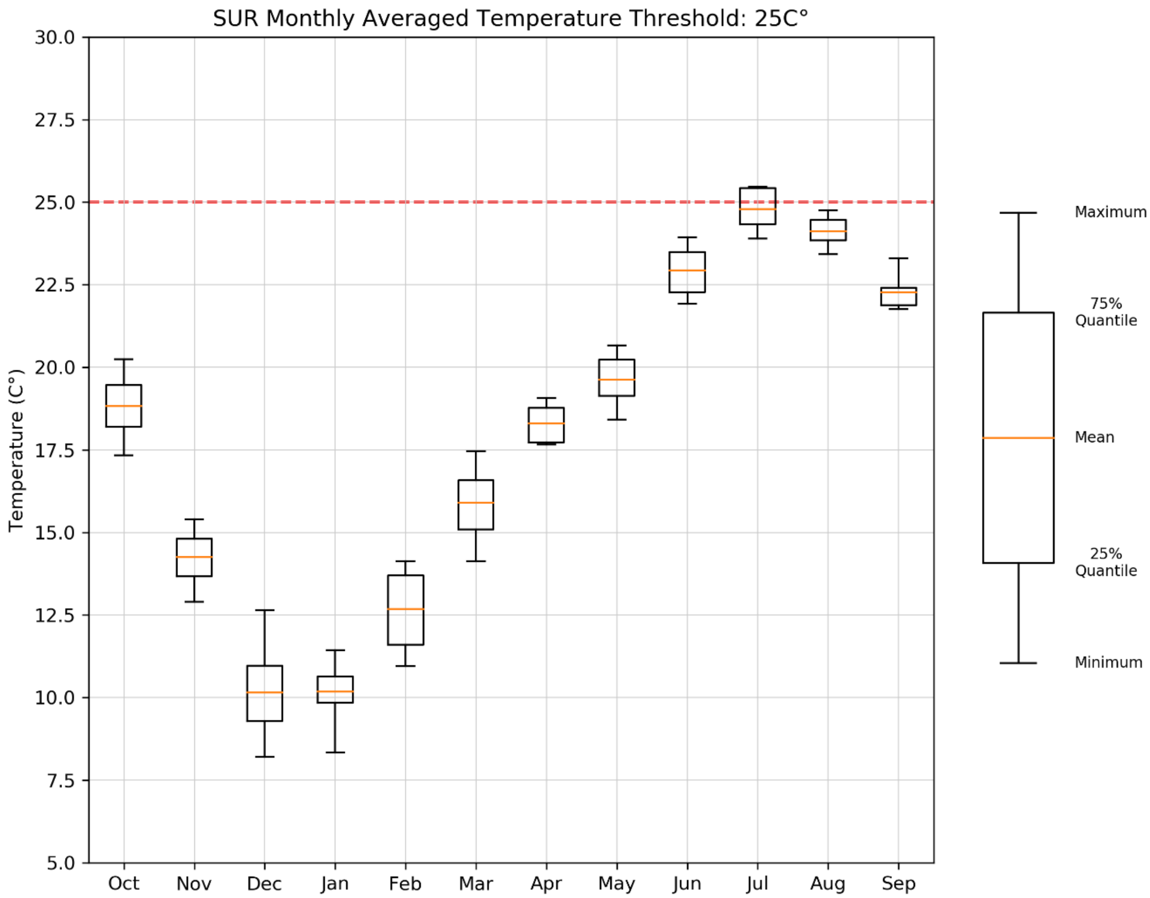

Figure 126. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SUR – Sugar Cut

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

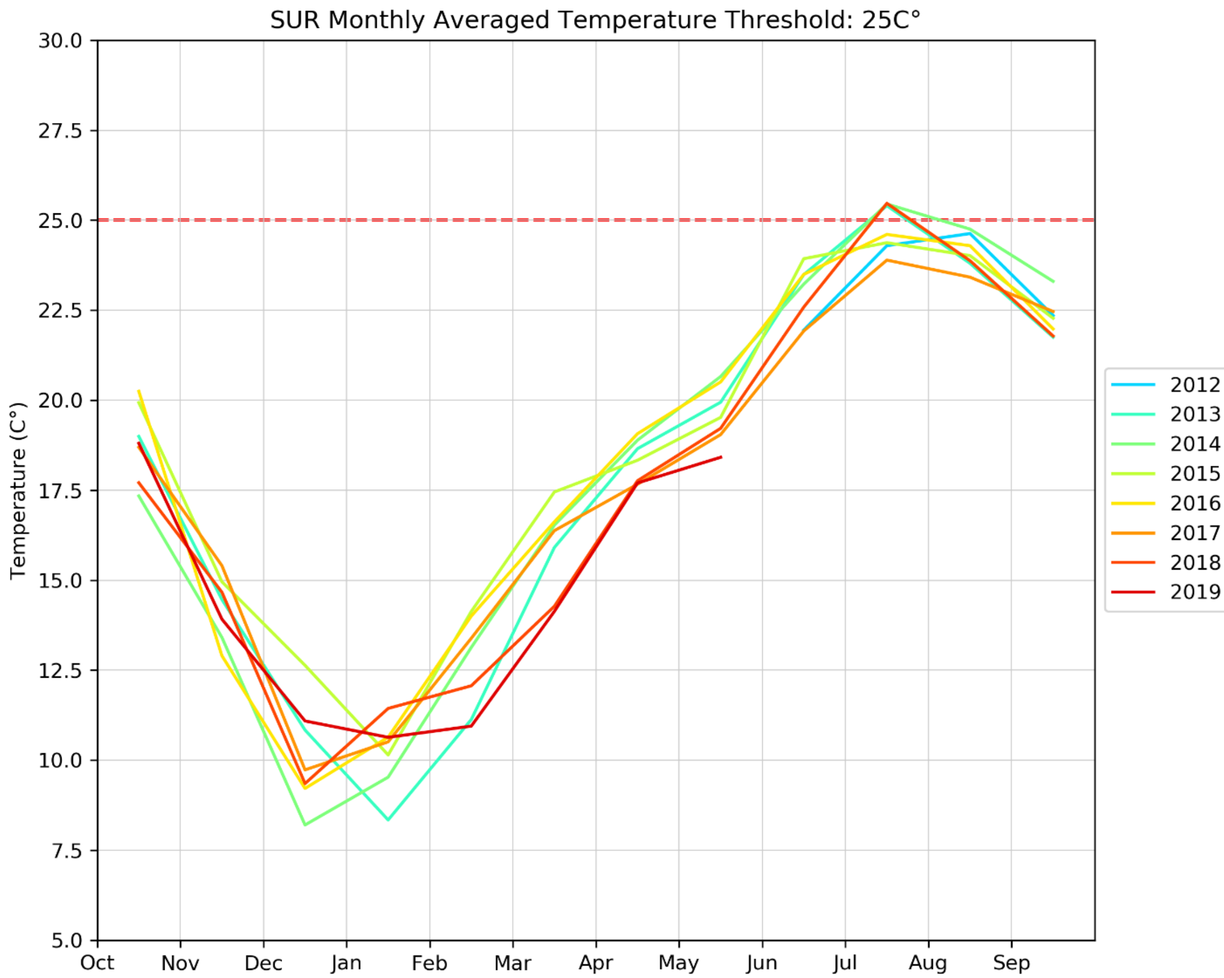

Figure 127. Monthly Average Temperature for the Period of Record at Station SUR – Sugar Cut

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

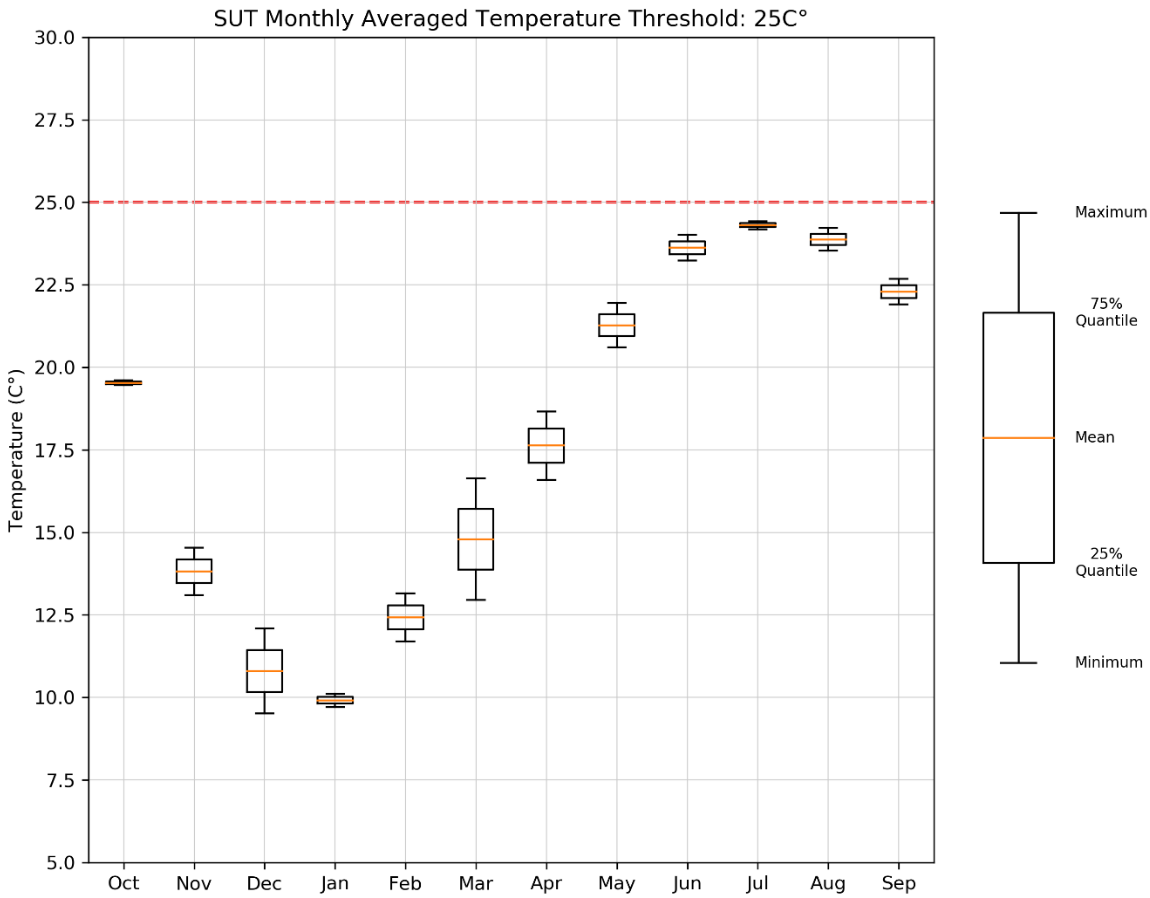

Figure 128. Bar and whisker plot summarizing range of monthly averaged temperature at station SUT – Sutter Slough at Courtland

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

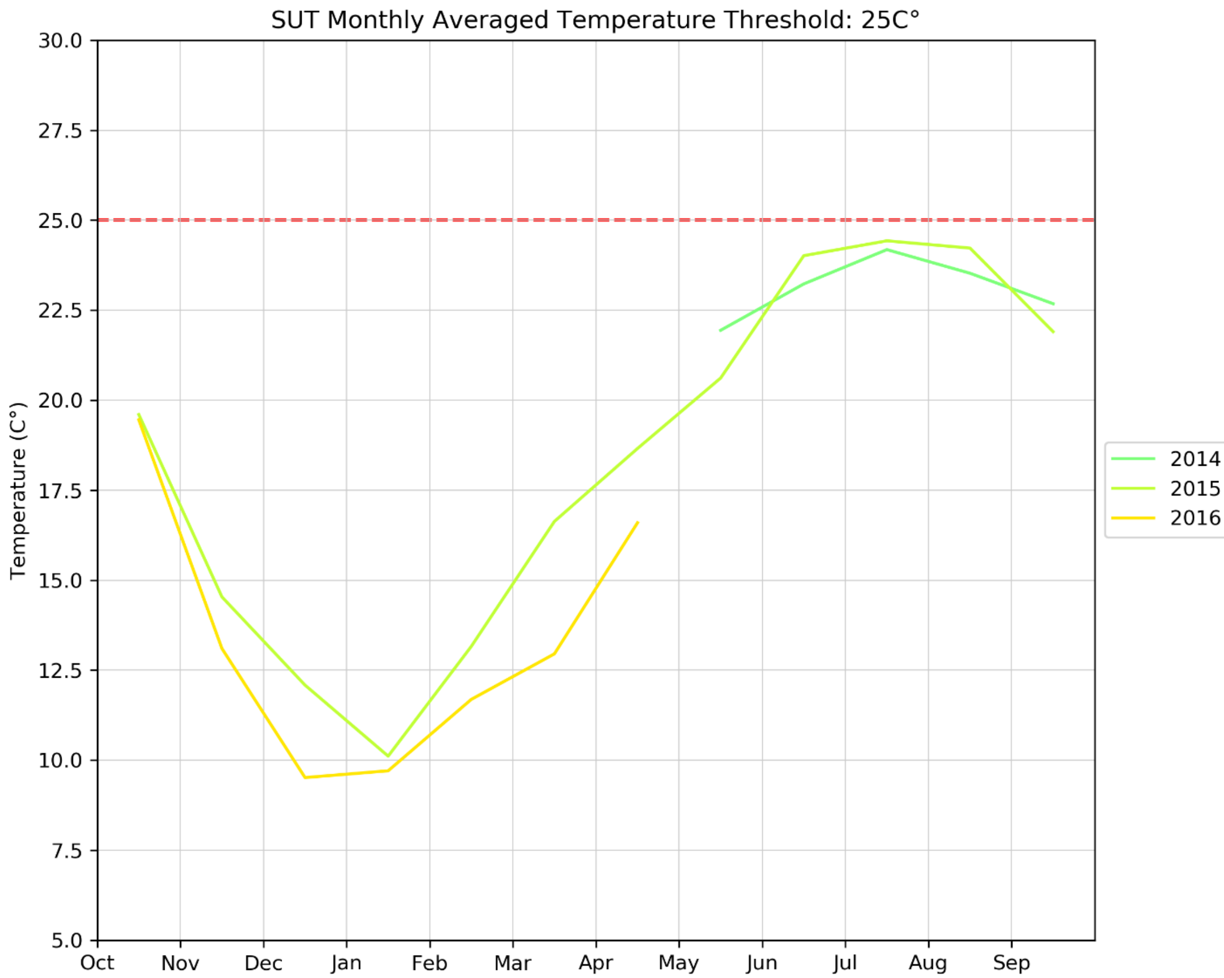

Figure 129. Monthly Average Temperature for the Period of Record at Station SUT – Sutter Slough at Courtland

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

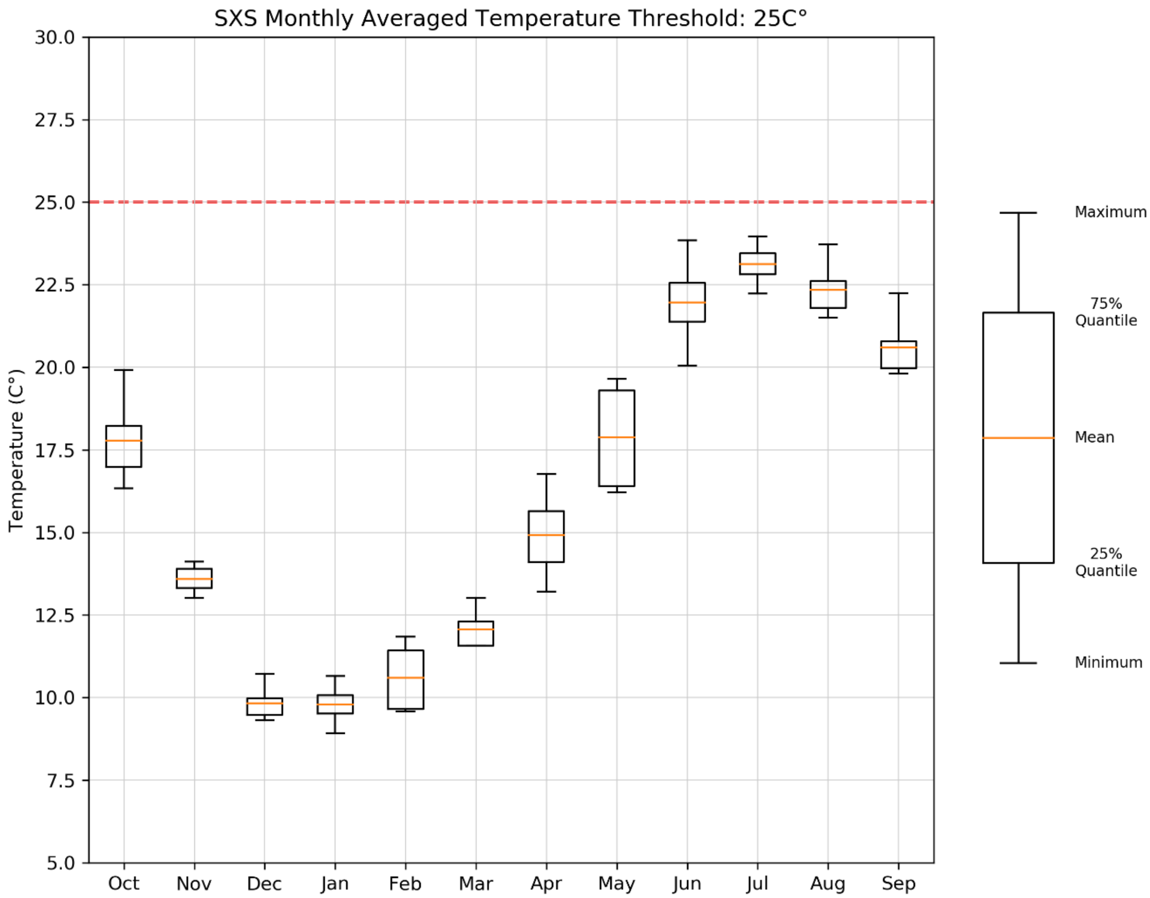

Figure 130. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station SXS – Steamboat Slough near Sacramento River

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

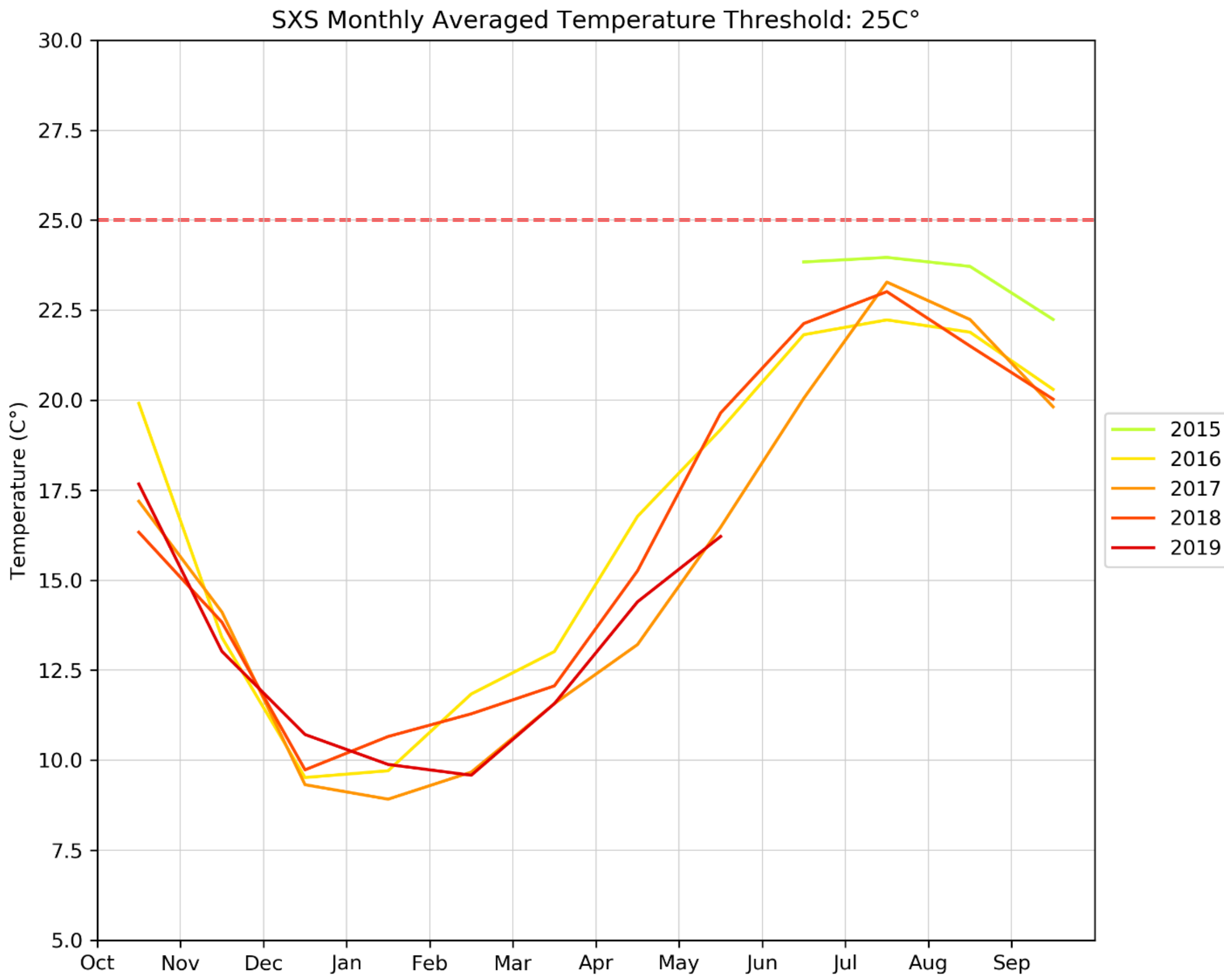

Figure 131. Monthly Average Temperature for the Period of Record at Station SXS – Steamboat Slough near Sacramento River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

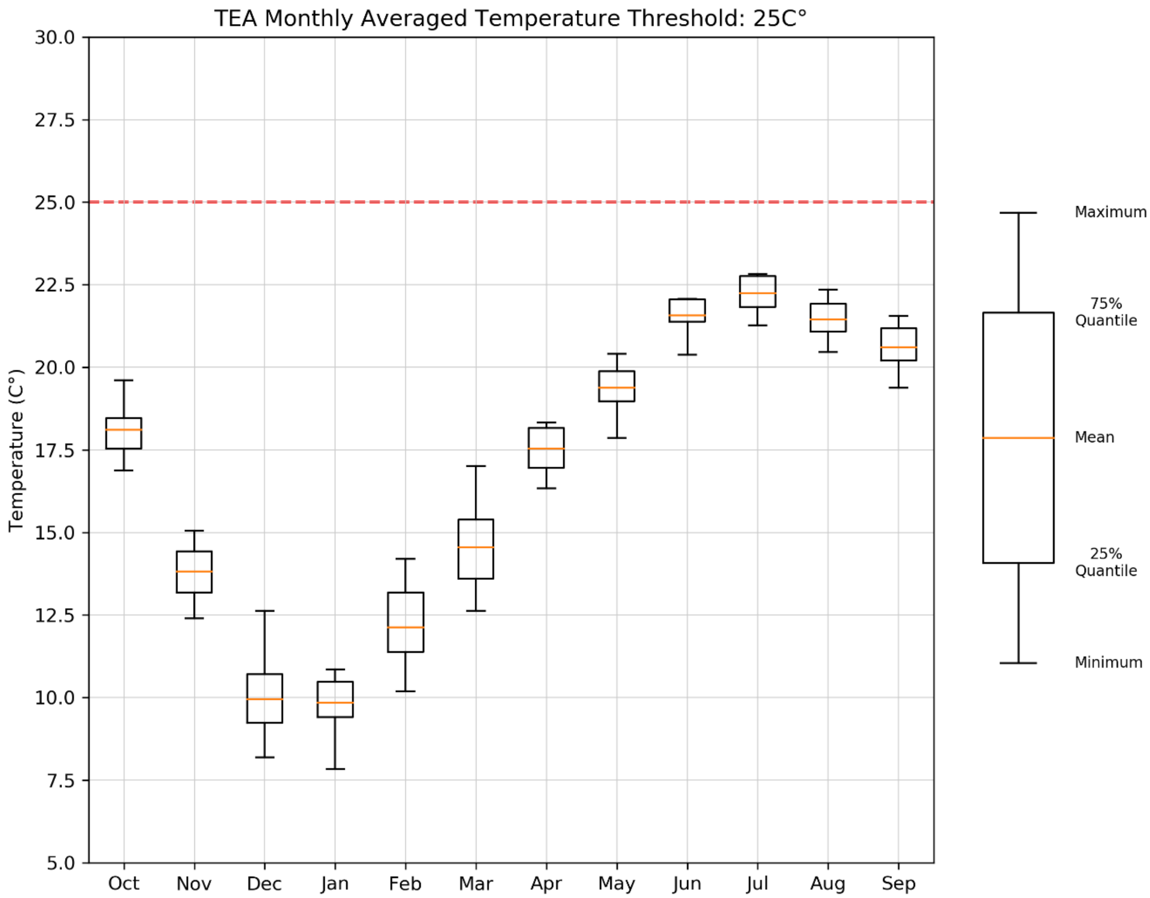

Figure 132. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TEA – Teal Club at Frank Horan Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

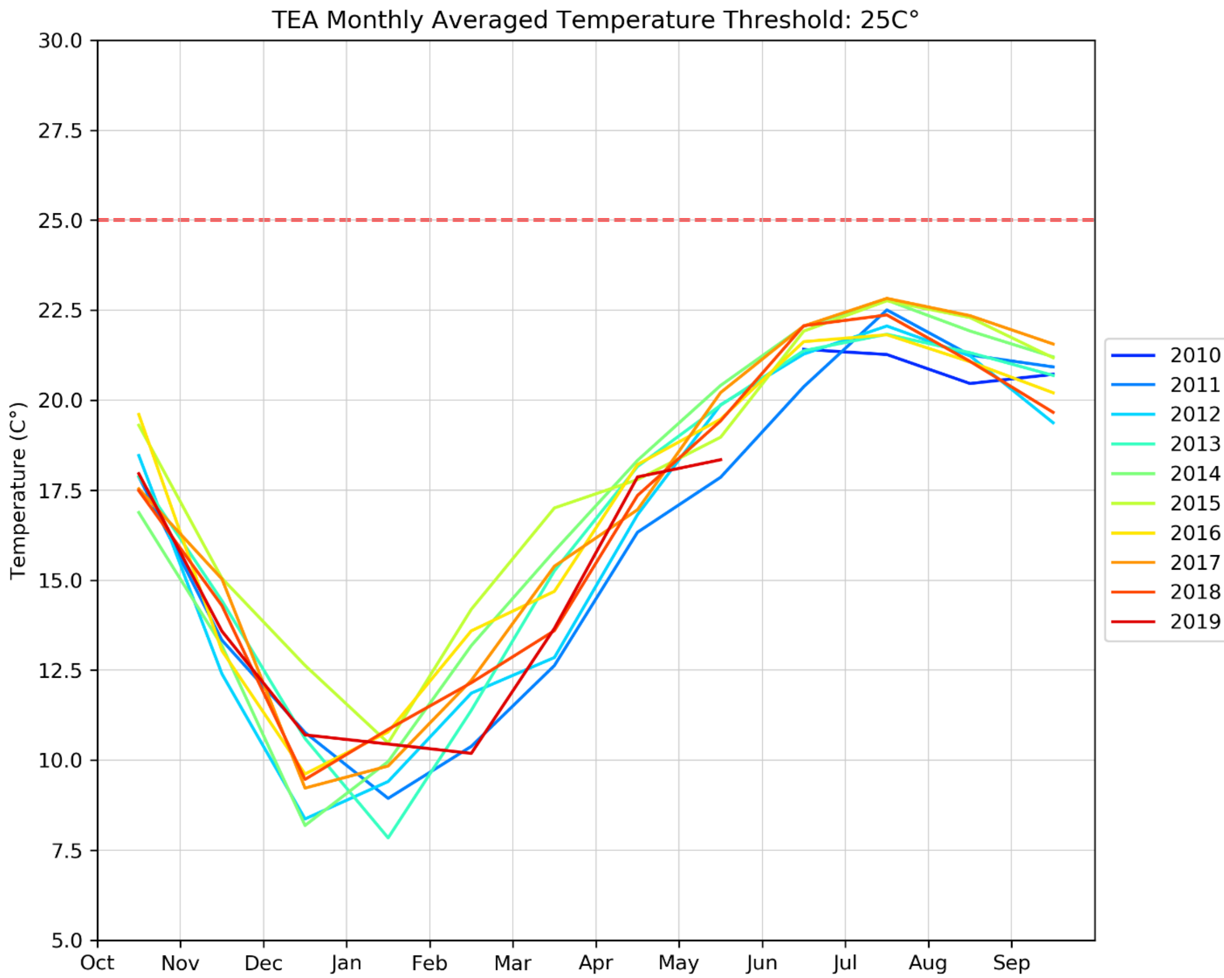

Figure 133. Monthly Average Temperature for the Period of Record at Station TEA – Teal Club at Frank Horan Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

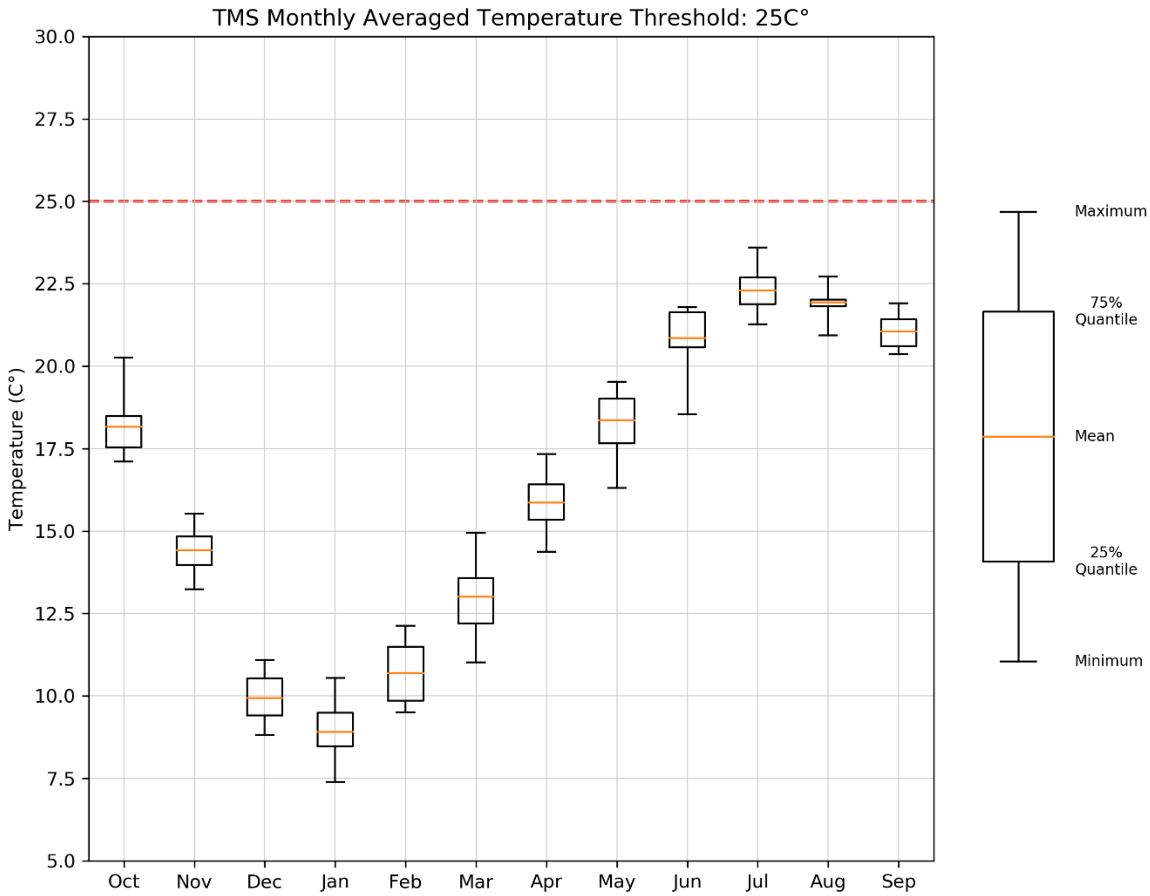

Figure 134. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TMS – Threemile Slough

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

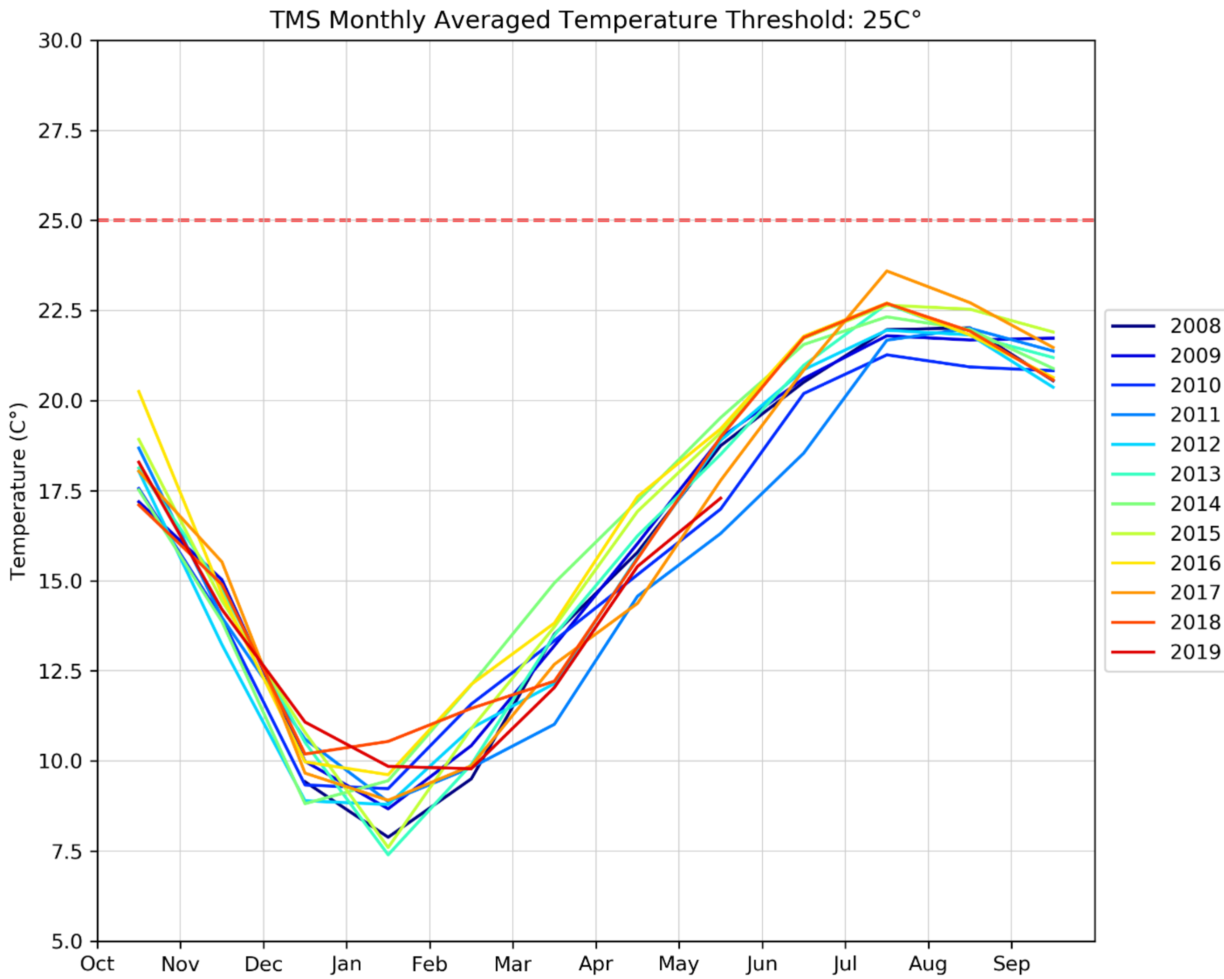

Figure 135. Monthly Average Temperature for the Period of Record at Station TMS – Threemile Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

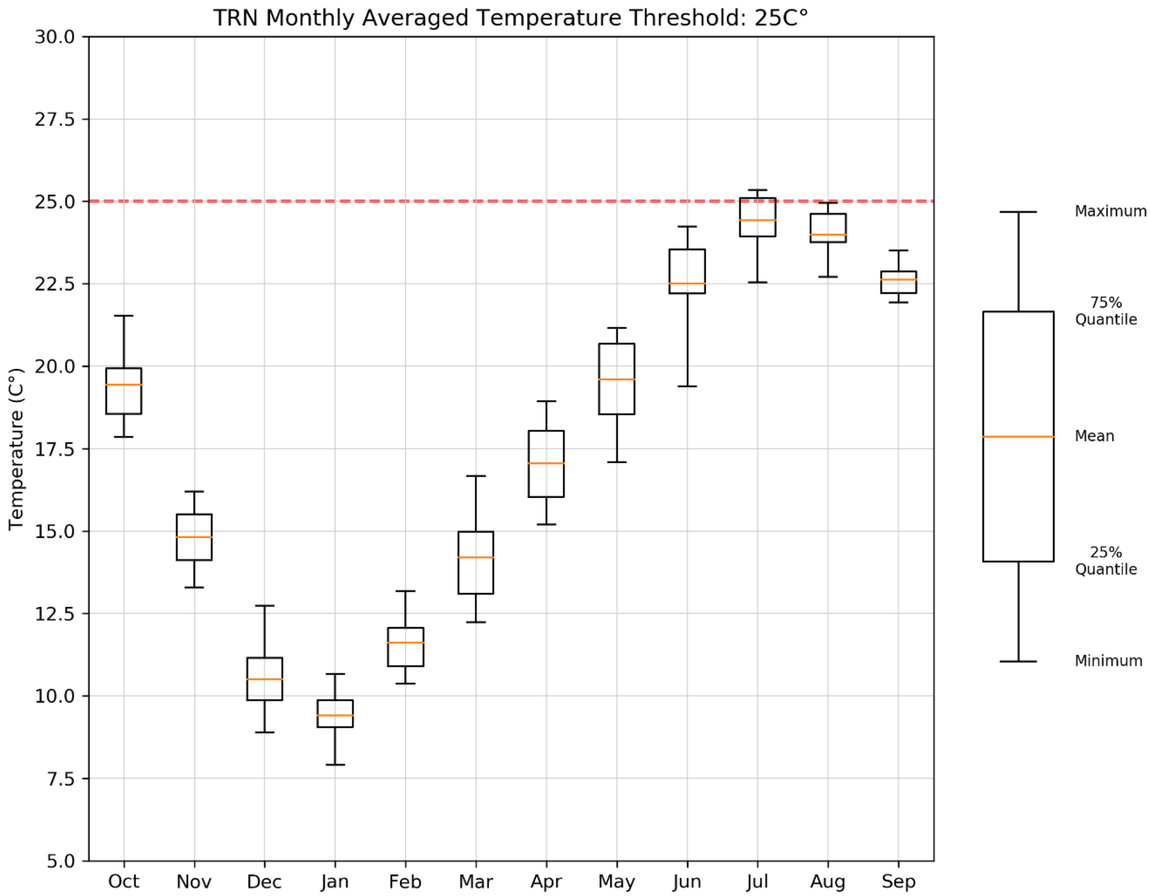

Figure 136 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TRN – Turner Cut Near Holt

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

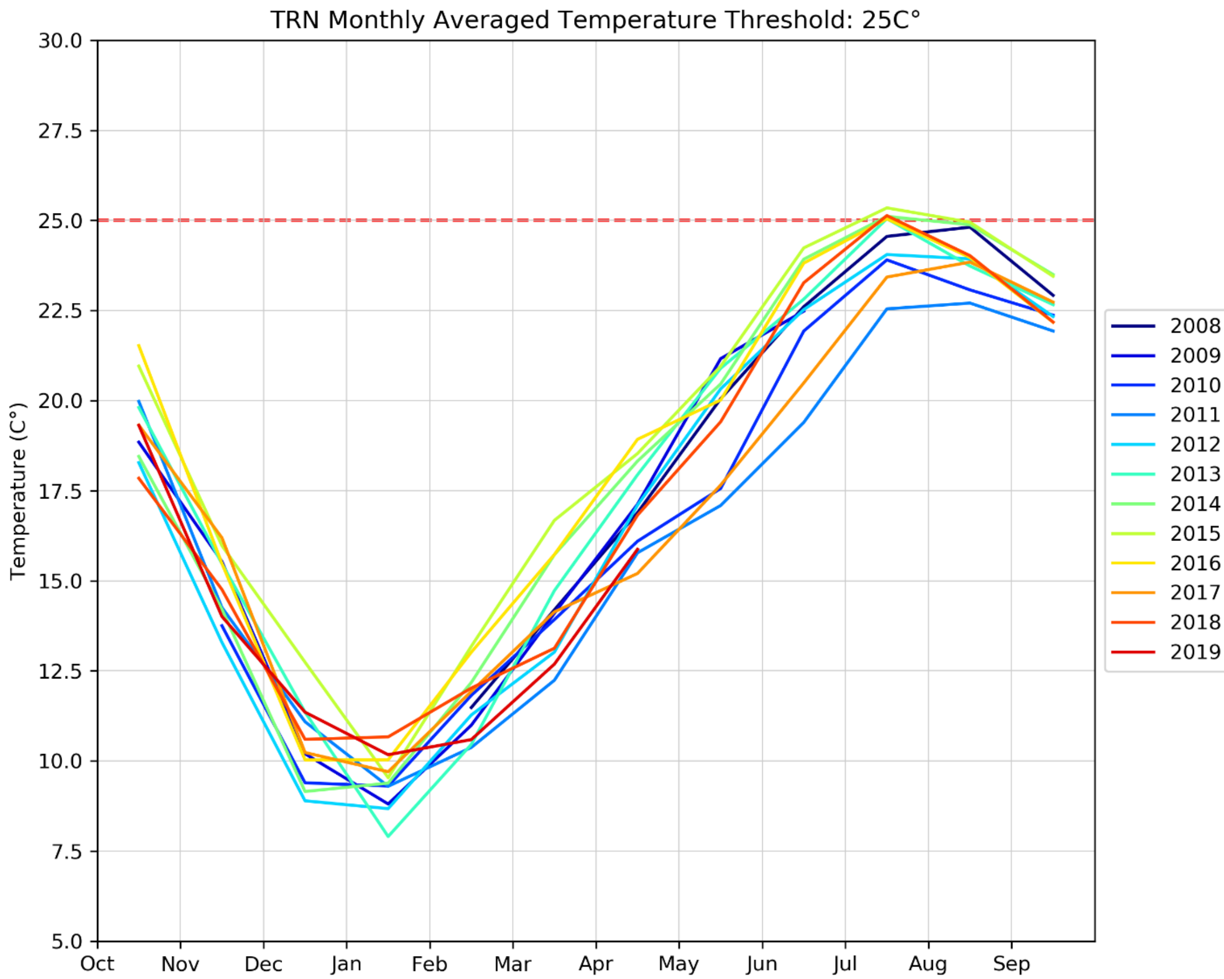

Figure 137 Monthly Average Temperature for the Period of Record at Station TMS – Turner Cut near Holt

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

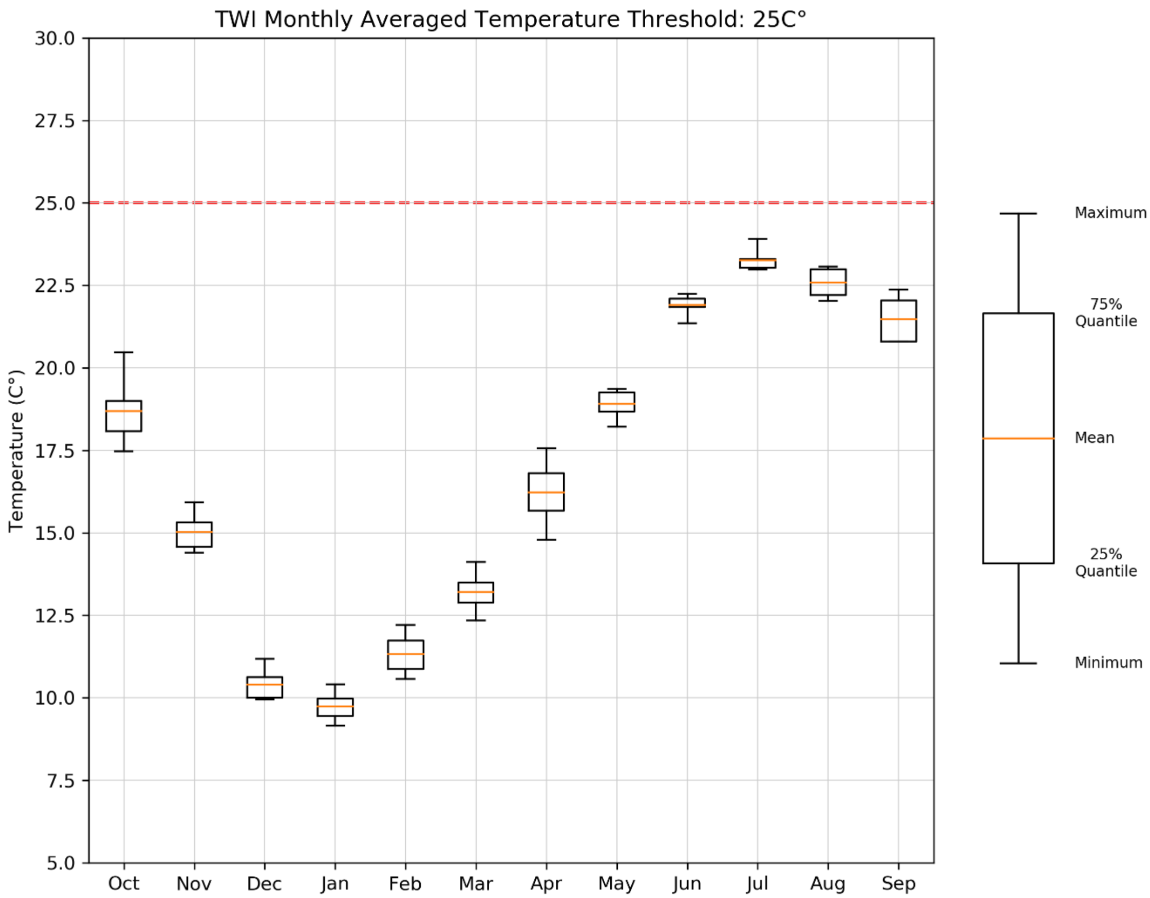

Figure 138 Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station TWI – San Joaquin River at Twitchell Island

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

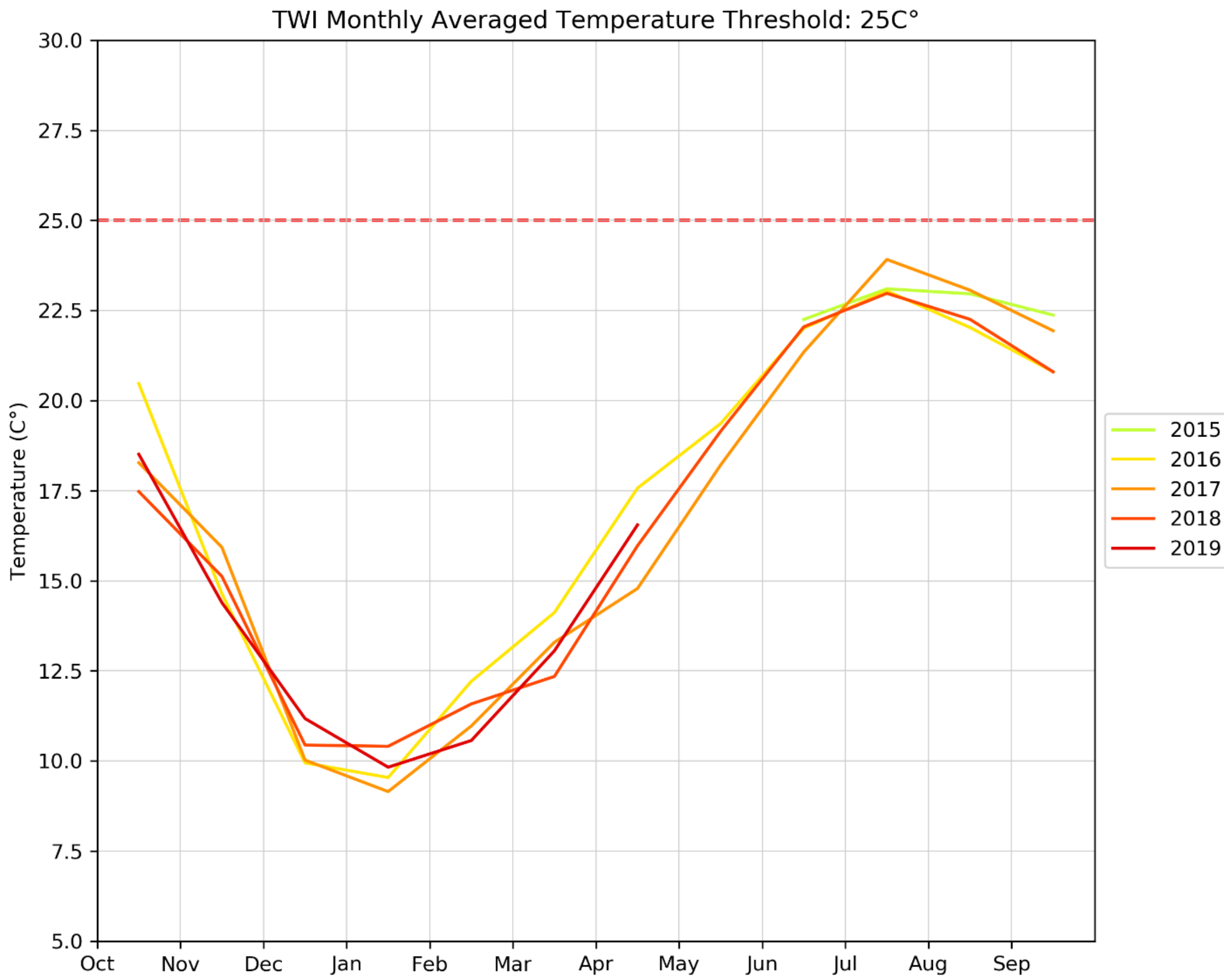

Figure 139 Monthly Average Temperature for the Period of Record at Station TWI – San Joaquin River at Twitchell Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

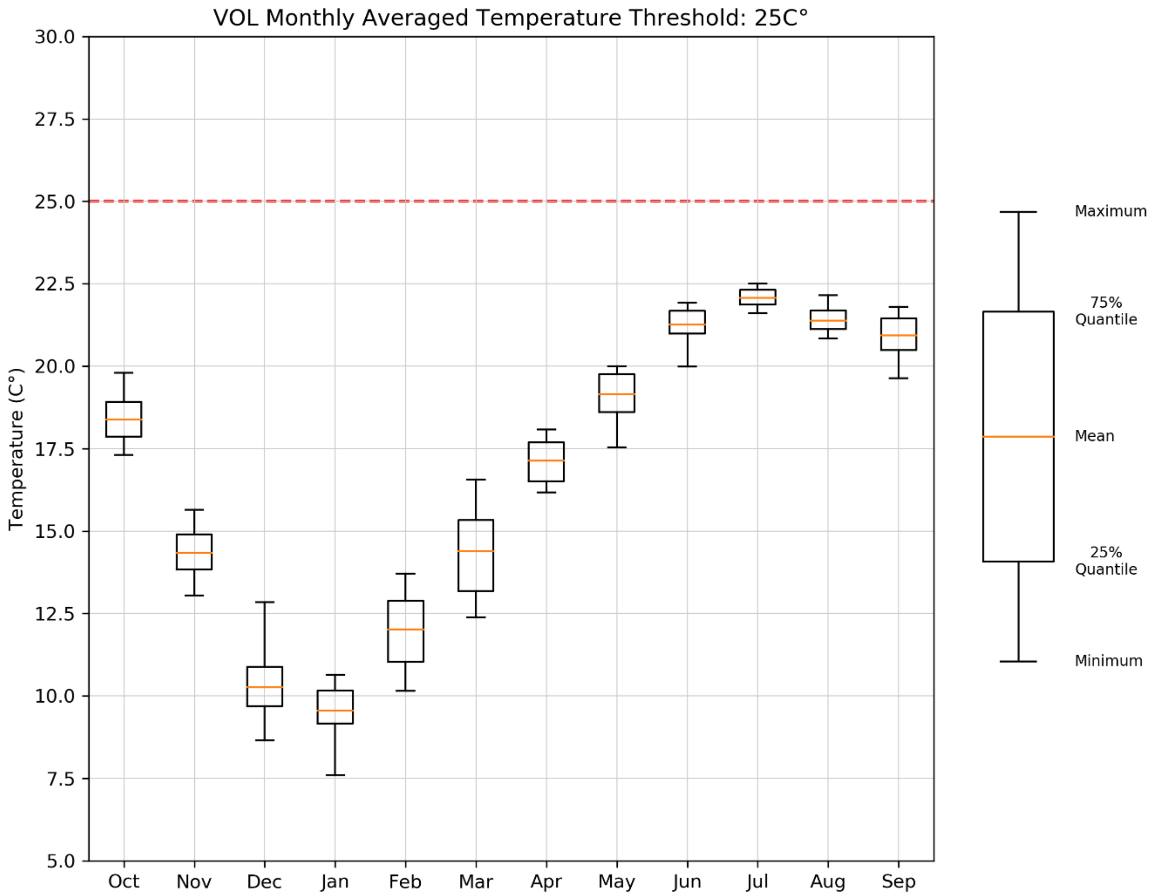

Figure 140. Bar and Whisker Plot Summarizing Range of Monthly Averaged Temperature at Station VOL – Volanti

Figure shows data plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

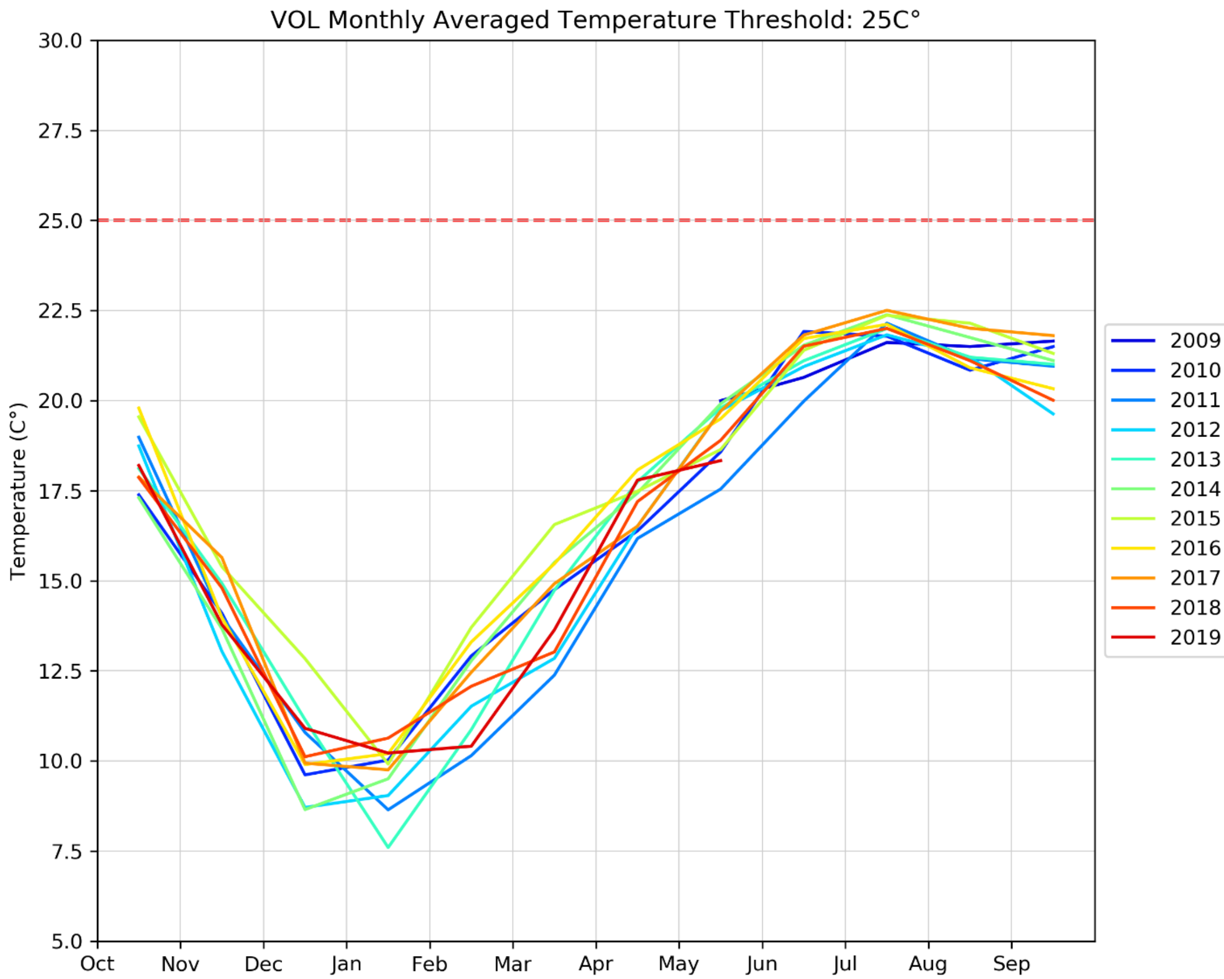

Figure 141. Monthly Average Temperature for the Period of Record at Station VOL – Volanti

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and temperature (in Celsius) on the y-axis.

A.2.1 Turbidity

Observed turbidity data were downloaded from the California Department of Water Resources' California Data Exchange Center[2] and Water Data Library[3] and the U.S. Geological Survey.[4]

The map in Figure 142 shows the locations of all observed turbidity stations that were used to calculate the turbidity data layers for the habitat calculations.

For each station, bar and whisker plots and monthly average turbidity time series plots, similar to those for temperature data, are provided in Figure 143 through Figure 190. The 12 Nephelometric Turbidity Unit (NTU) minimum limit for Delta smelt habitat is included on all plots for reference.

[2] California Department of Water Resources, California Data Exchange Center. 2022. Historical Data Selector. Available: https://cdec.water.ca.gov/dynamicapp/selectQuery.

[3] California Department of Water Resources, 2022. Water Data Library (WDL) Station Map. Available: https://wdl.water.ca.gov/waterdatalibrary/.

[4] U.S. Geological Survey. 2022. USGS Water-Quality Data for the Nation. Available: https://waterdata.usgs.gov/nwis/qw.

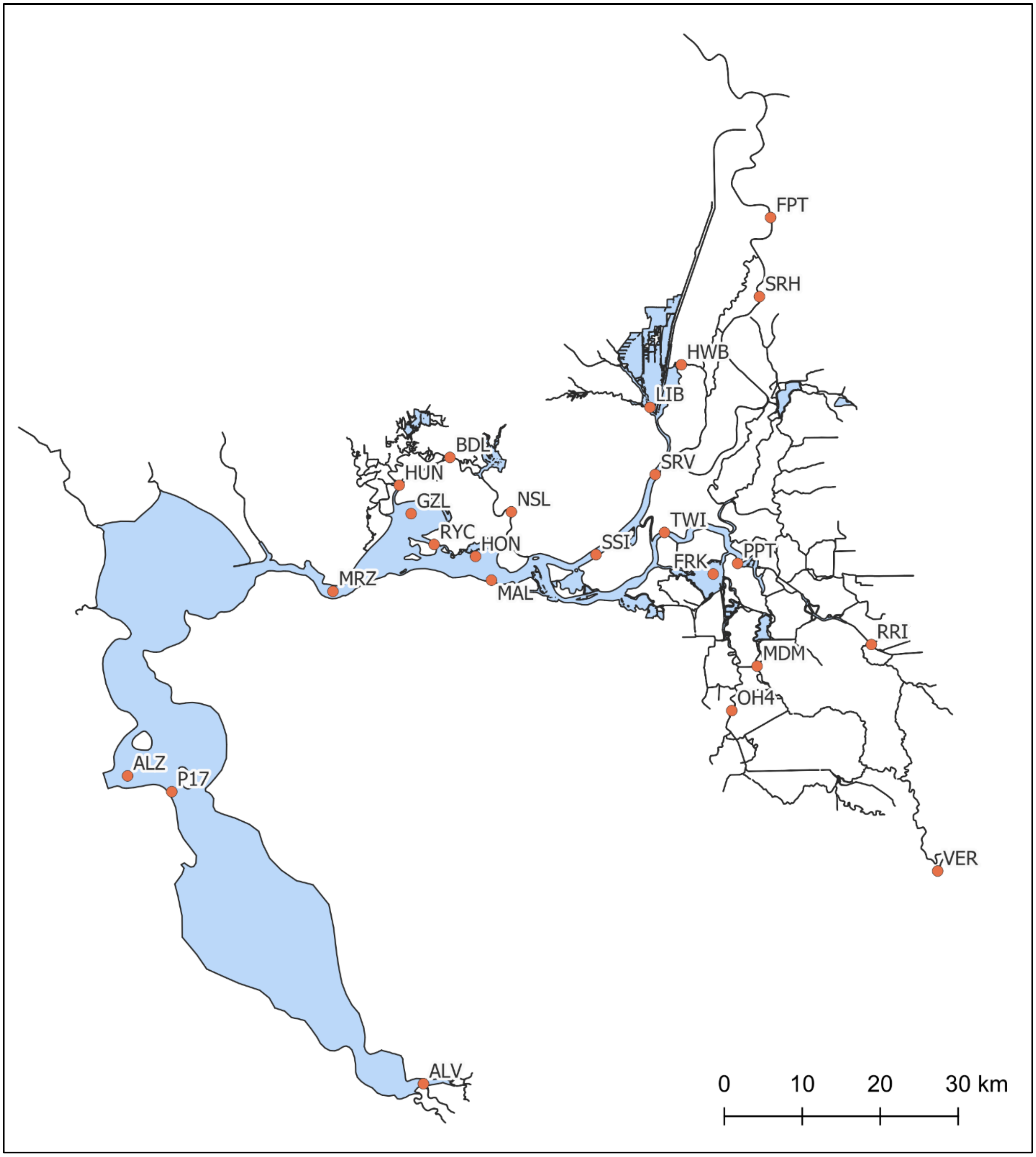

Figure 142. Locations of Observed Turbidity Stations Used to Calculate the Turbidity Data Layers for the Habitat Calculations

Figure is a map of the San Francisco Bay Estuary showing red points denoted by three-letter station codes representing sampling stations.

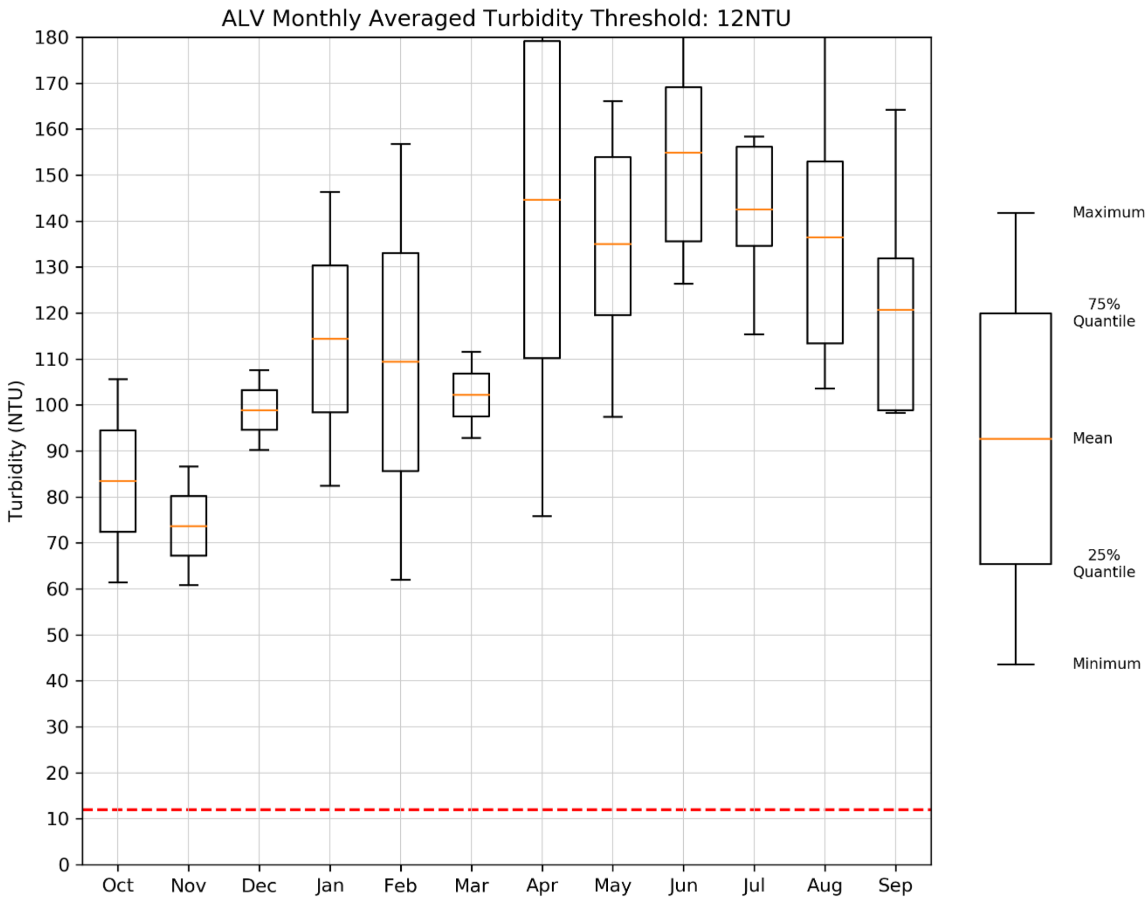

Figure 143. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station ALV – Alviso Slough

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

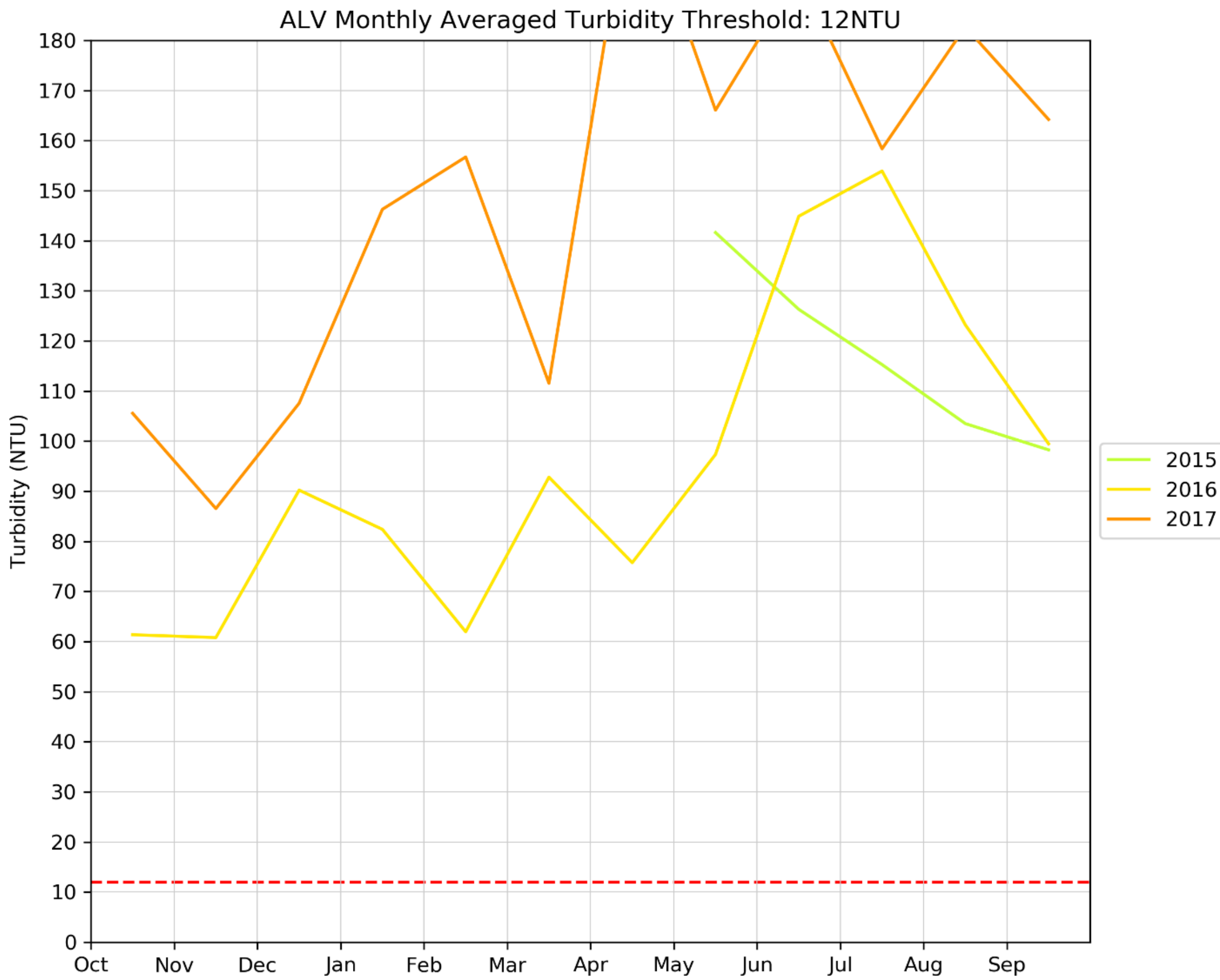

Figure 144. Monthly Average Turbidity for the Period of Record at Station ALV – Alviso Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

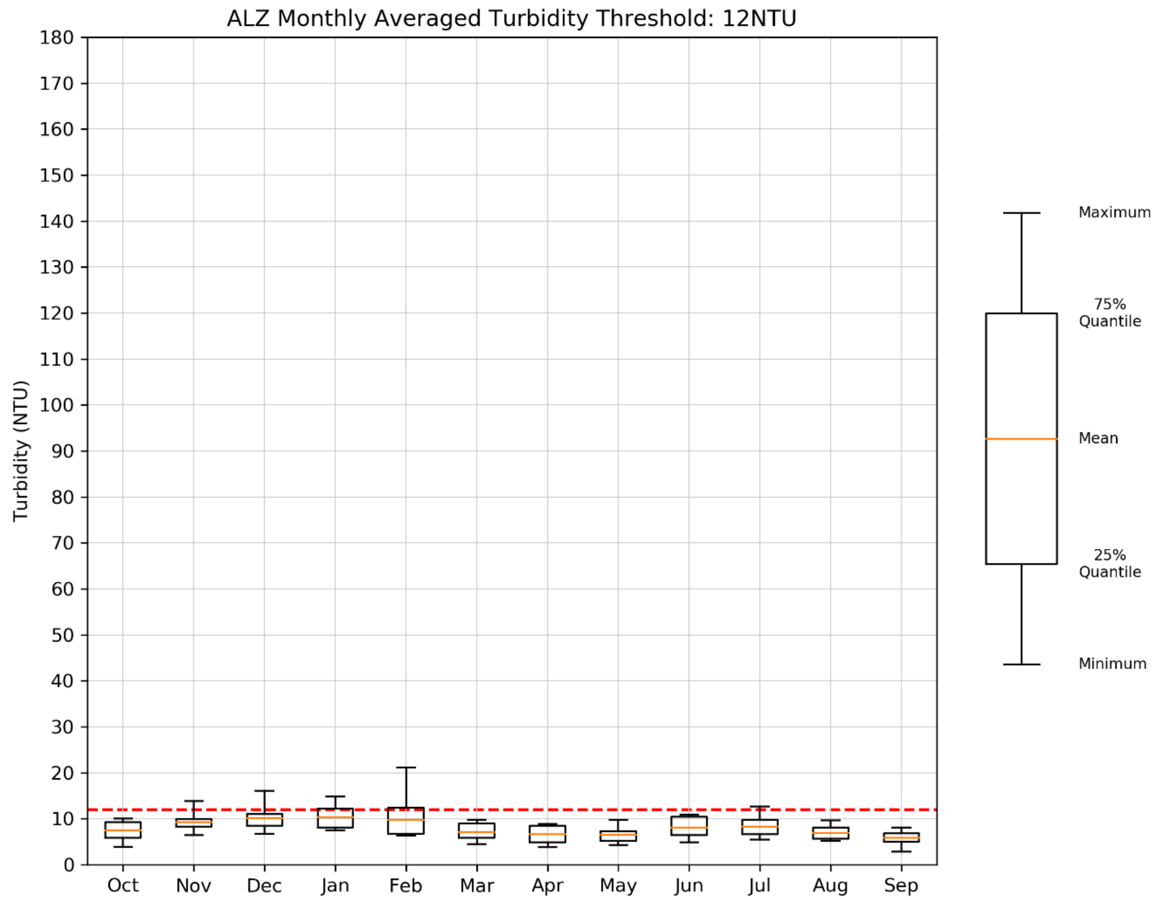

Figure 145. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station ALZ – Alcatraz Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean: top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

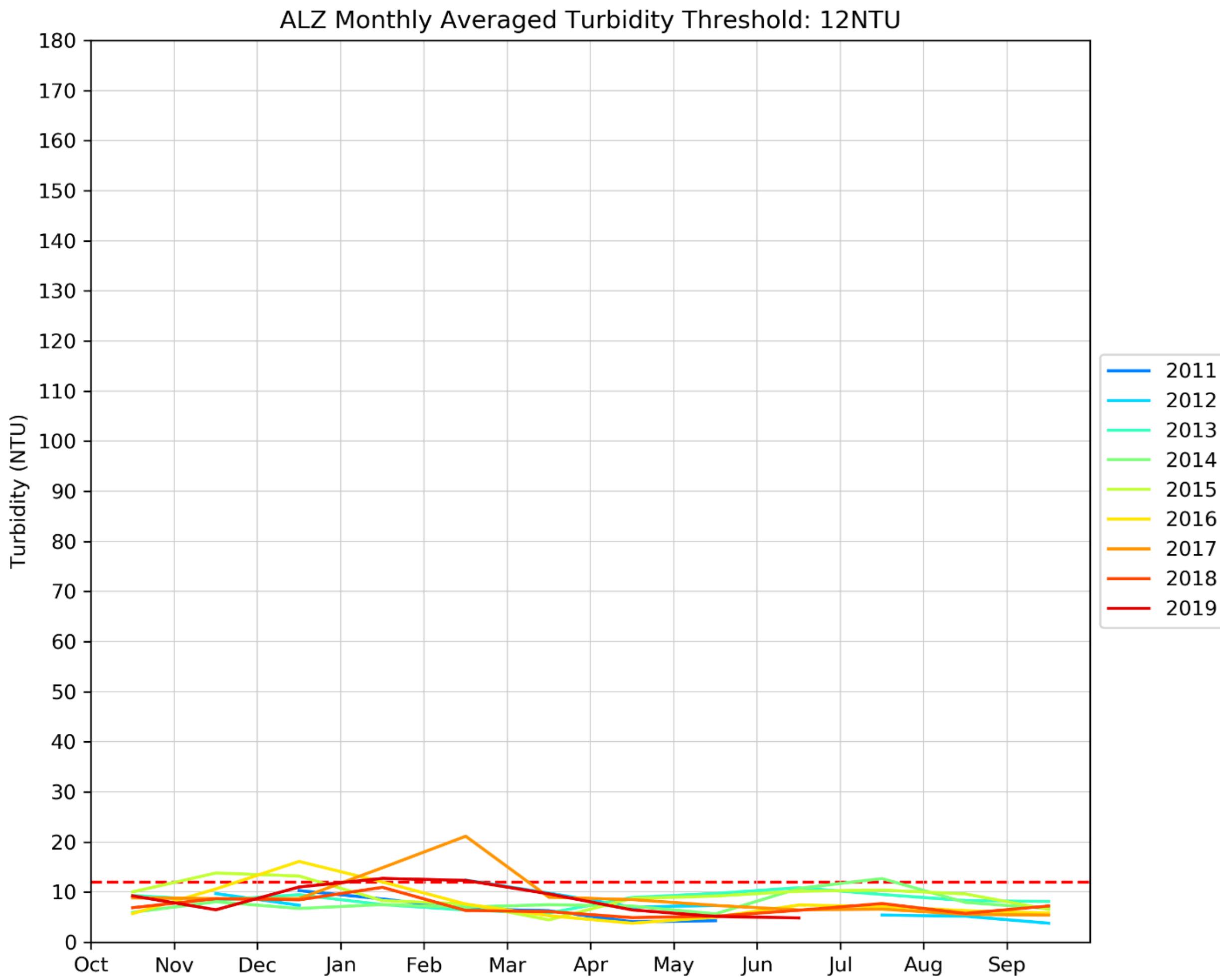

Figure 146. Monthly Average Turbidity for the Period of Record at Station ALZ – Alcatraz Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

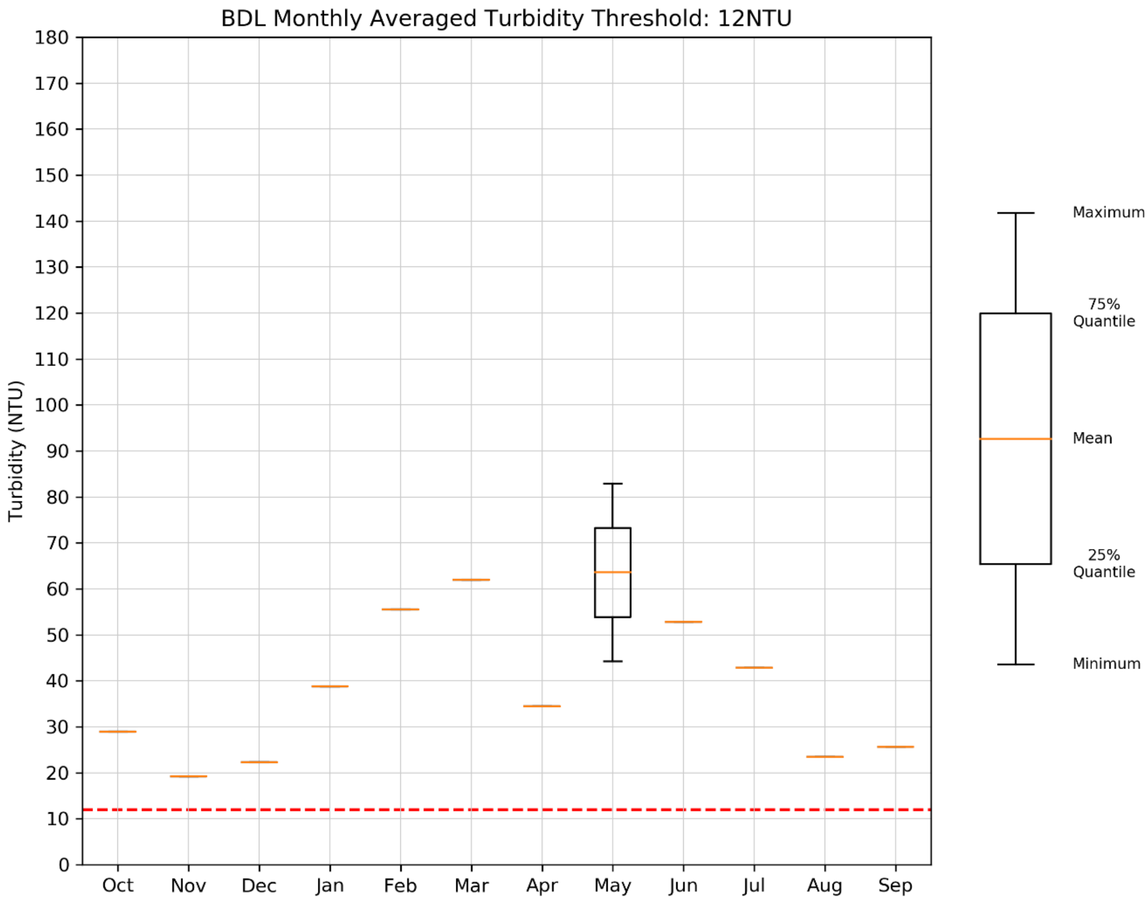

Figure 147. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station BDL – Montezuma Slough at Beldon Landing

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

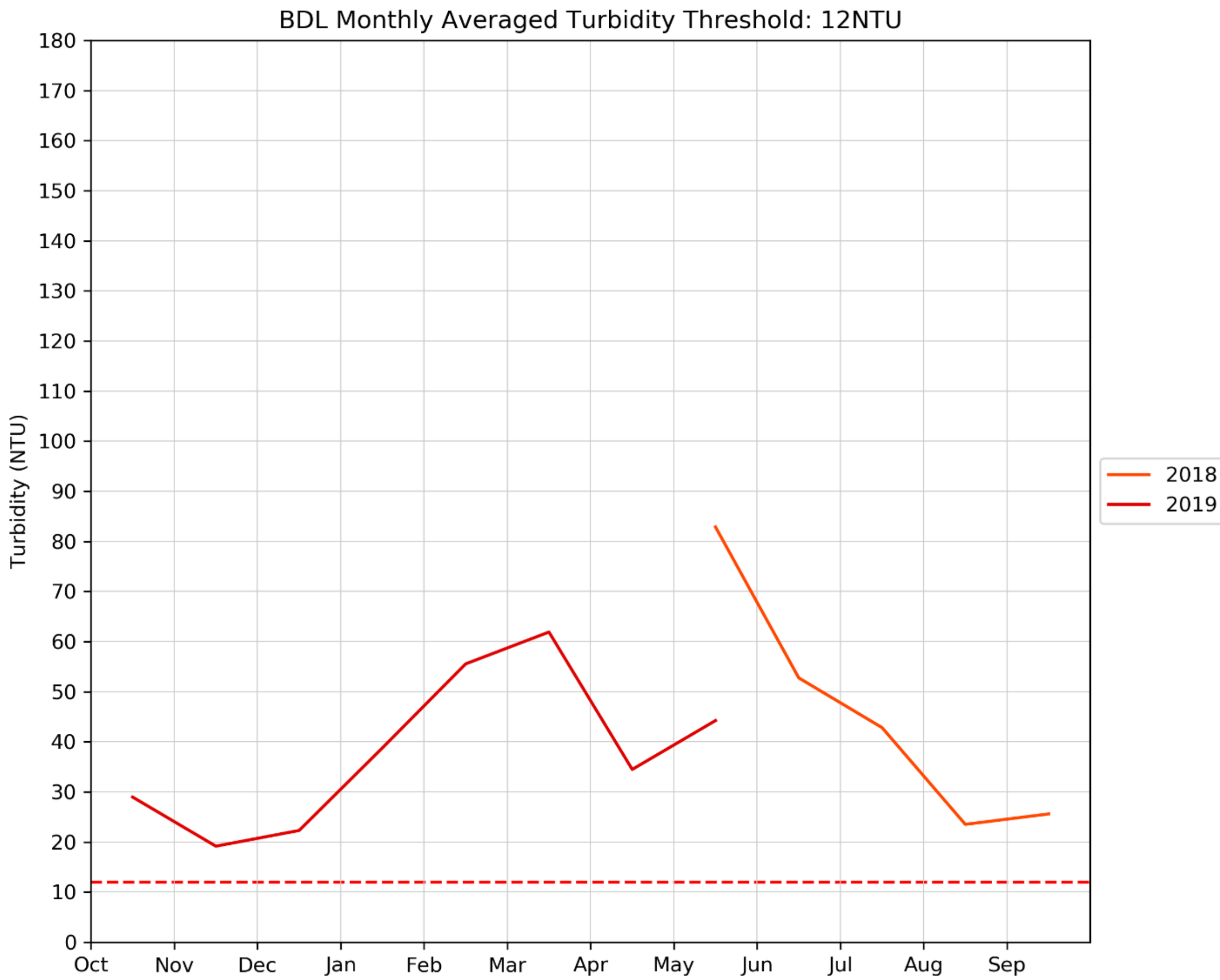

Figure 148. Monthly Average Turbidity for the Period of Record at Station BDL – Montezuma Slough at Beldon Landing

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

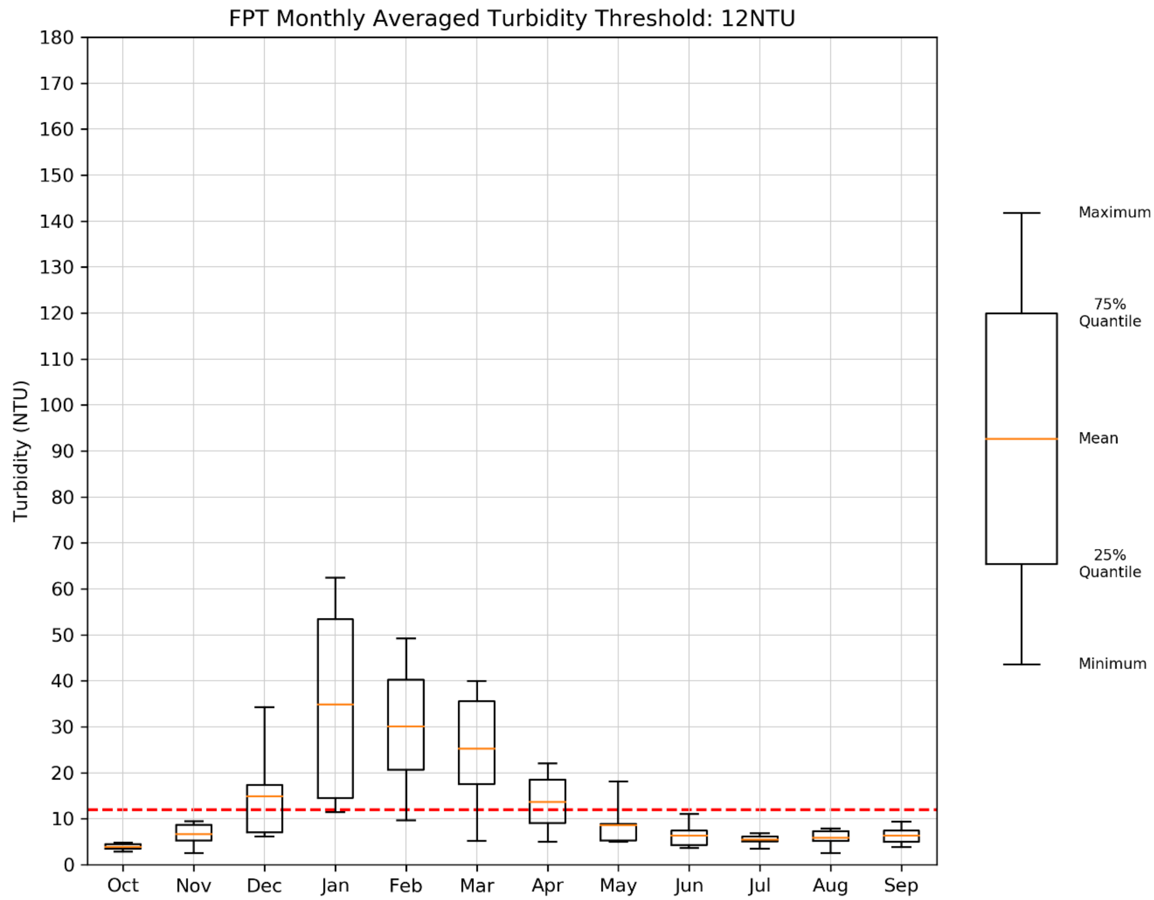

Figure 149. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station FPT – Sacramento River at Freeport

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

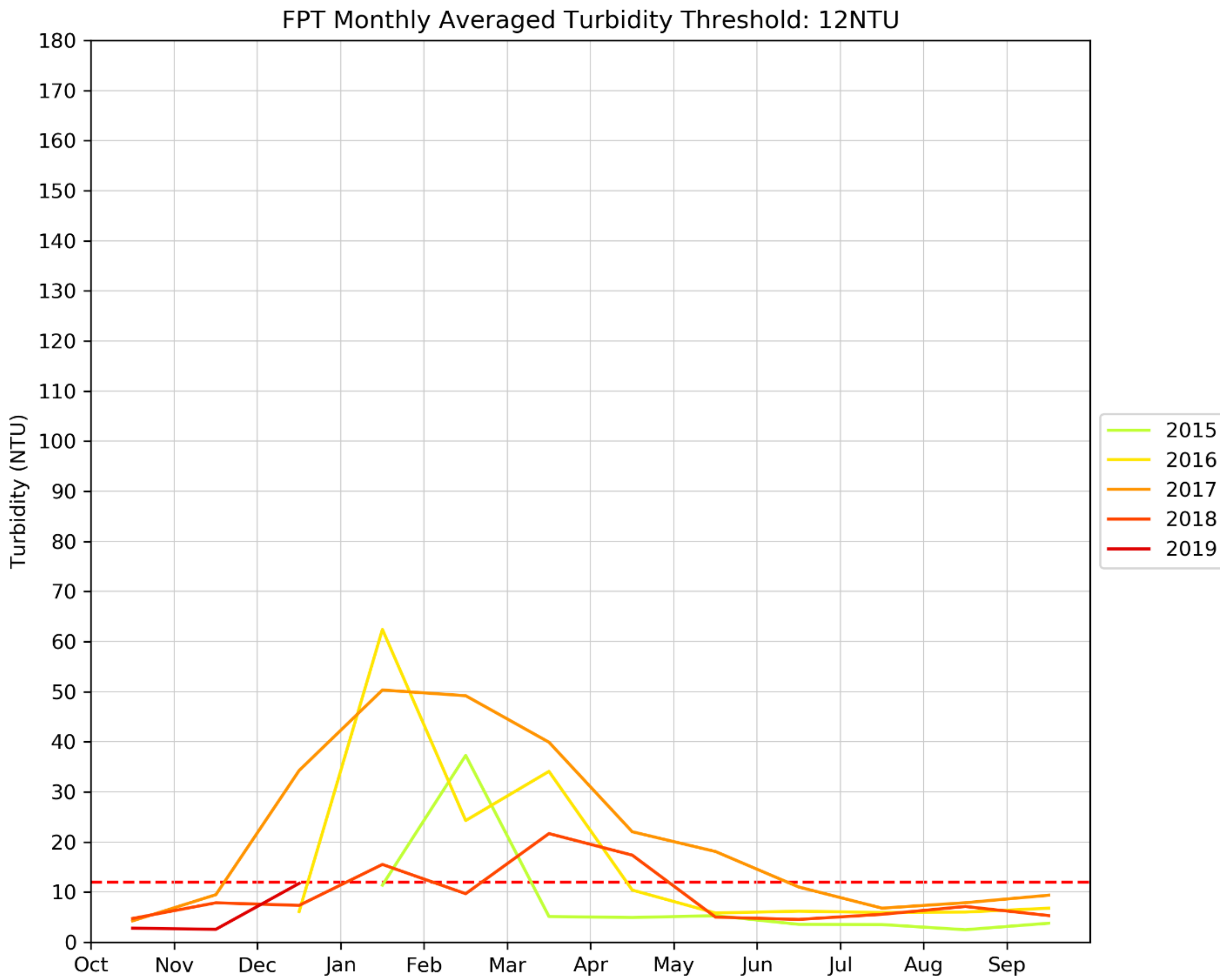

Figure 150. Monthly Average Turbidity for the Period of Record at Station FPT – Sacramento River at Freeport

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

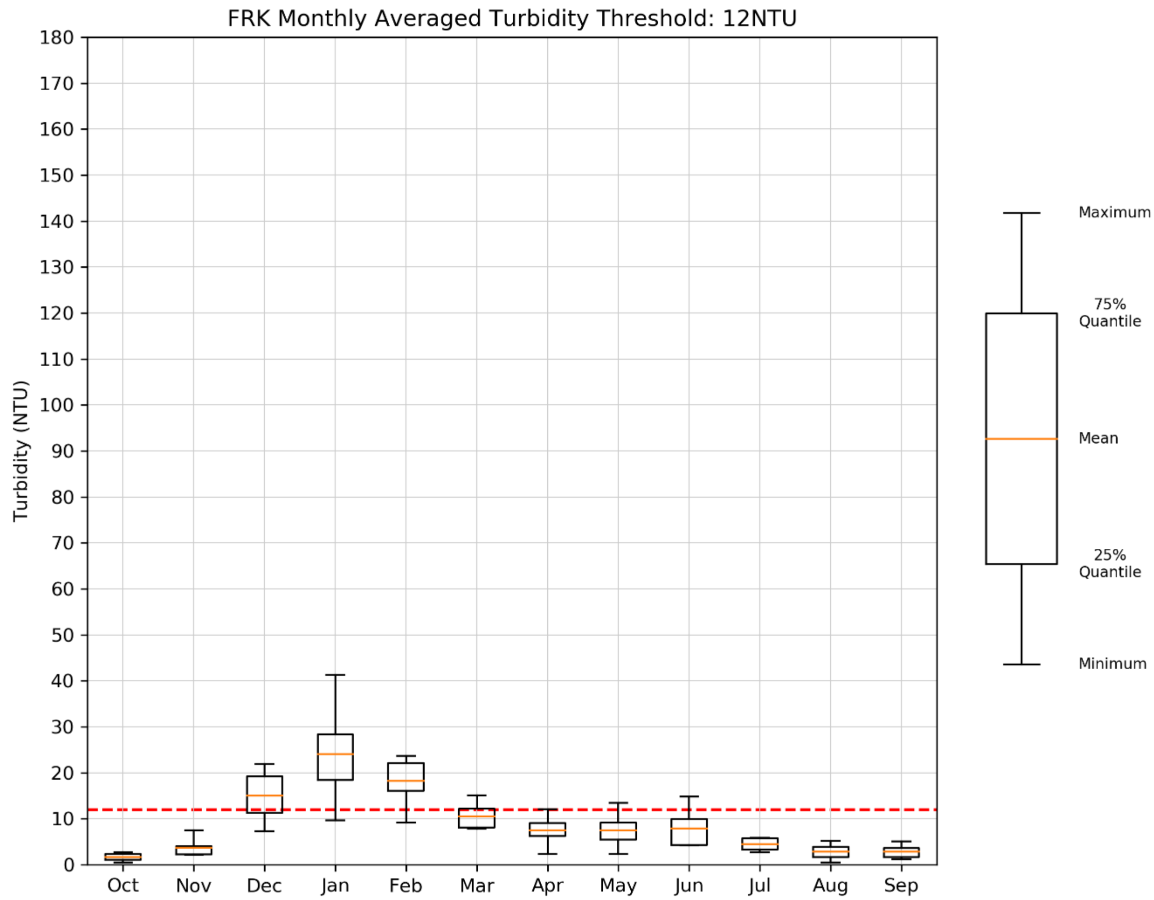

Figure 151. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station FRK – San Joaquin River Frank's Tract Mid Tract

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

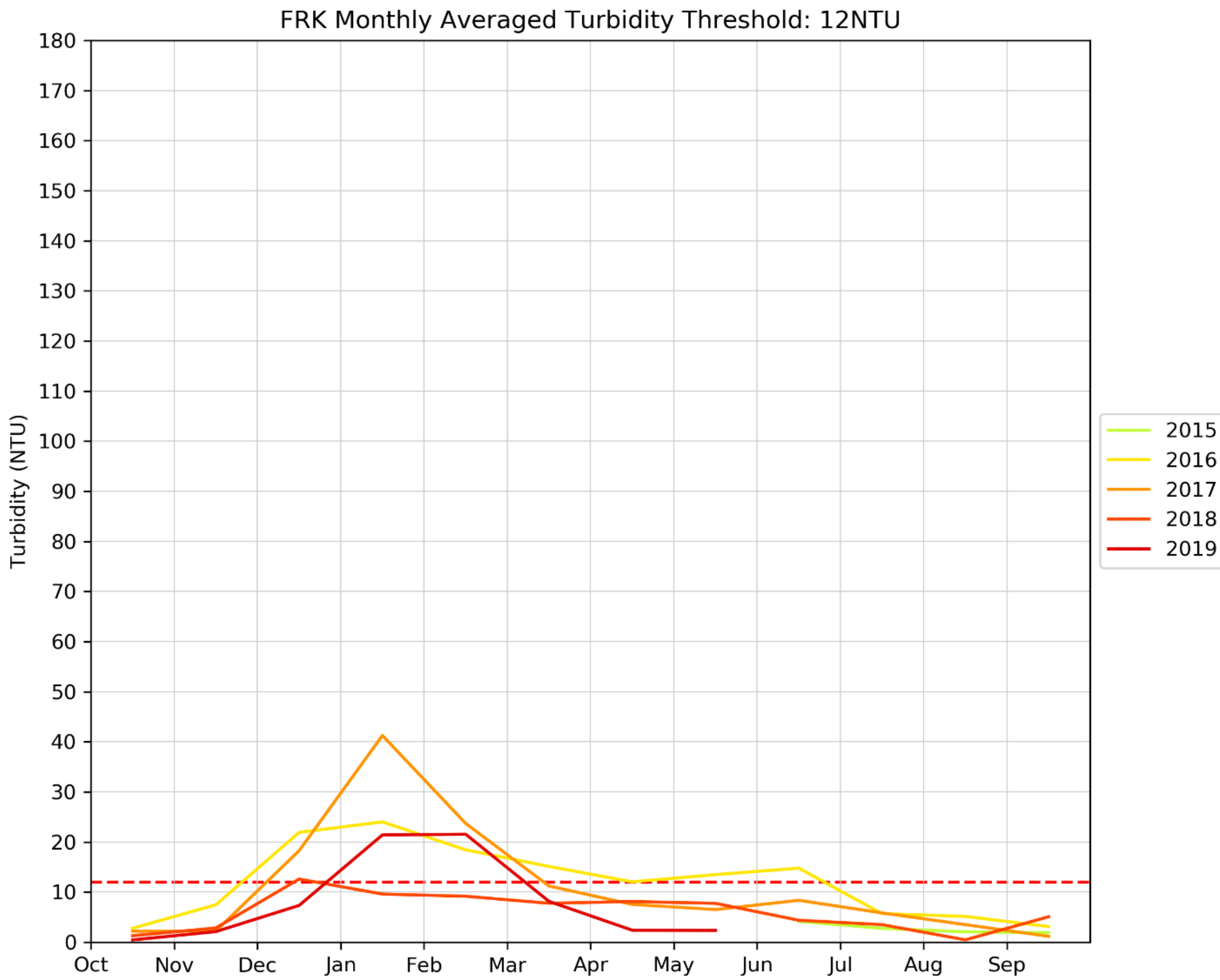

Figure 152. Monthly Average Turbidity for the Period of Record at Station FRK – San Joaquin River Frank's Tract Mid Tract

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

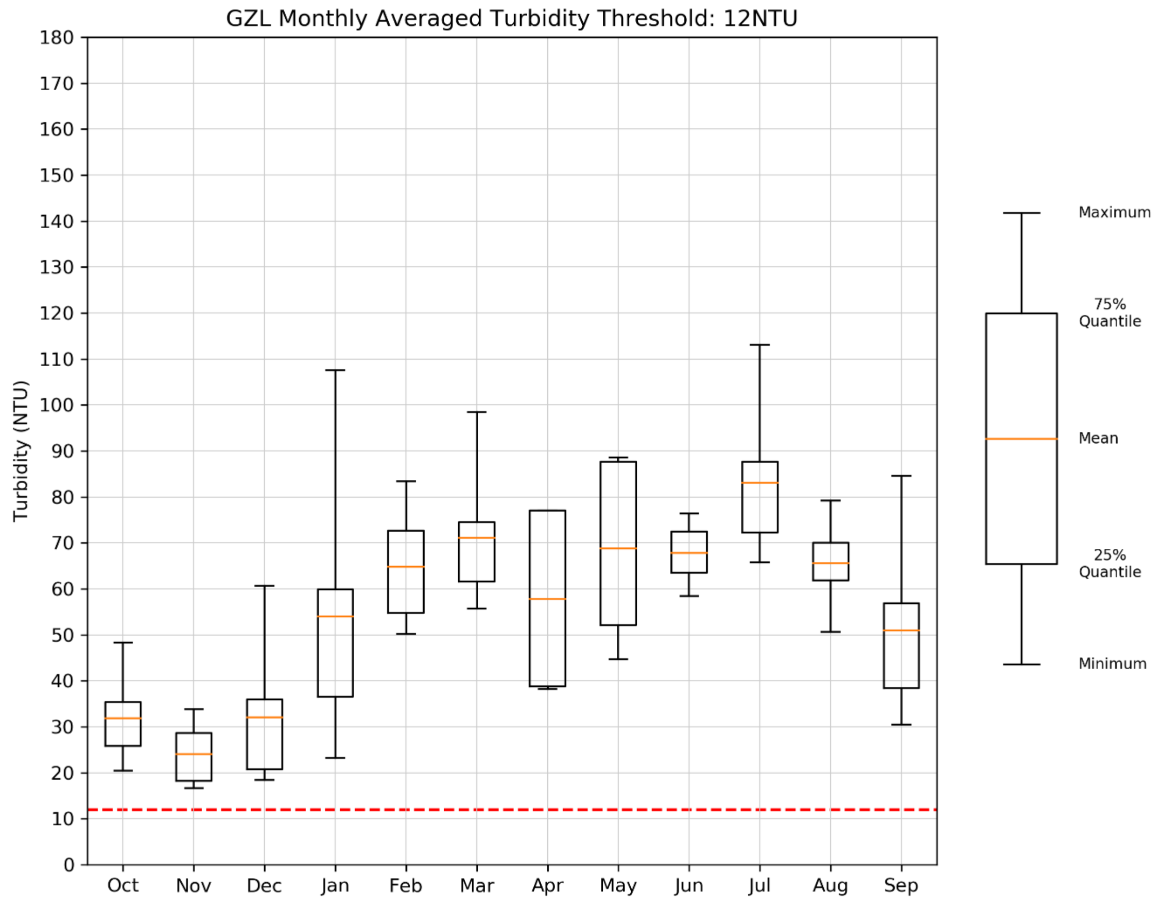

Figure 153. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station GZL – Grizzly Bay

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

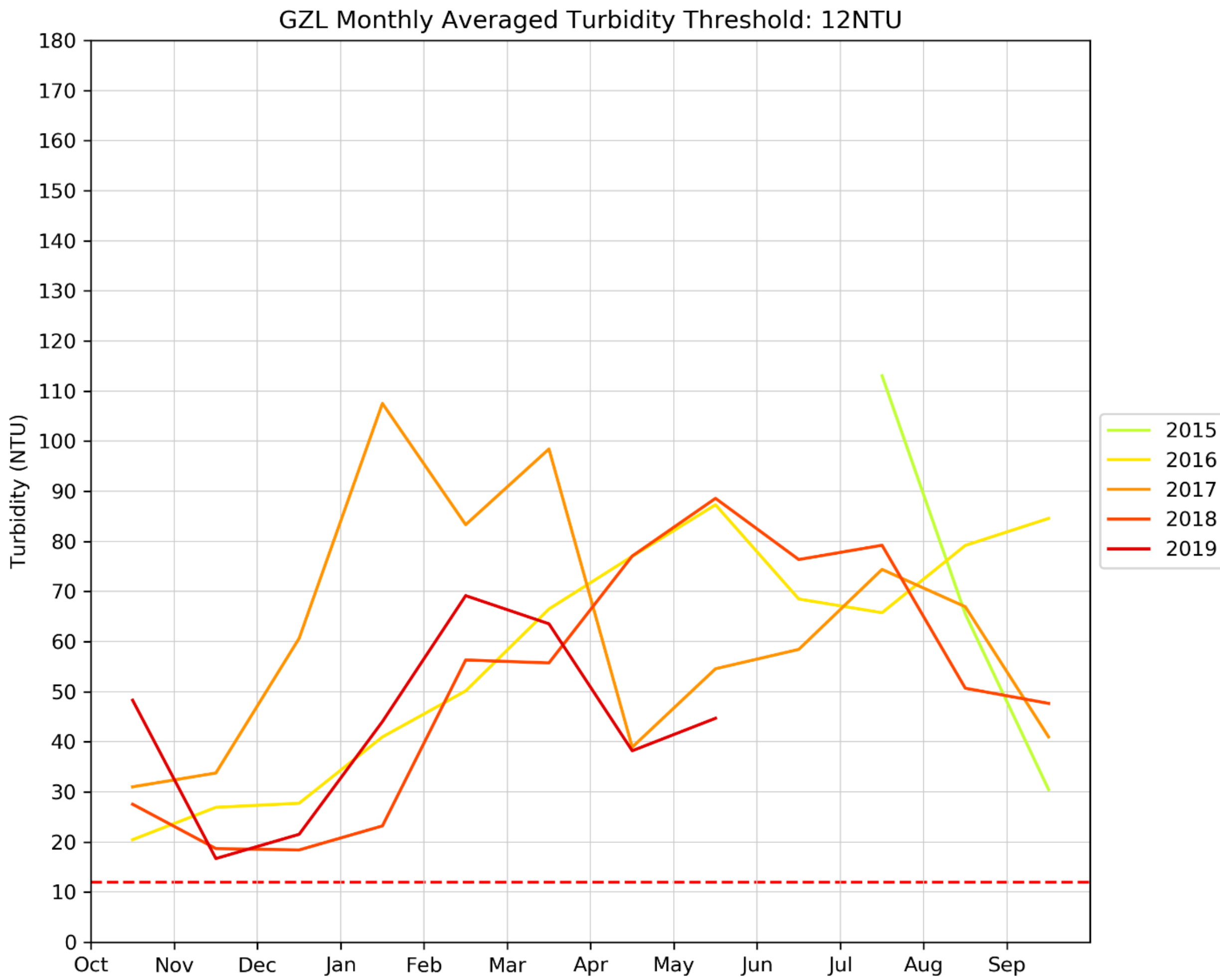

Figure 154. Monthly Average Turbidity for the Period of Record at Station GZL – Grizzly Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

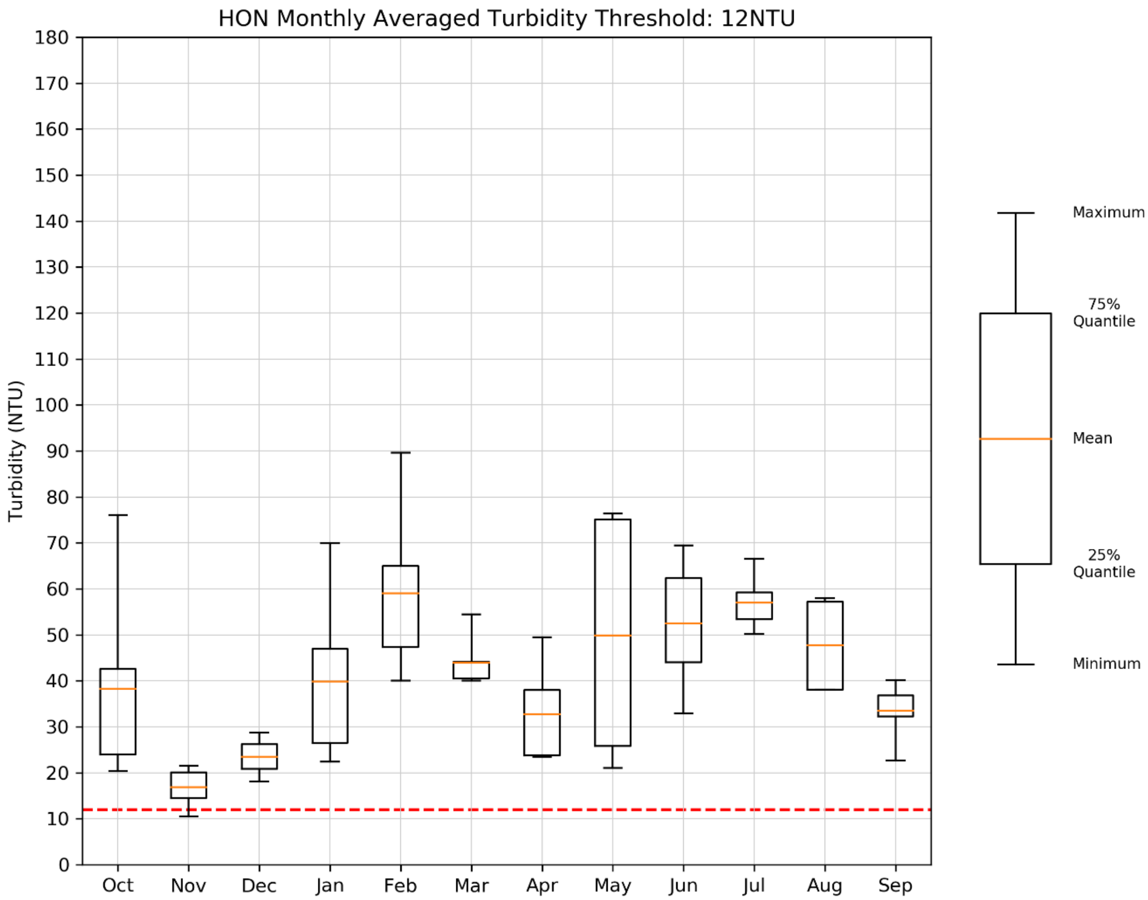

Figure 155. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HON – Honker Bay

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

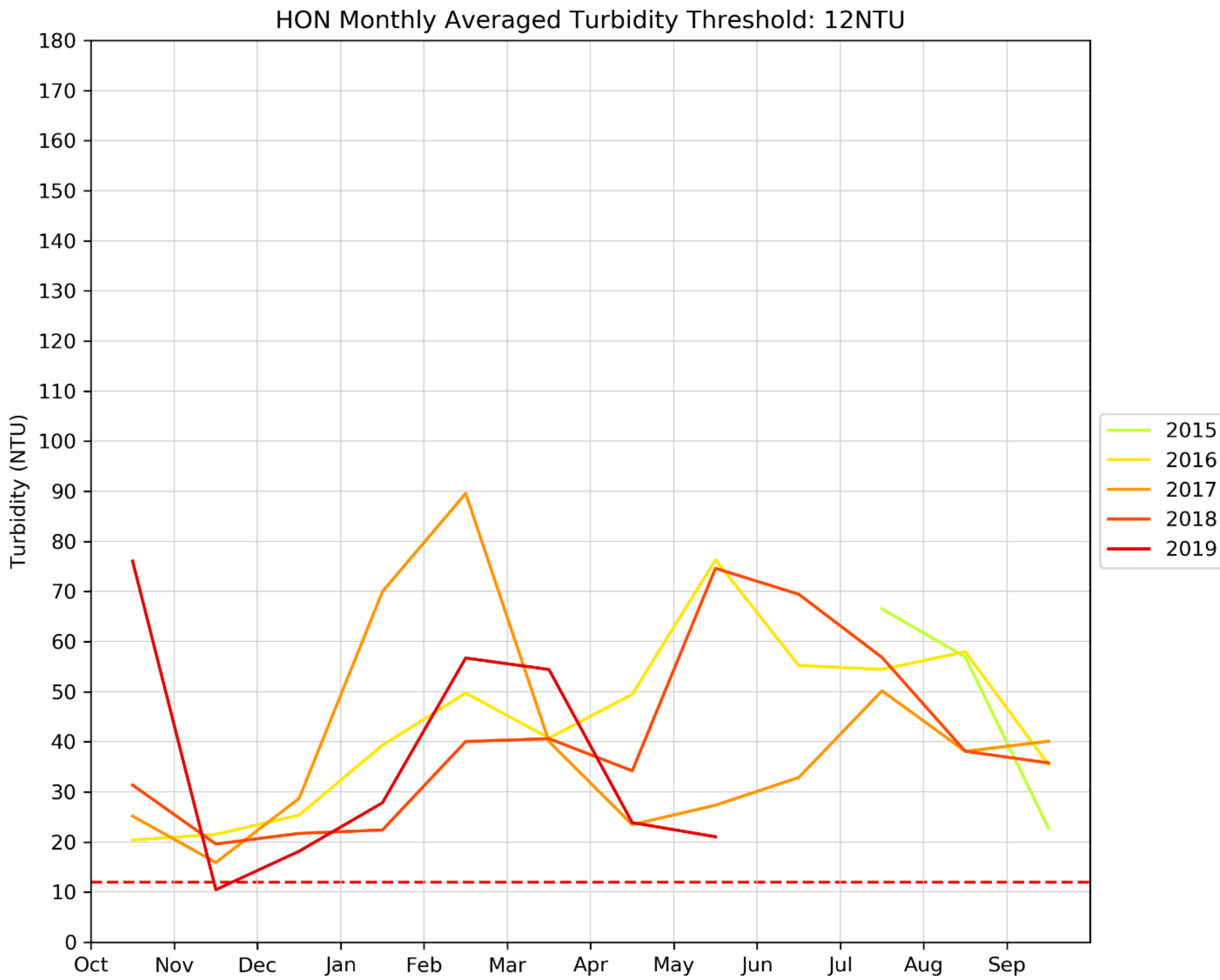

Figure 156. Monthly Average Turbidity for the Period of Record at Station HON – Honker Bay

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

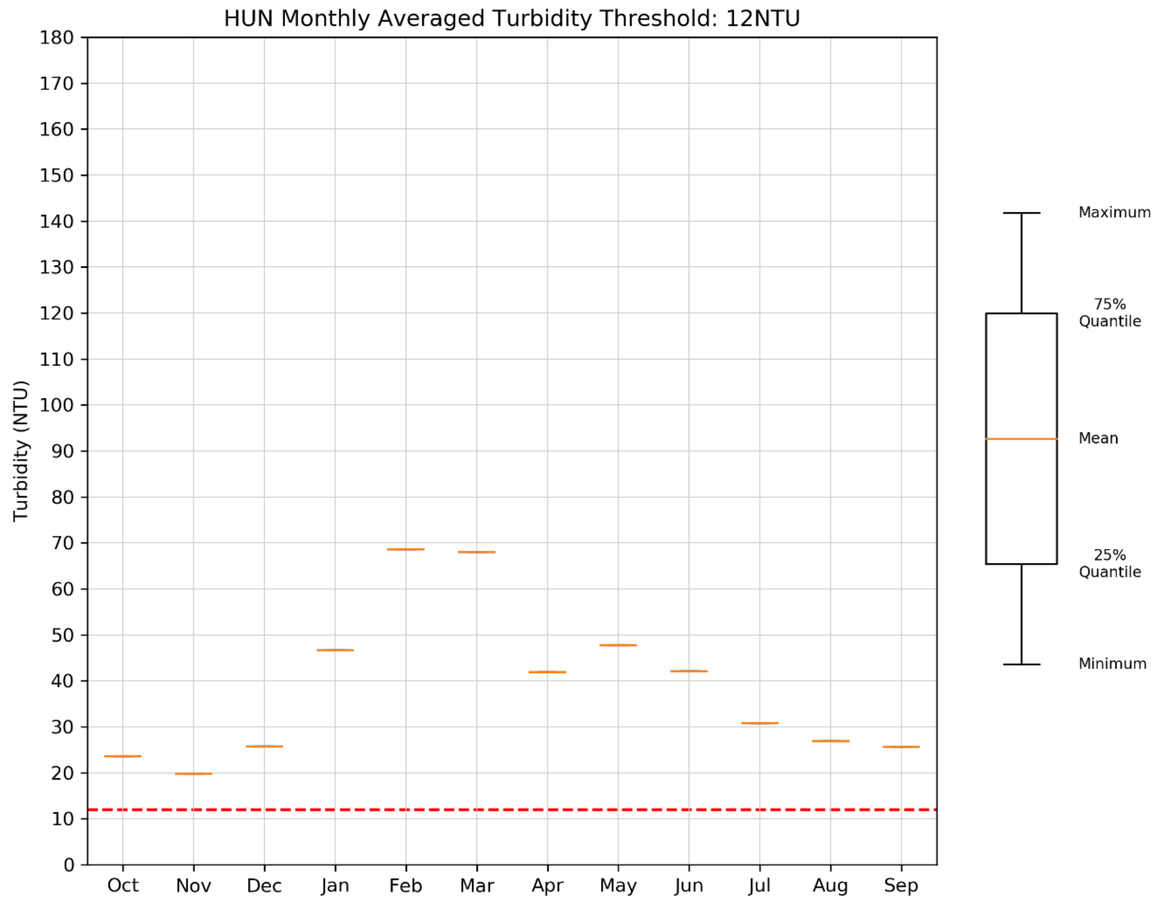

Figure 157. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HUN – Hunter Cut at Montezuma Slough

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

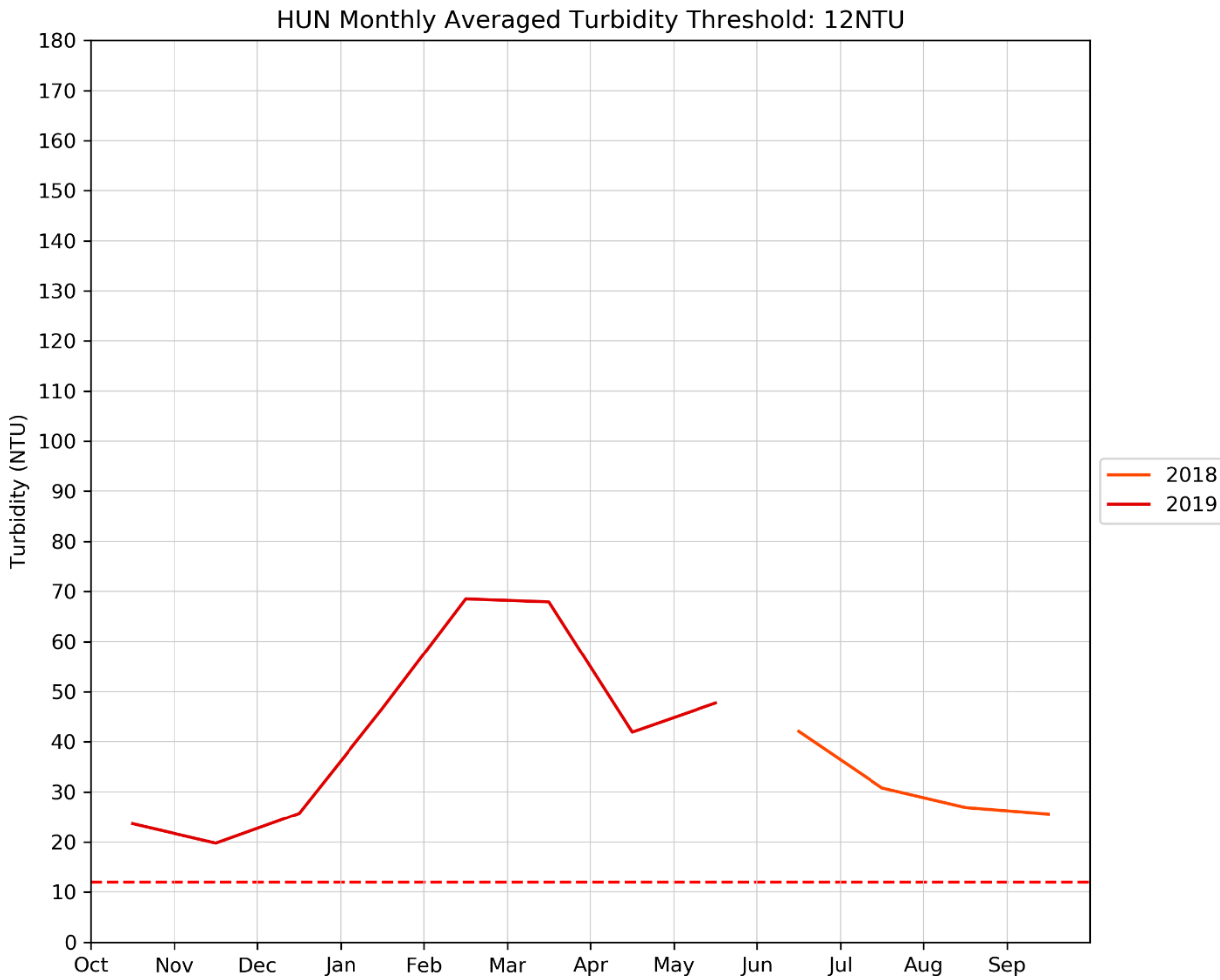

Figure 158. Monthly Average Turbidity for the Period of Record at Station HUN – Hunter Cut at Montezuma Slough

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

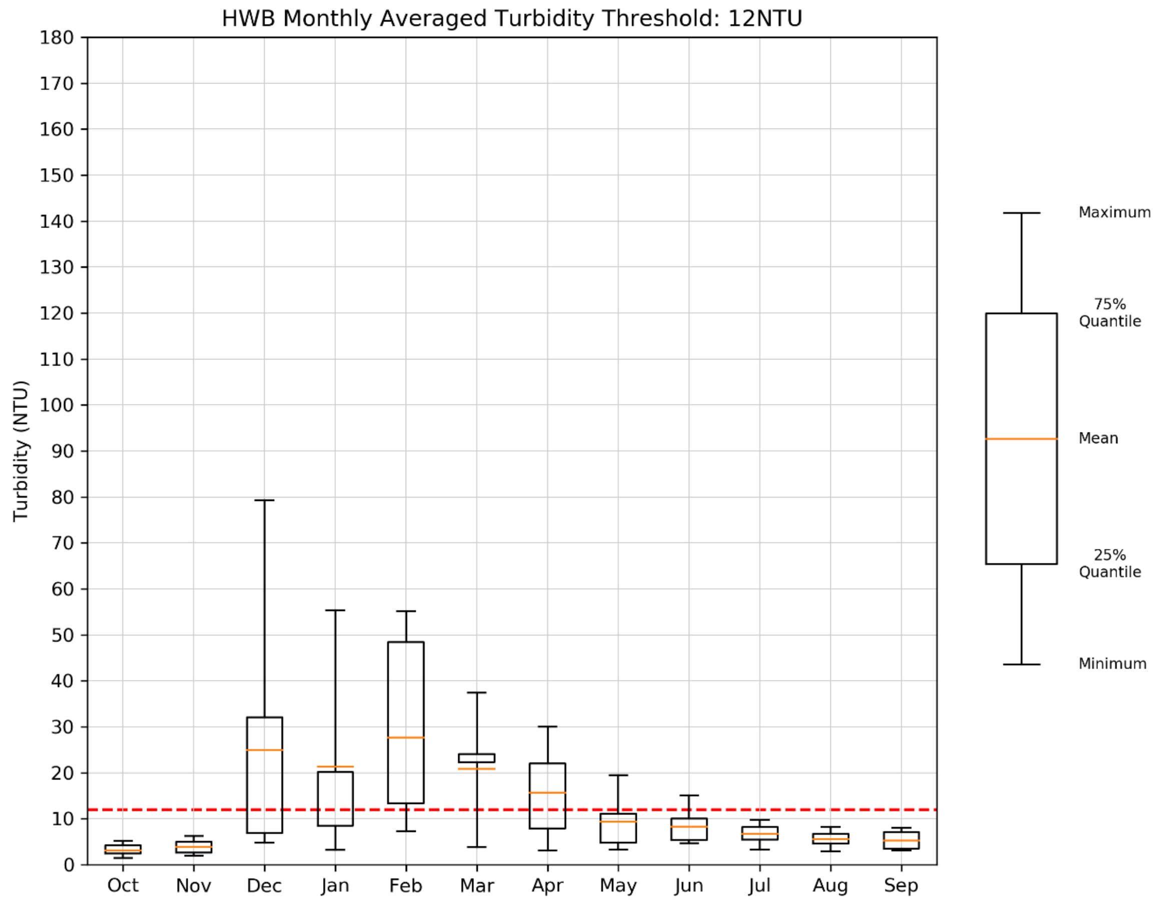

Figure 159. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

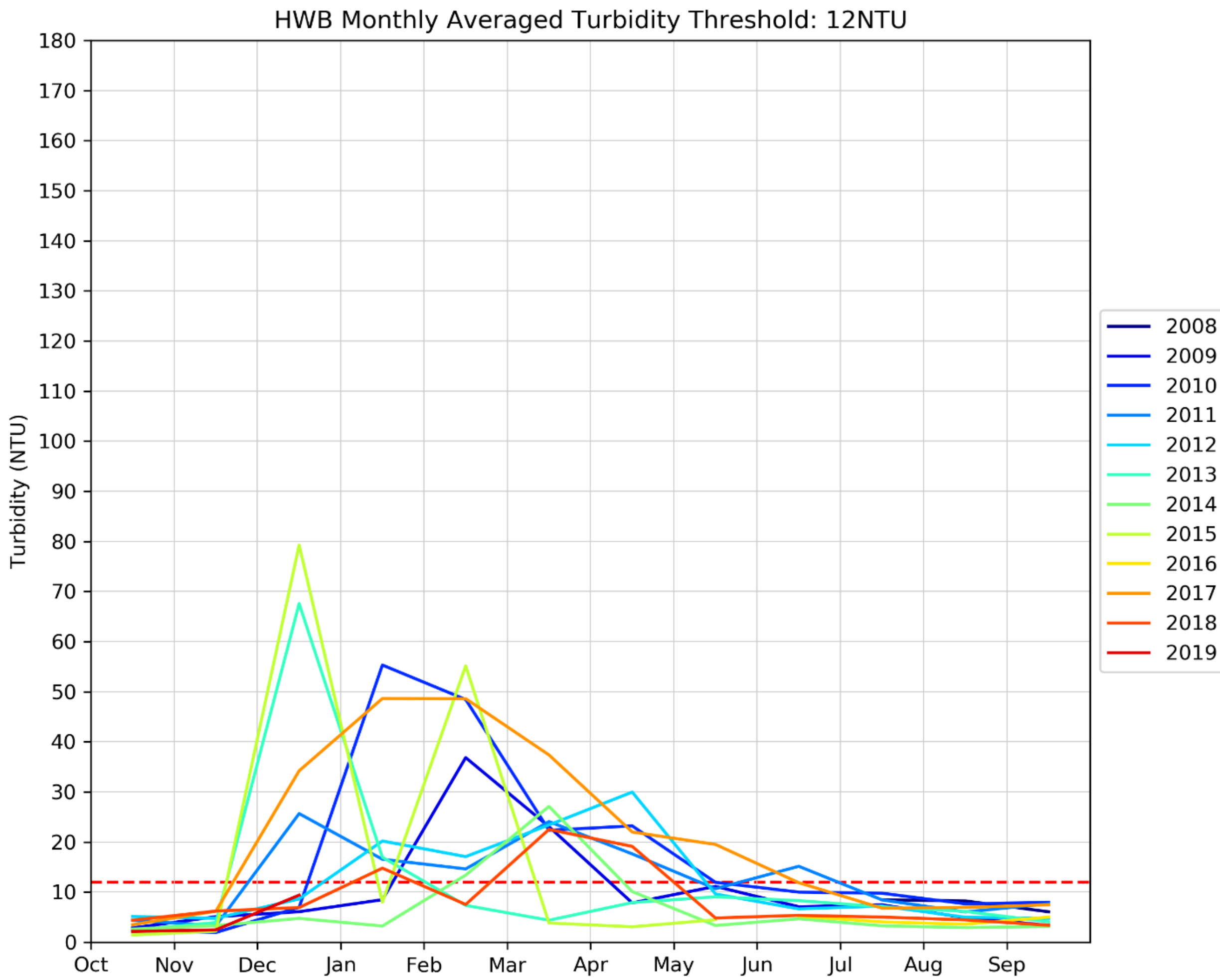

Figure 160. Monthly Average Turbidity for the Period of Record at Station HWB – Miner Slough at Highway 84 Bridge

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

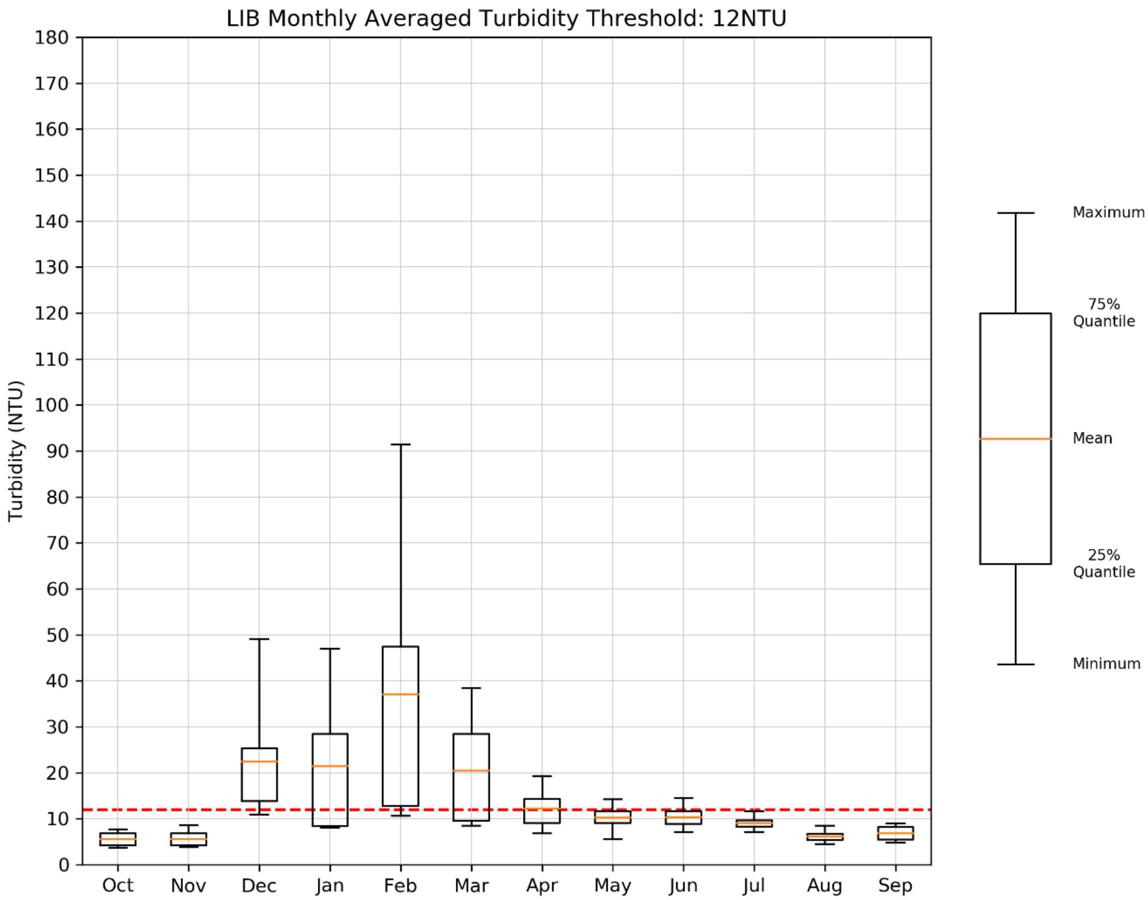

Figure 161. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station LIB – Liberty Island at Approximately Center South End

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

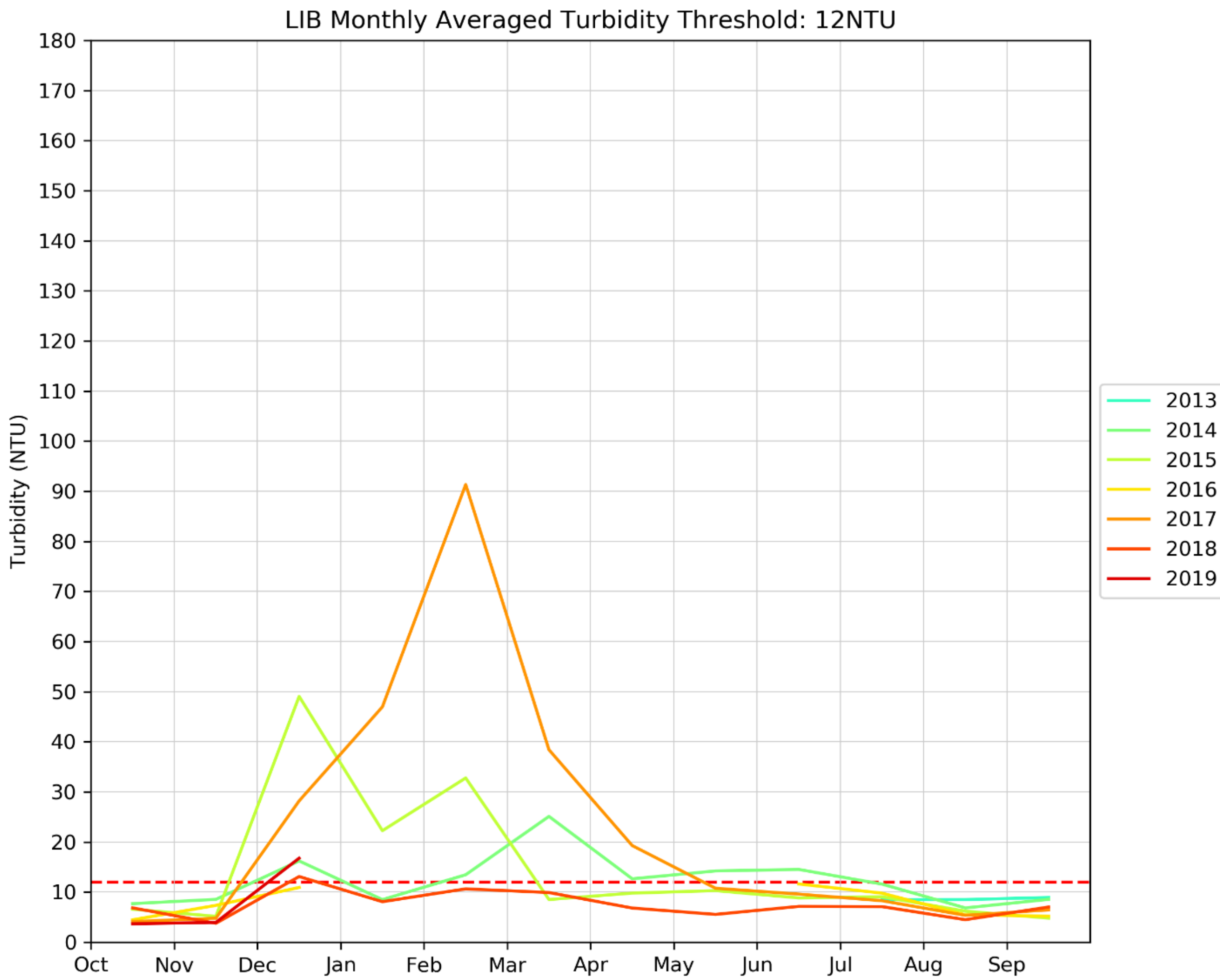

Figure 162. Monthly Average Turbidity for the Period of Record at Station LIB –Liberty Island at Approximately Center South End

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

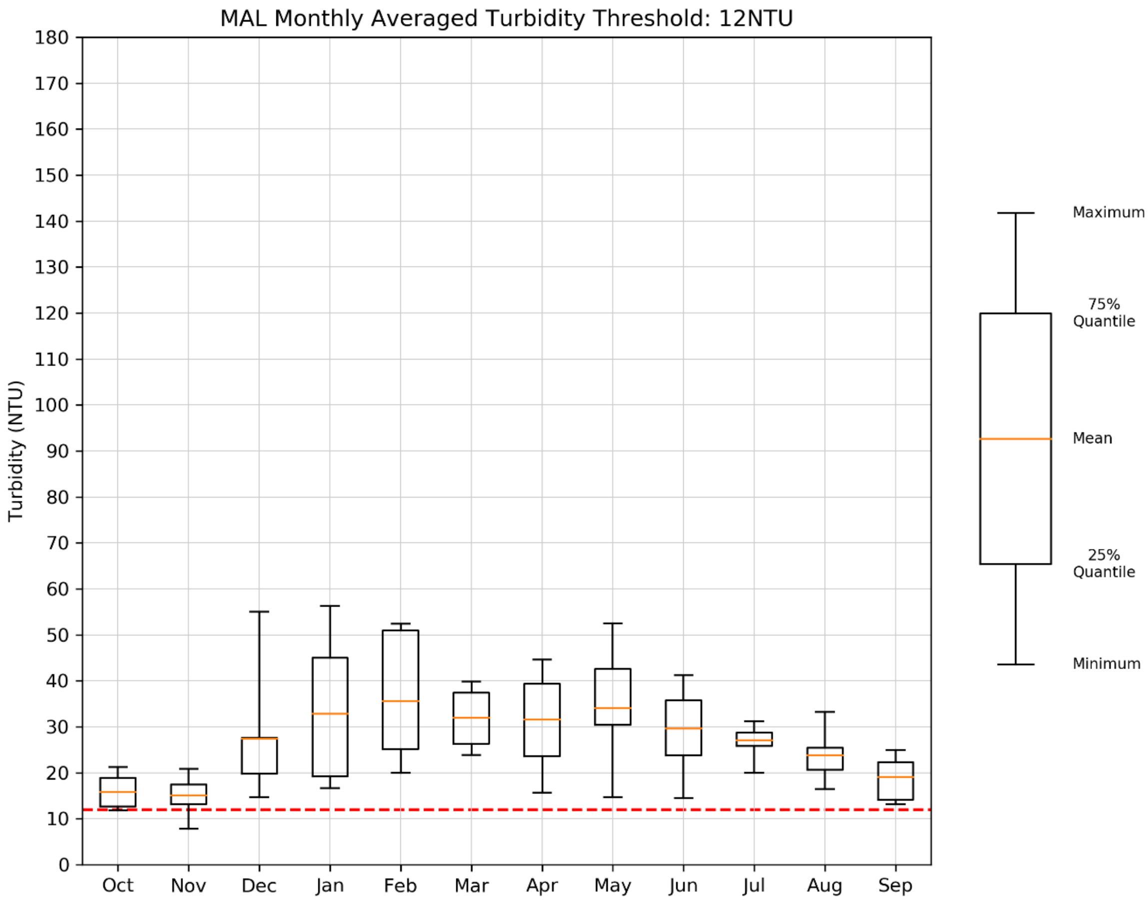

Figure 163. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MAL – Sacramento River at Mallard Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

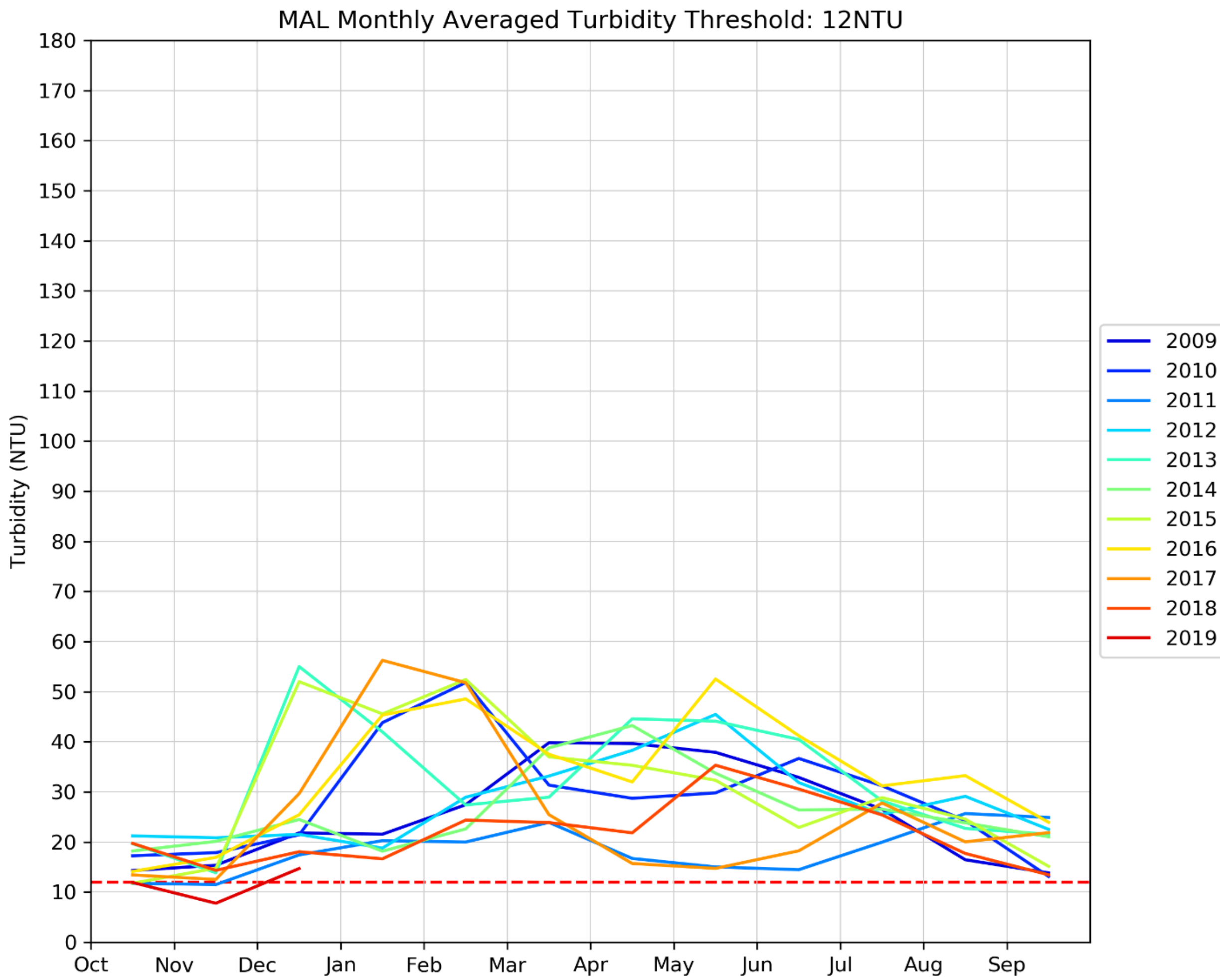

Figure 164. Monthly Average Turbidity for the Period of Record at Station MAL – Sacramento River at Mallard Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

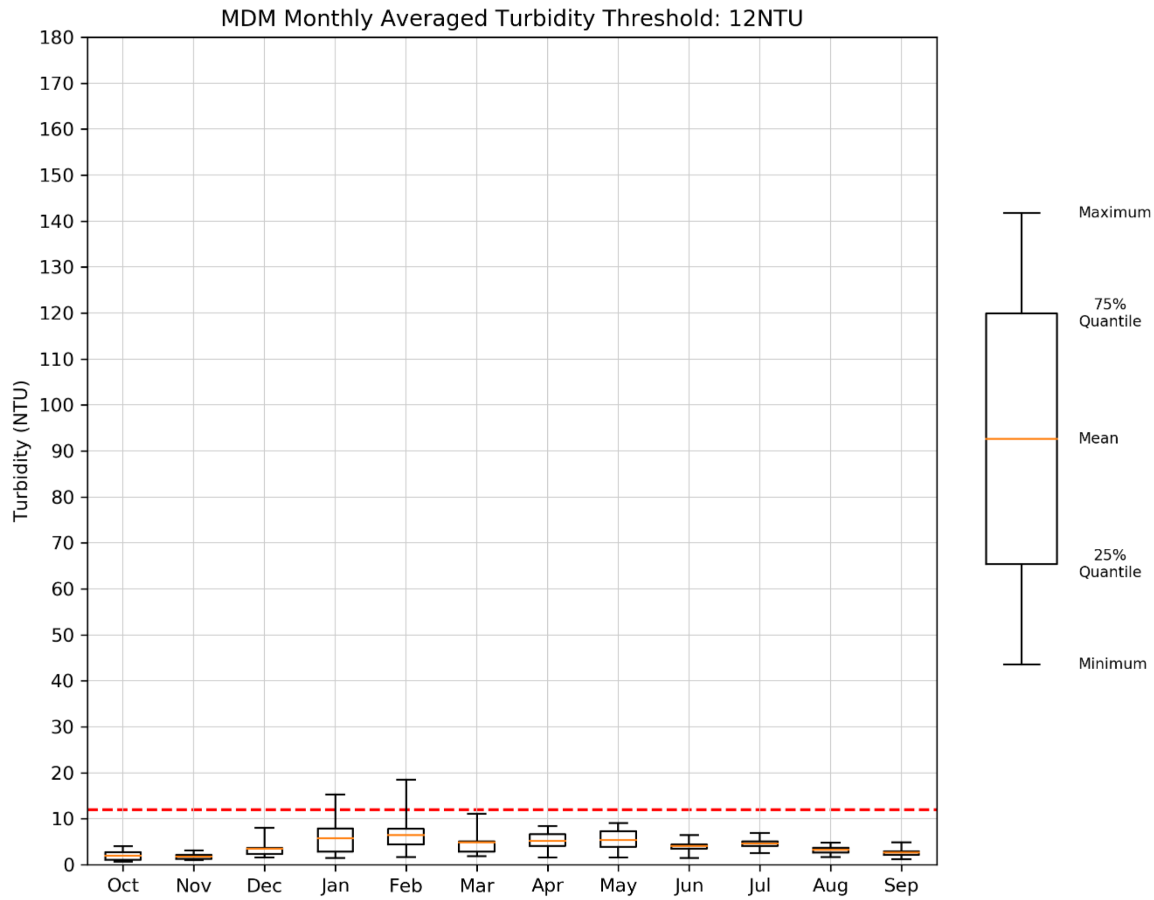

Figure 165. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MDM –- Middle River at Middle River

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

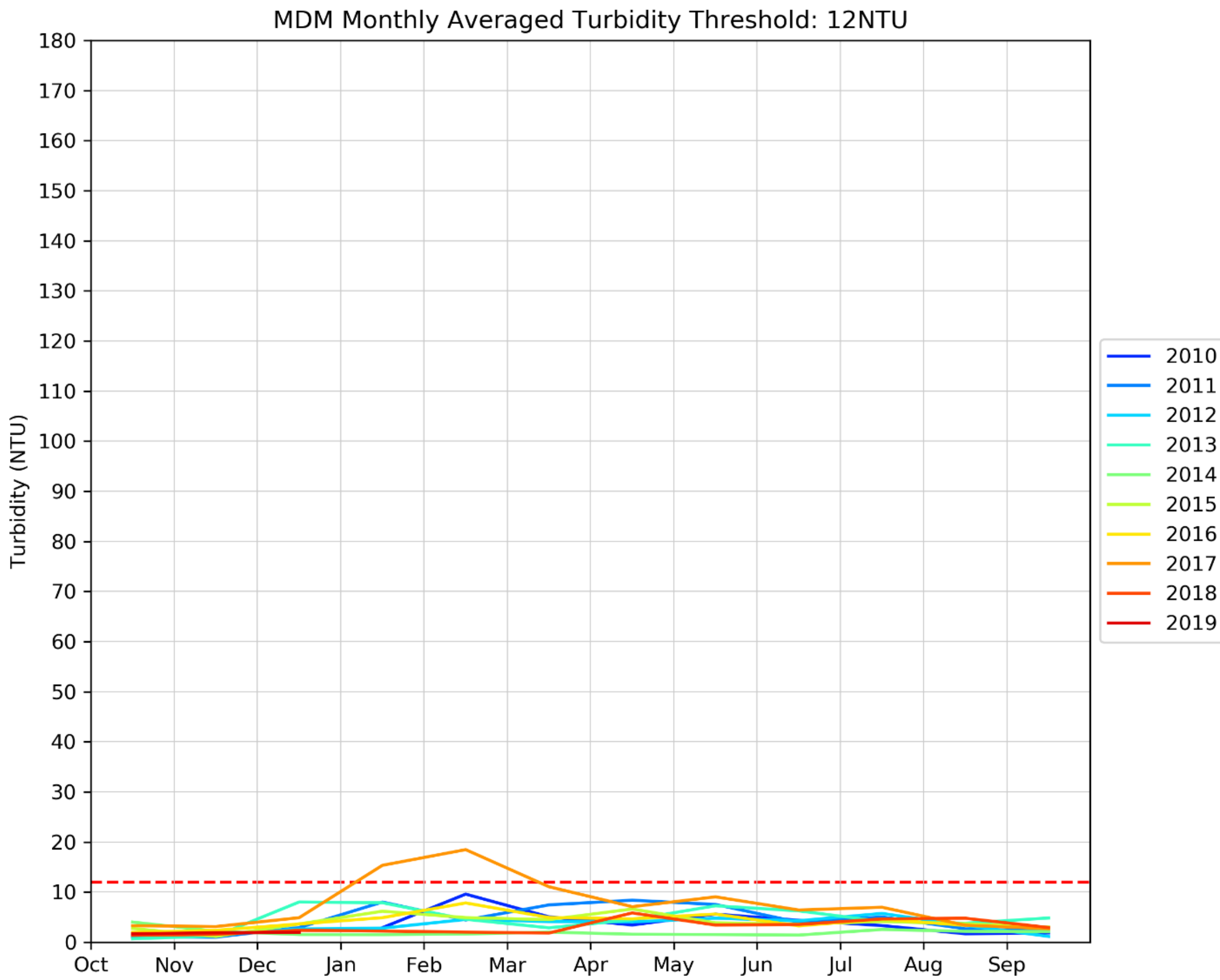

Figure 166. Monthly Average Turbidity for the Period of Record at Station MDM – Middle River at Middle River

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

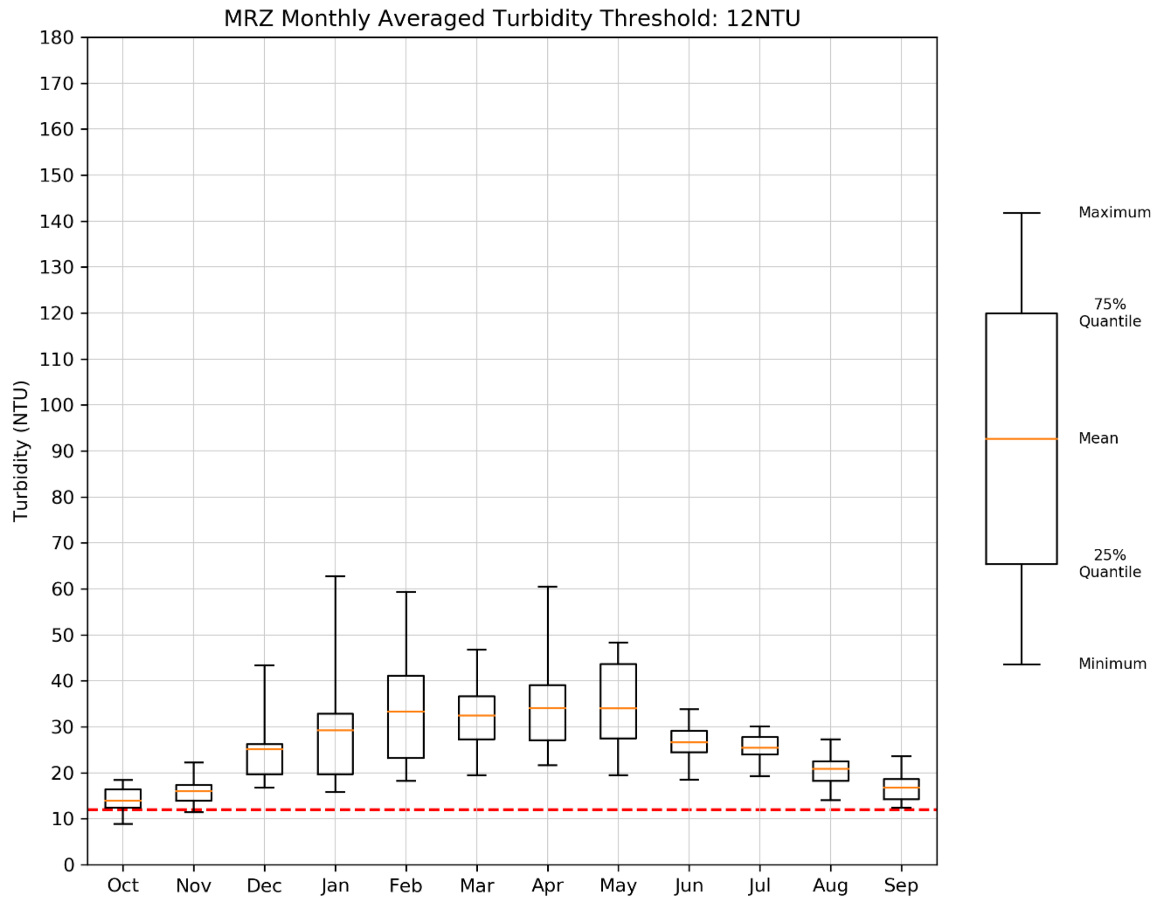

Figure 167. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station MRZ - Martinez

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

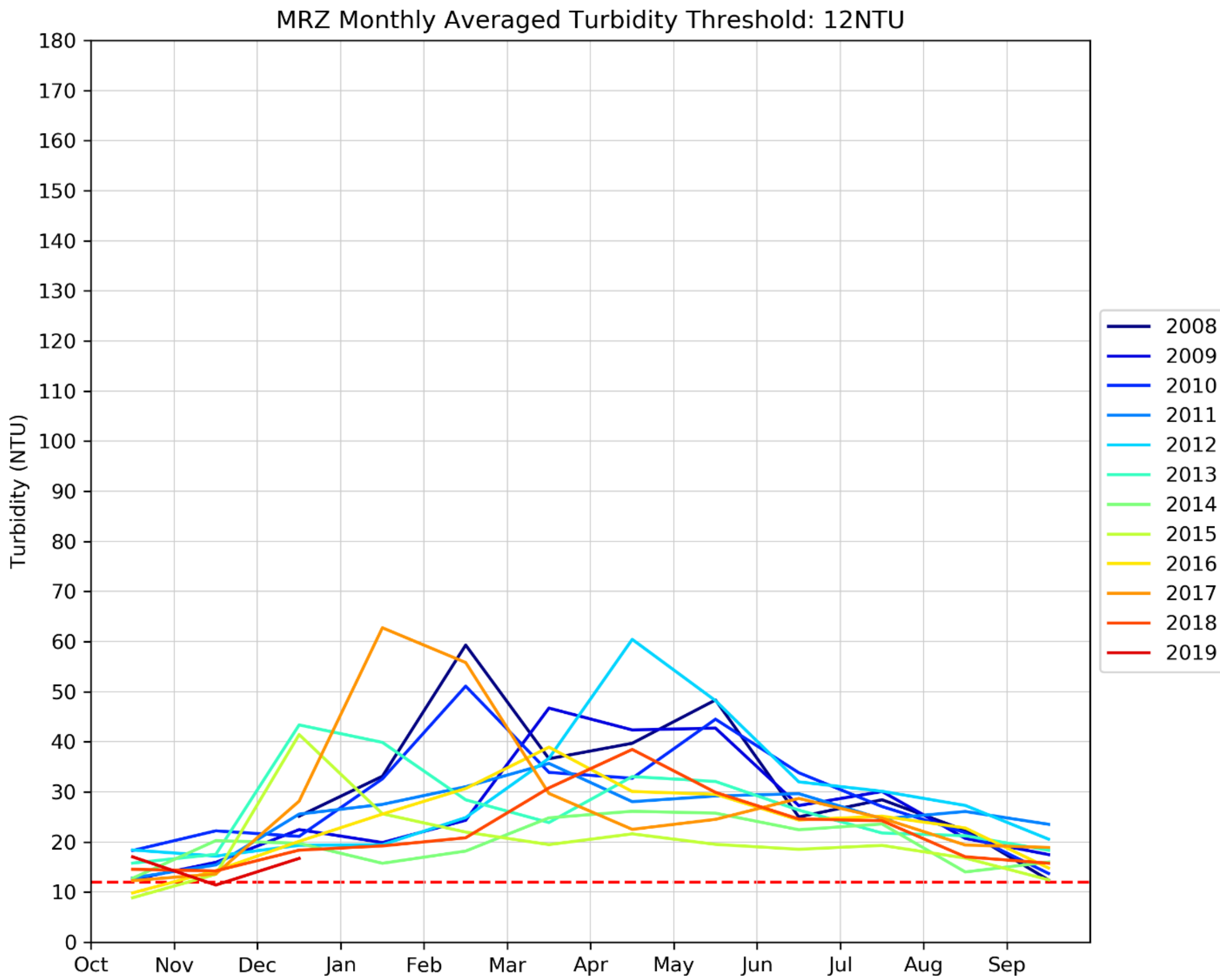

Figure 168. Monthly Average Turbidity for the Period of Record at Station MRZ – Martinez

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

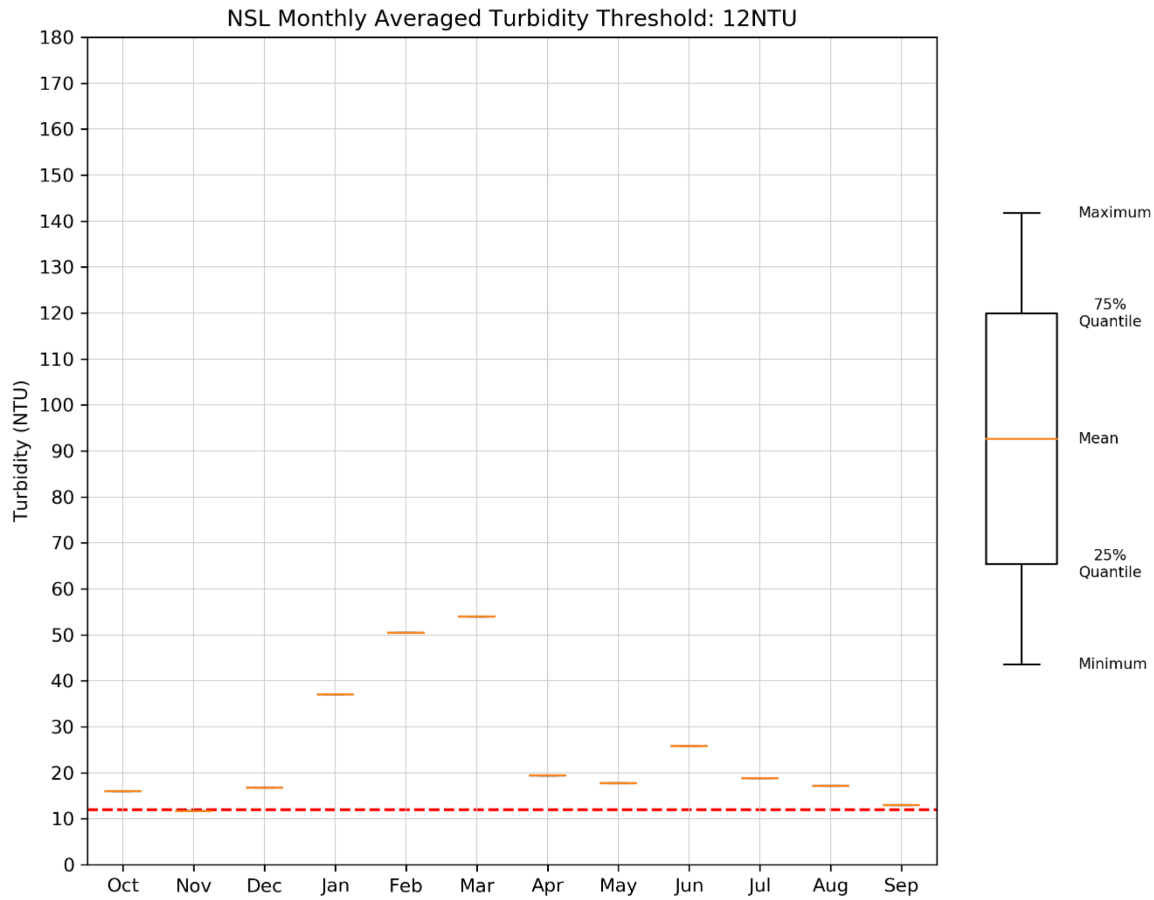

Figure 169. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station NSL – Montezuma Slough at National Steel

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

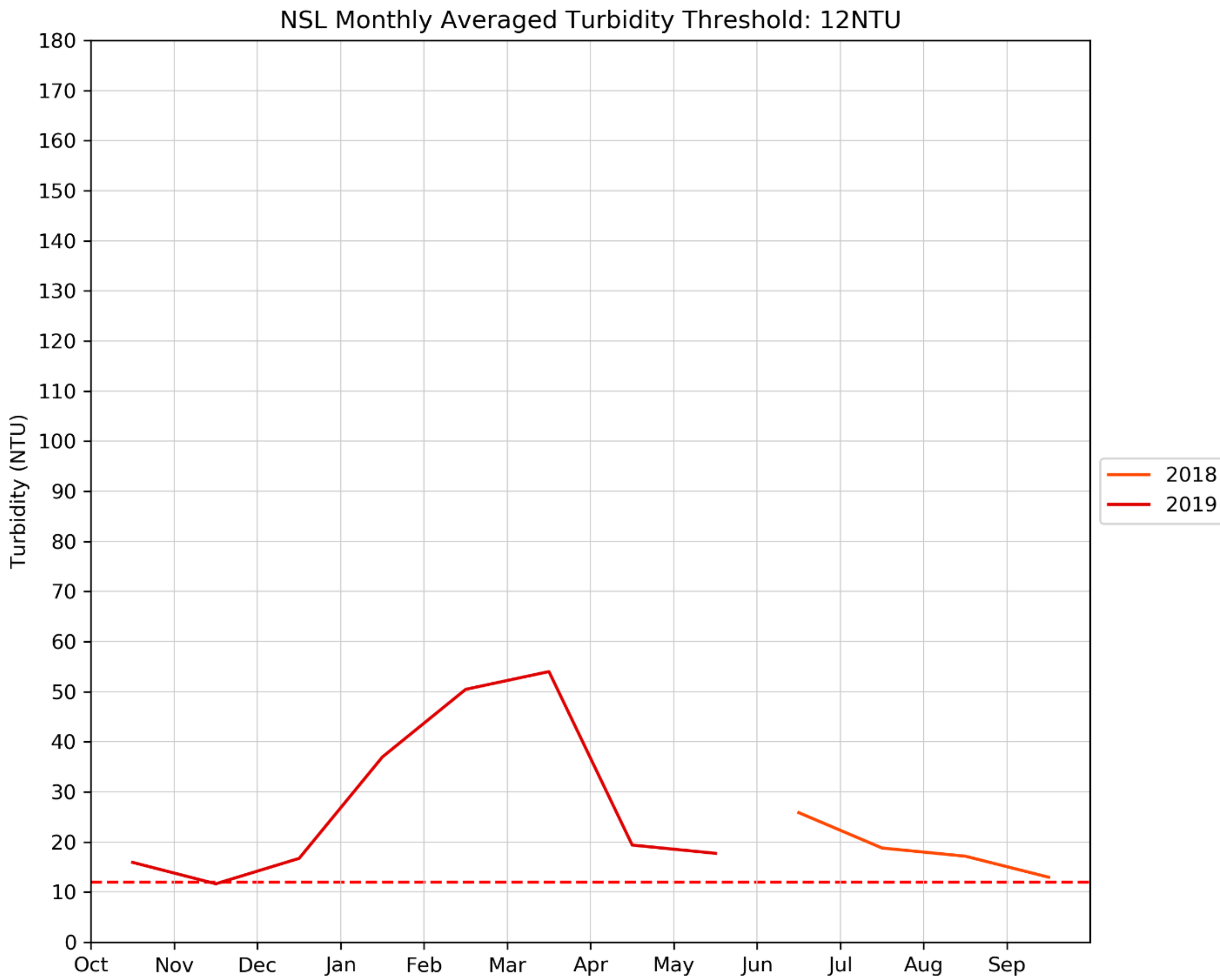

Figure 170. Monthly Average Turbidity for the Period of Record at Station NSL – Montezuma Slough at National Steel

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

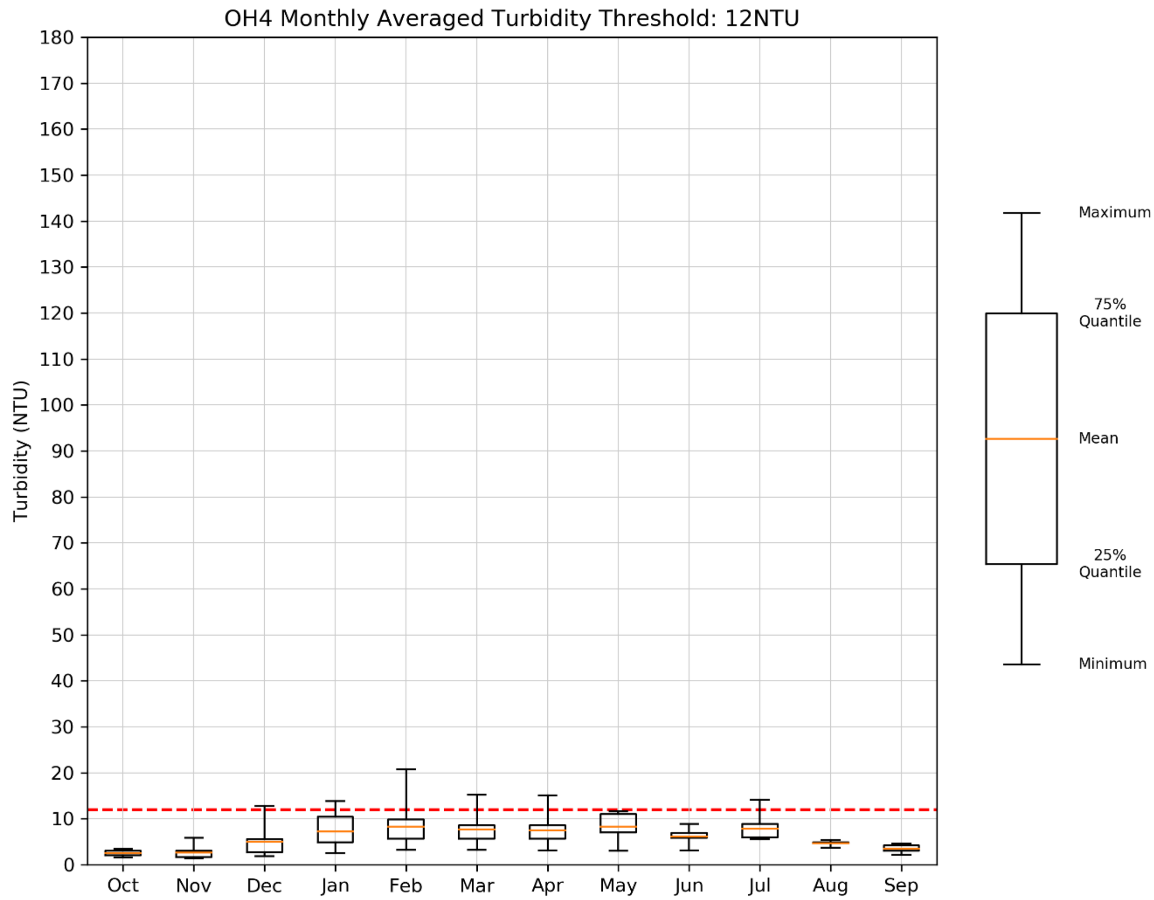

Figure 171. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station OH4 – Old River at Highway 4

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

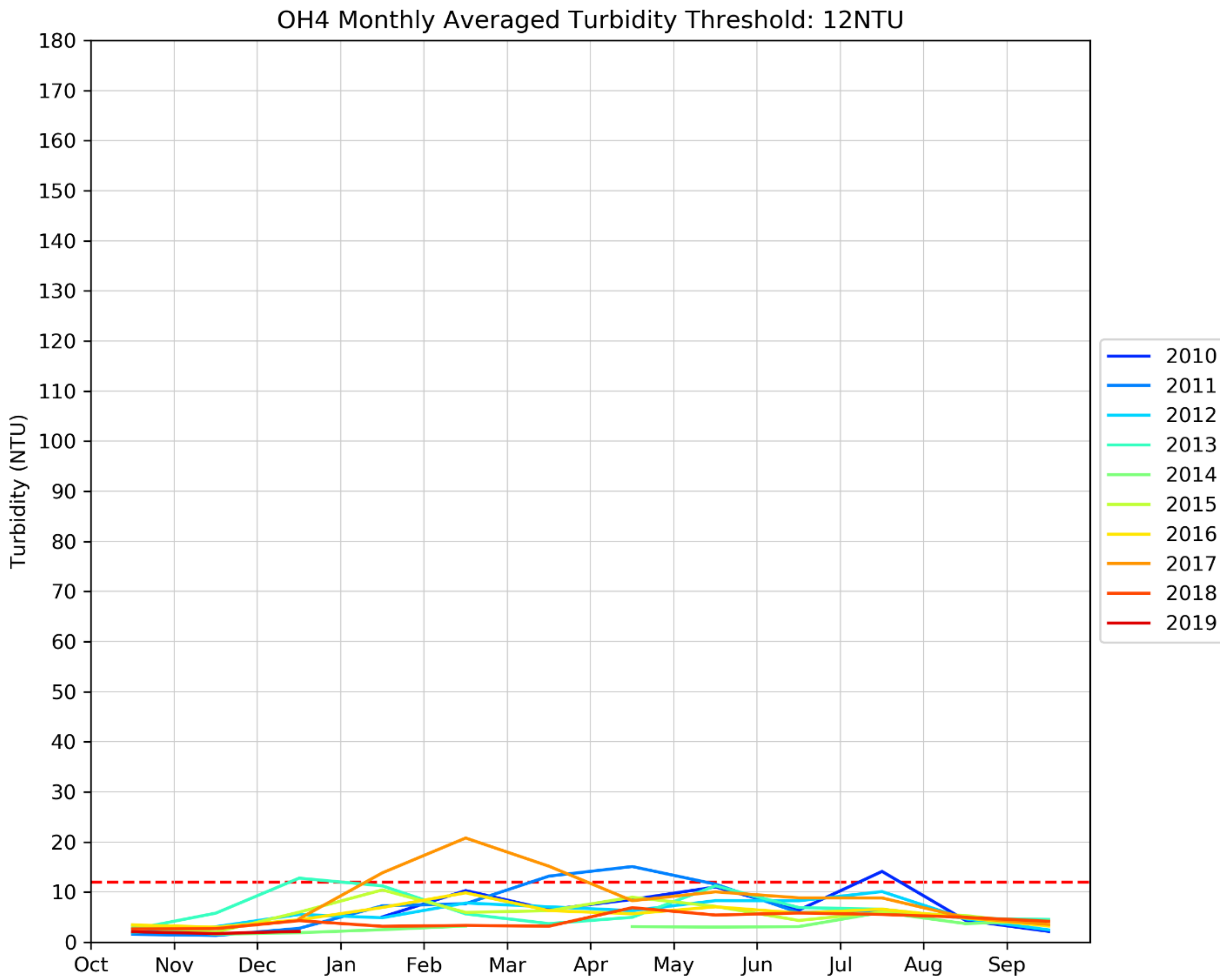

Figure 172. Monthly Average Turbidity for the Period of Record at Station OH4 – Old River at Highway 4

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

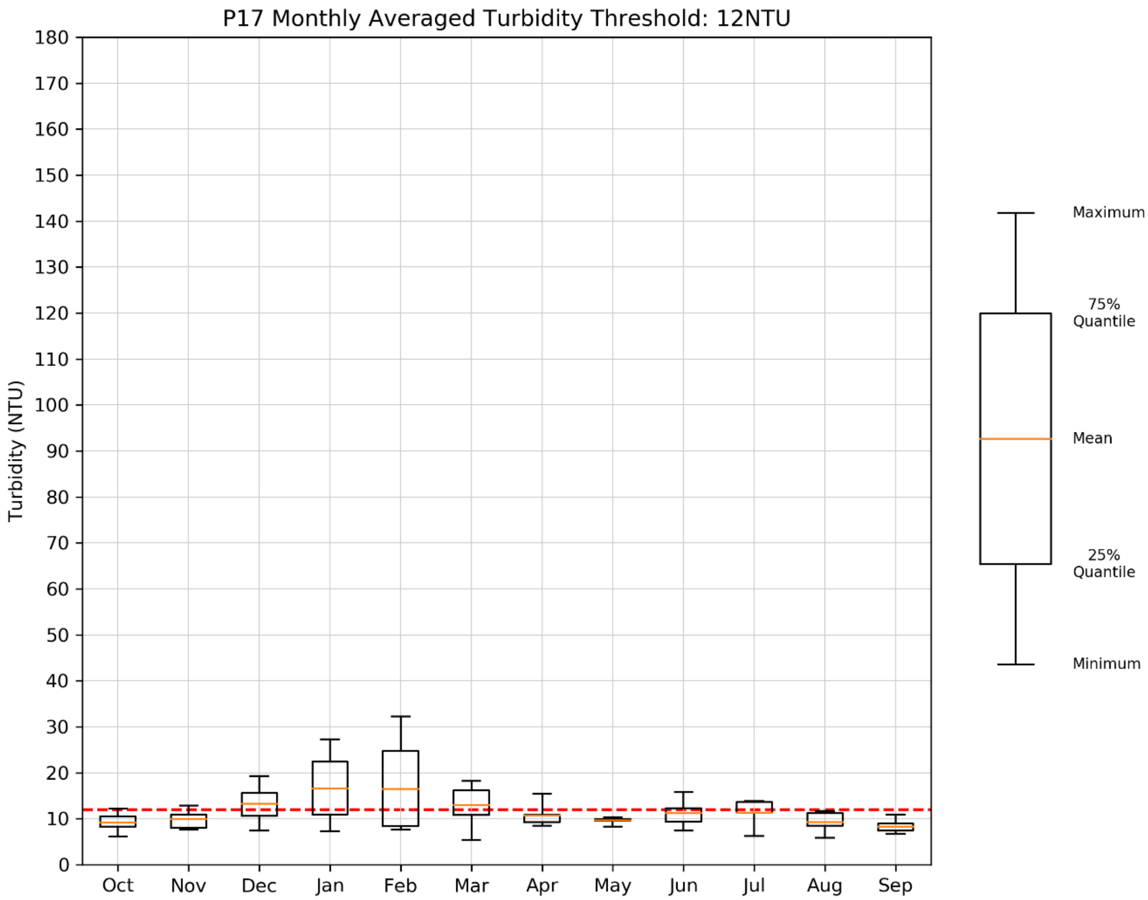

Figure 173. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station P17 – Pier 17

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

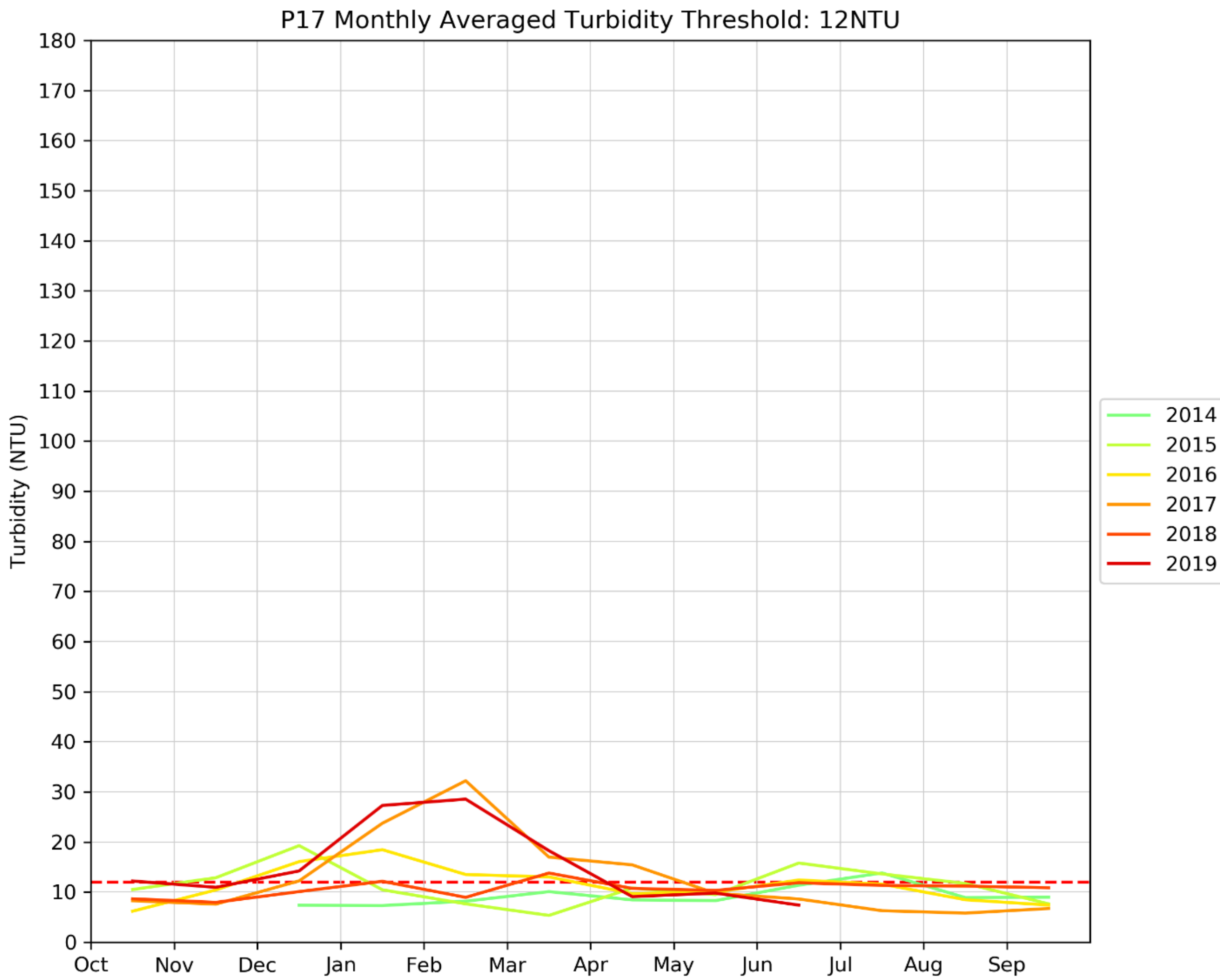

Figure 174. Monthly Average Turbidity for the Period of Record at Station P17 – Pier 17

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

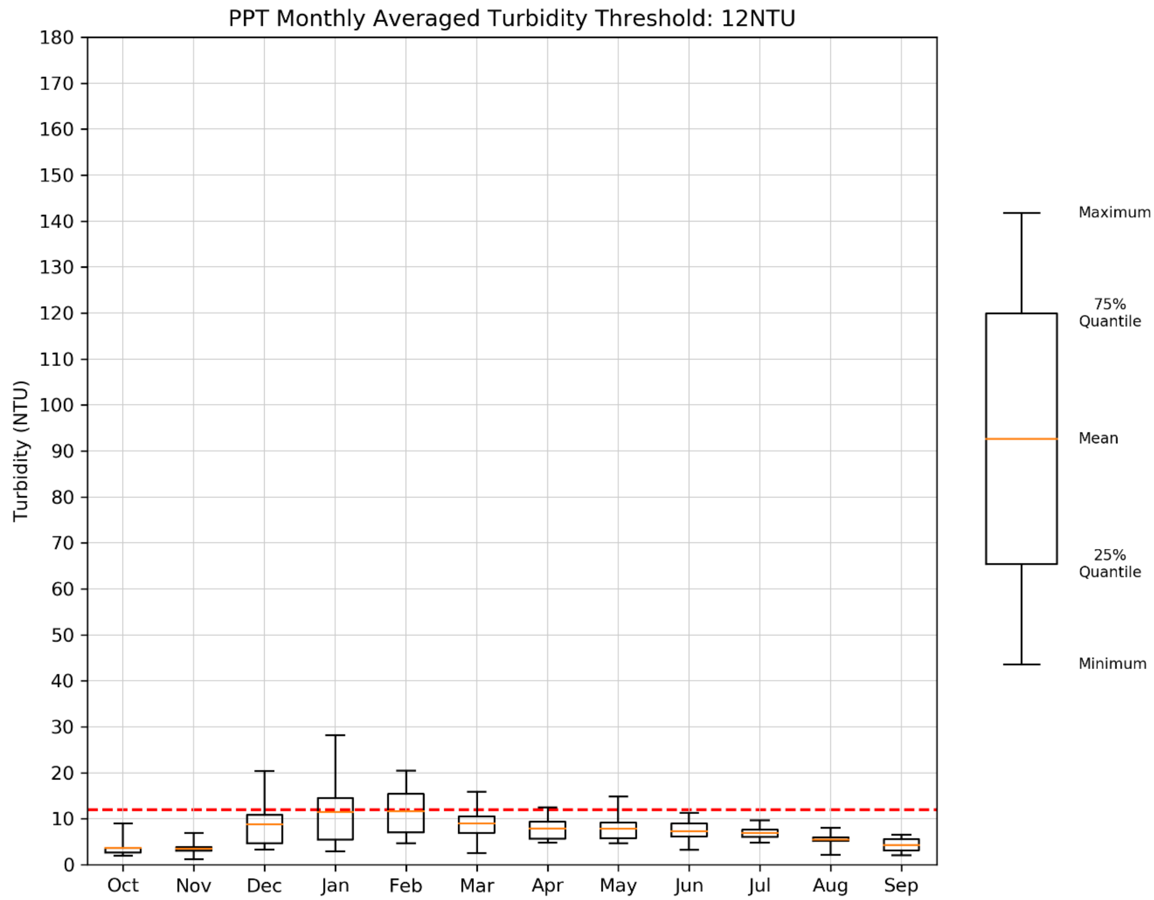

Figure 175. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station PPT – San Joaquin River at Prisoners Point near Terminus

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

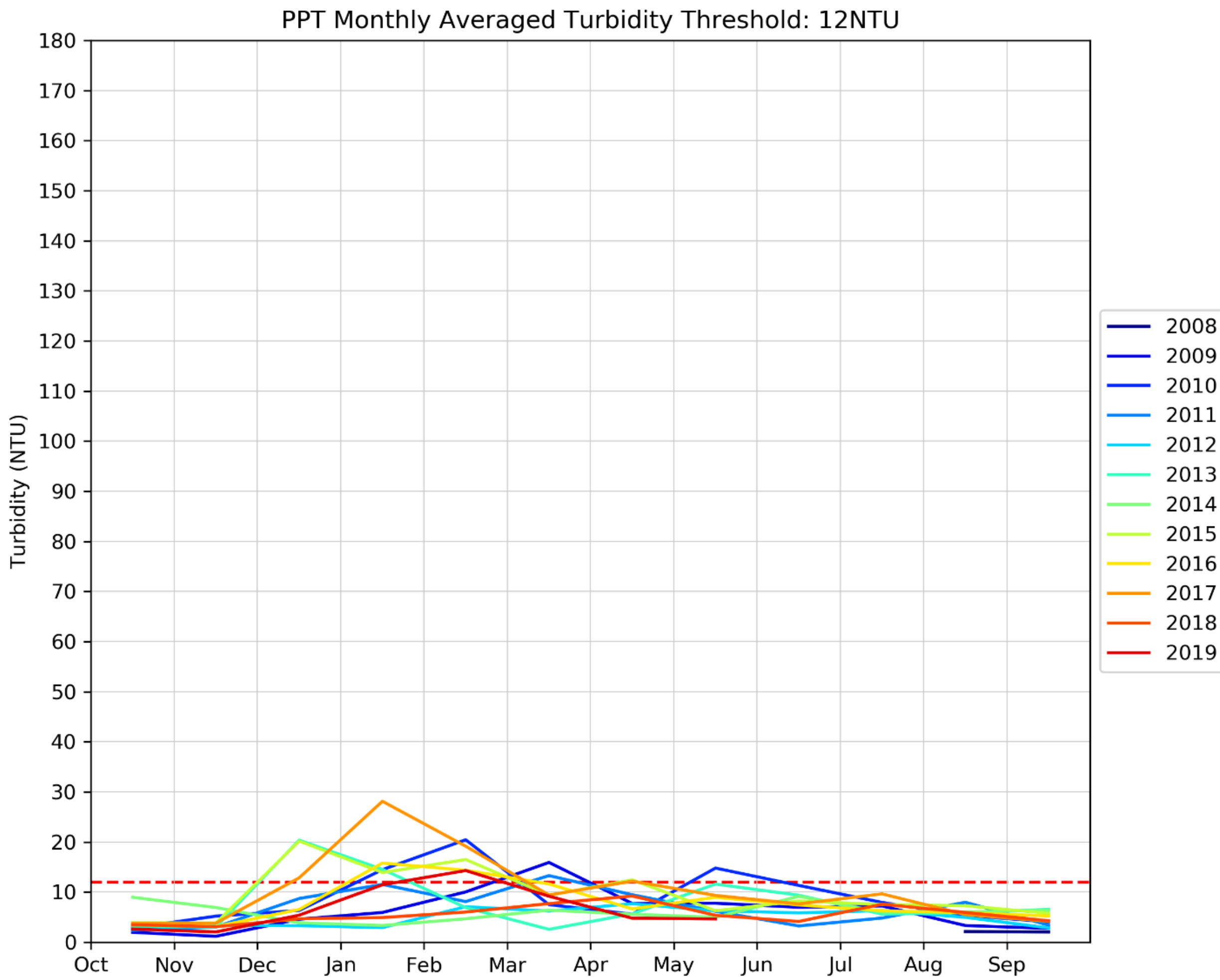

Figure 176. Monthly Average Turbidity for the Period of Record at Station PPT – San Joaquin River at Prisoners Point near Terminus

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

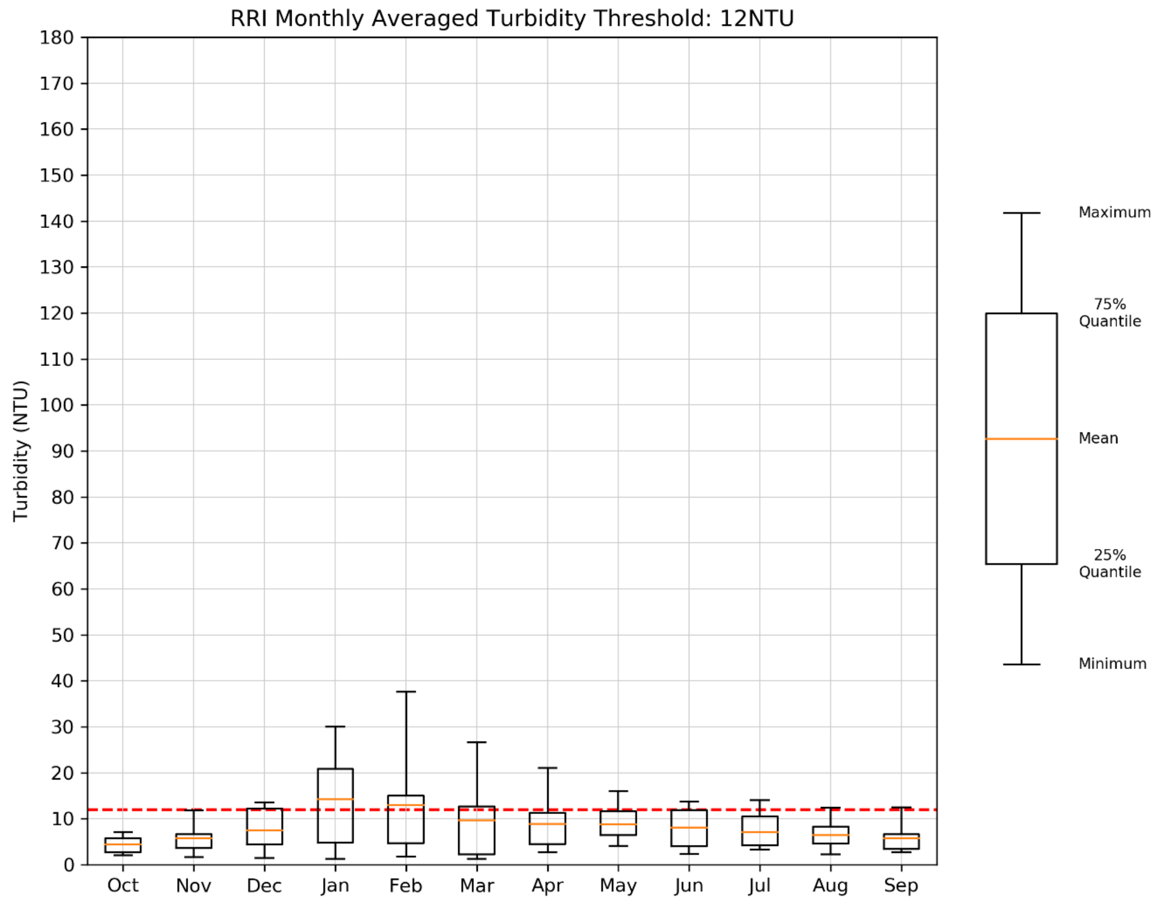

Figure 177. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station RRI – Rough and Ready Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

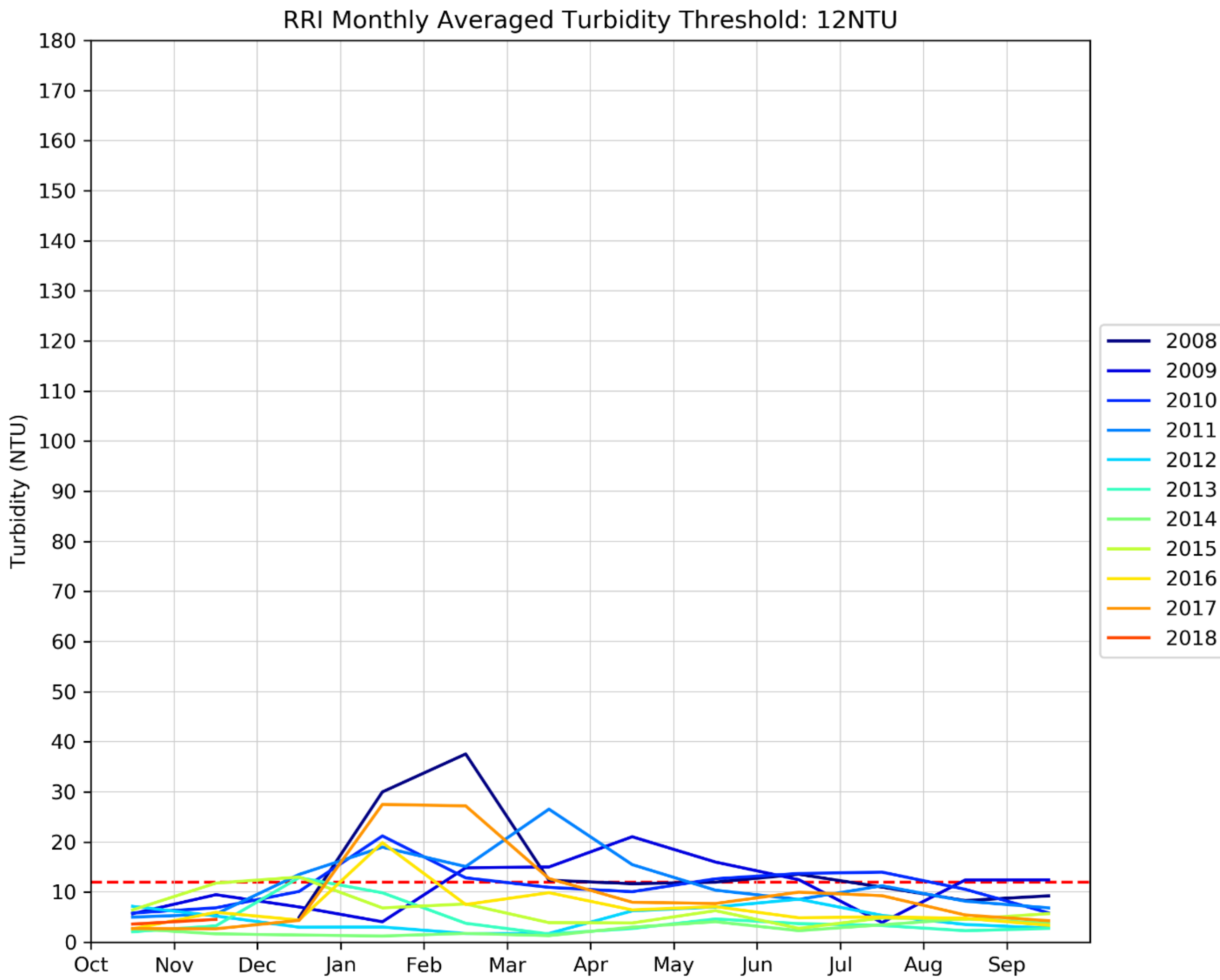

Figure 178. Monthly Average Turbidity for the Period of Record at Station RRI – Rough and Ready Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

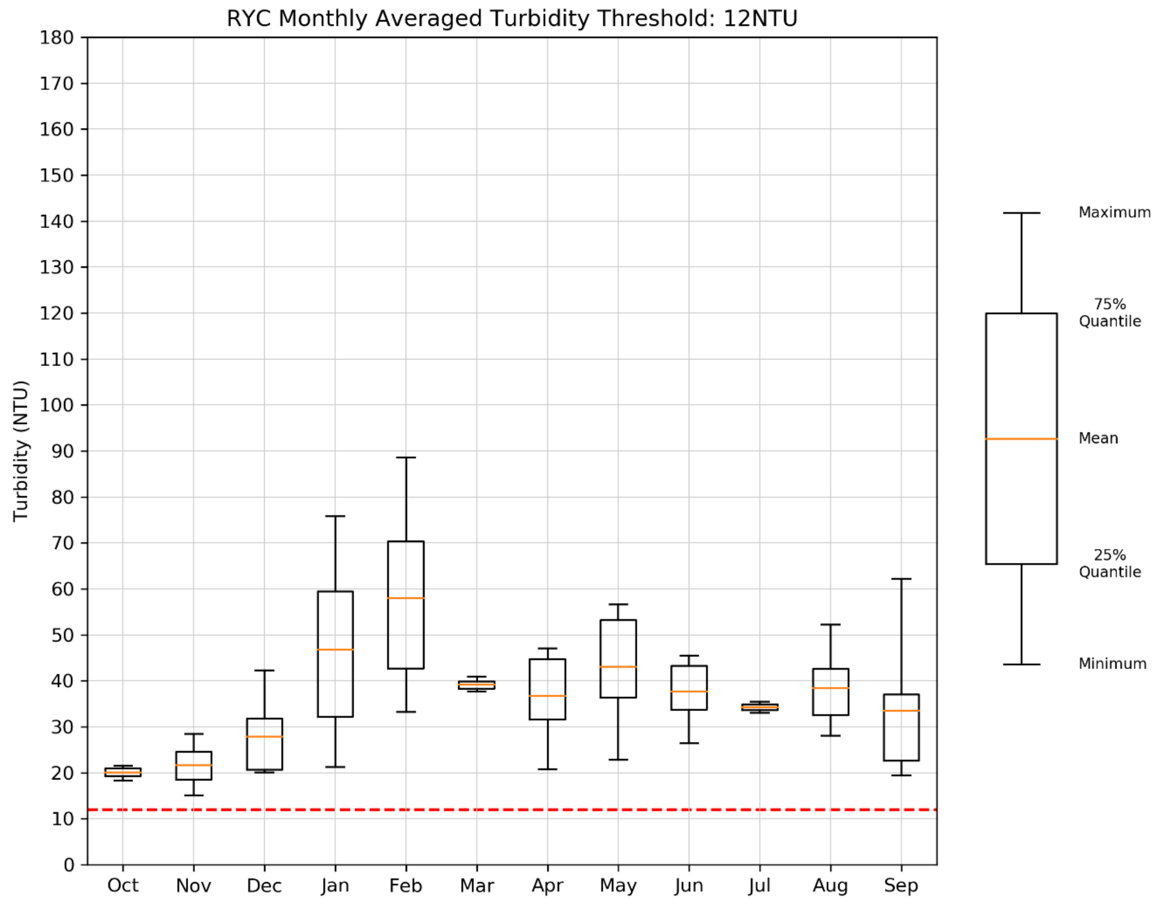

Figure 179. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

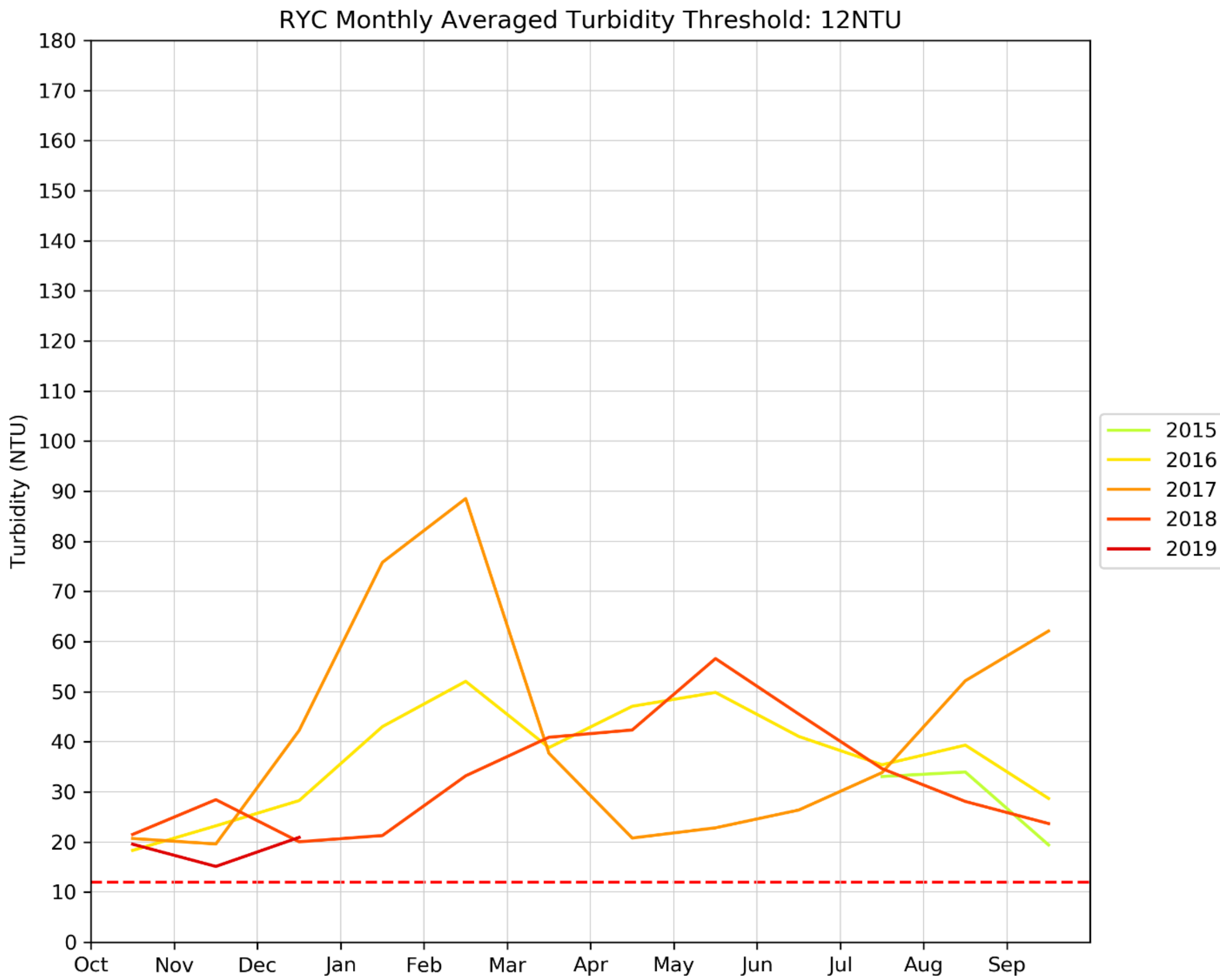

Figure 180. Monthly Average Turbidity for the Period of Record at Station RYC – Suisun Bay Cutoff near Ryer

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

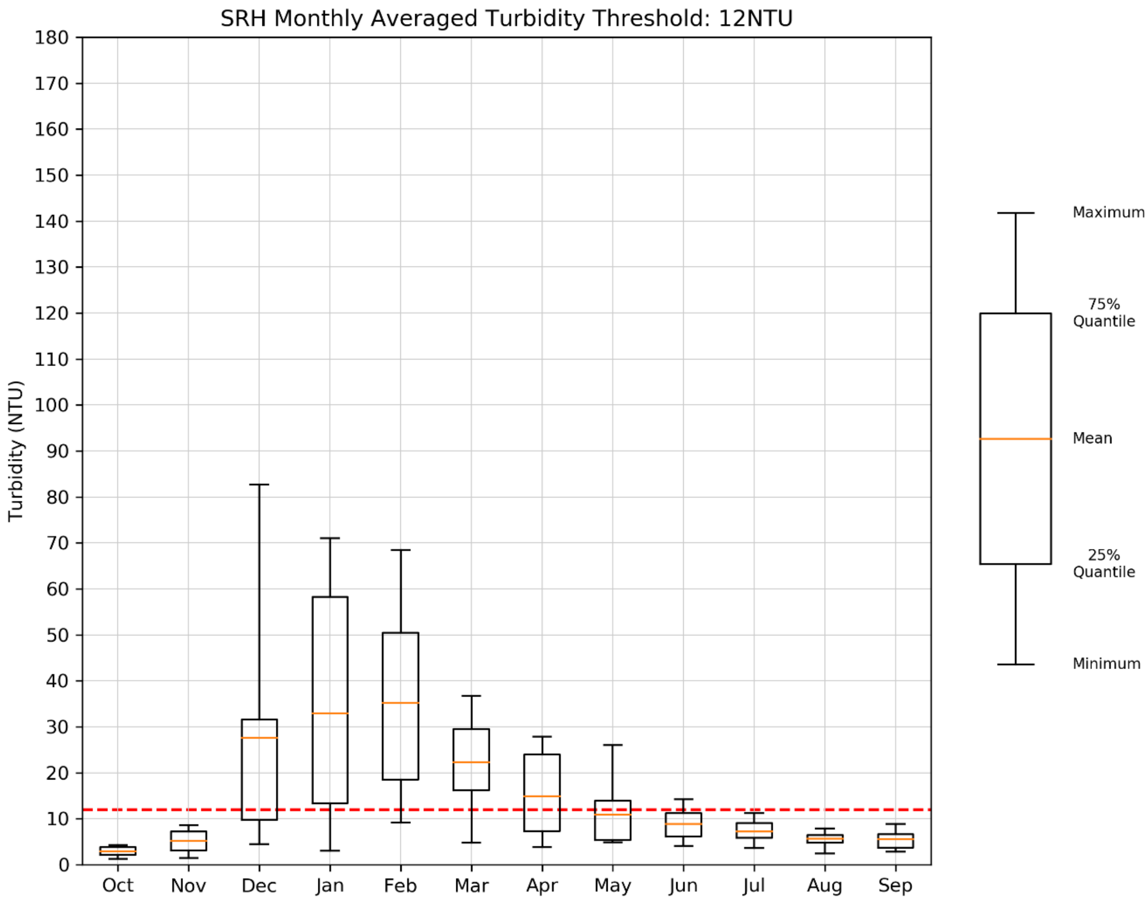

Figure 181. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SRH – Sacramento River at Hood

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

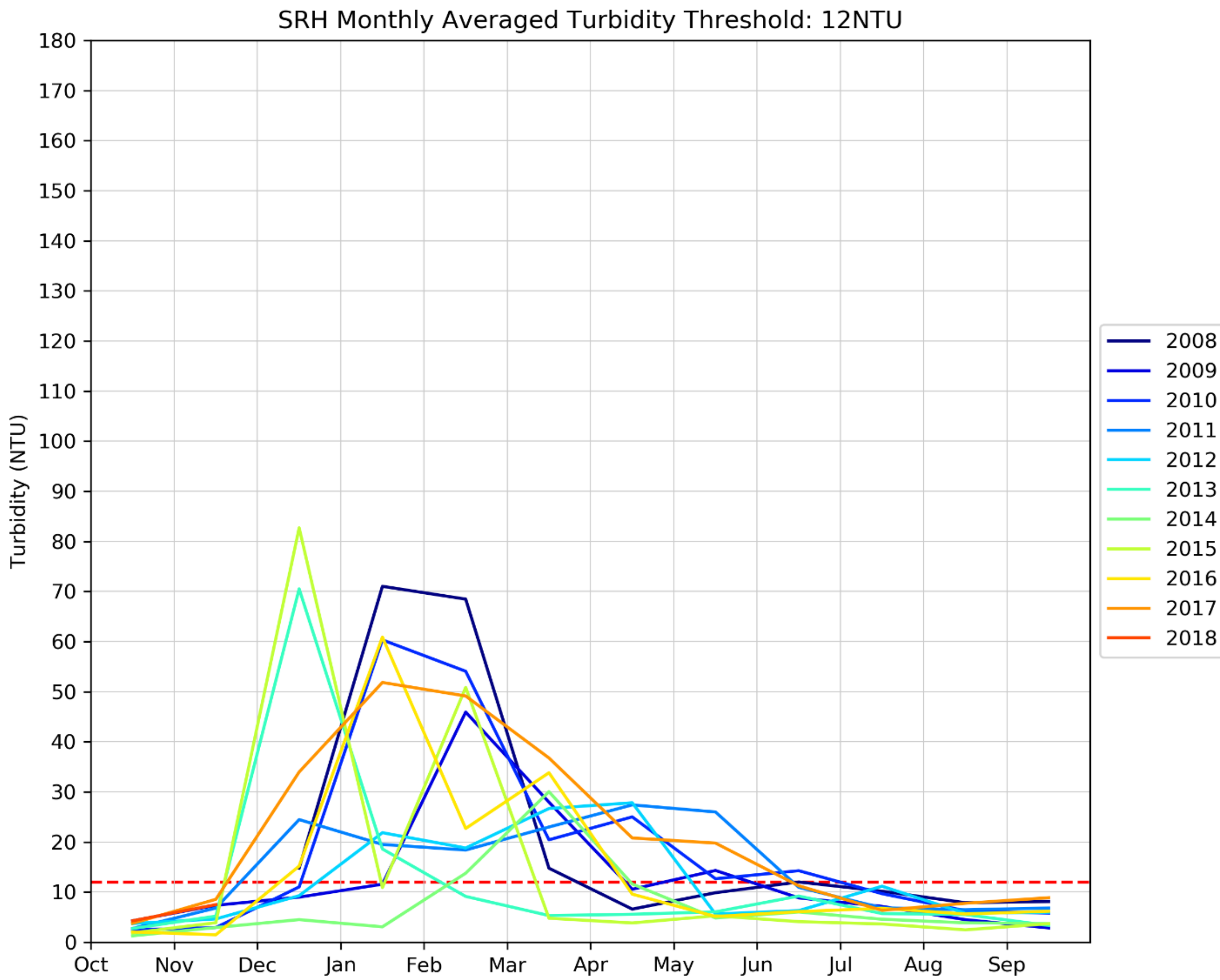

Figure 182. Monthly Average Turbidity for the Period of Record at Station SRH – Sacramento River at Hood

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

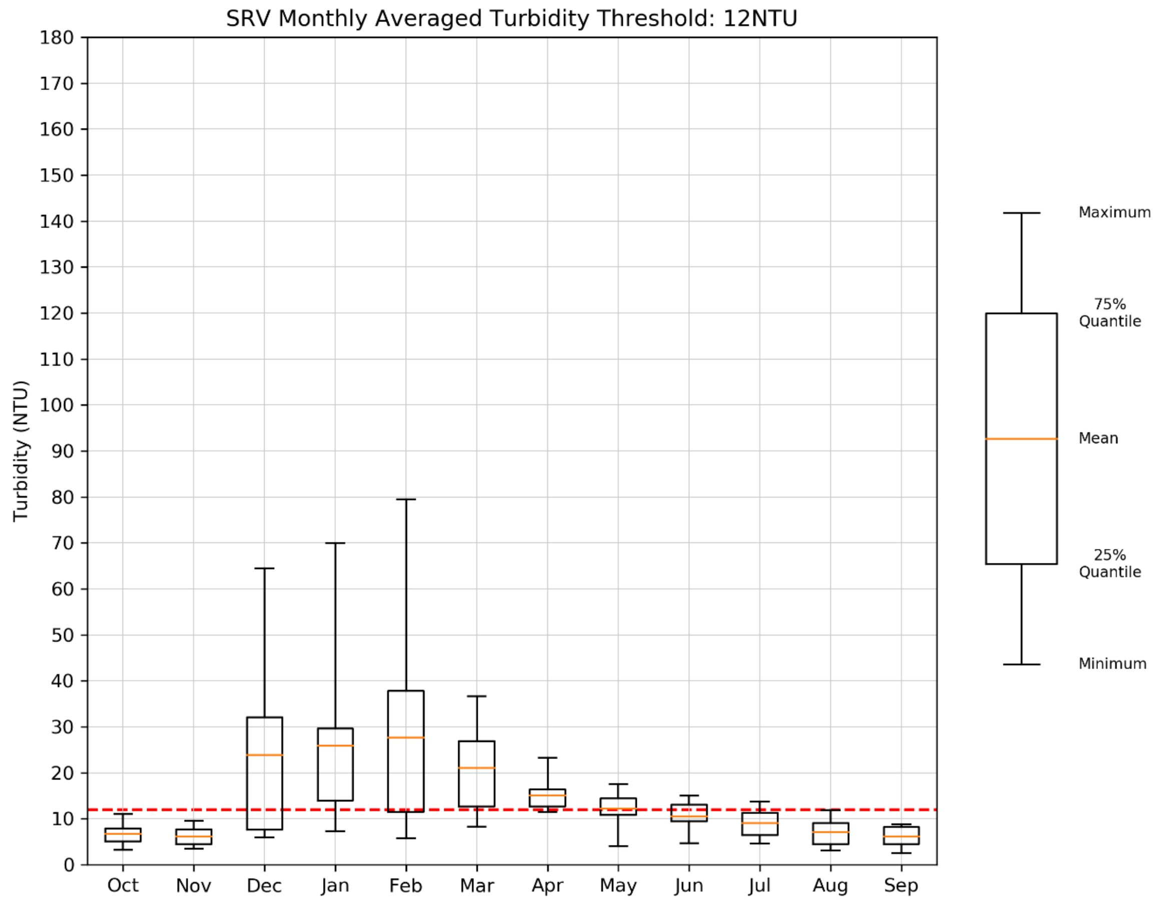

Figure 183. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SRV - Sacramento River at Rio Vista

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

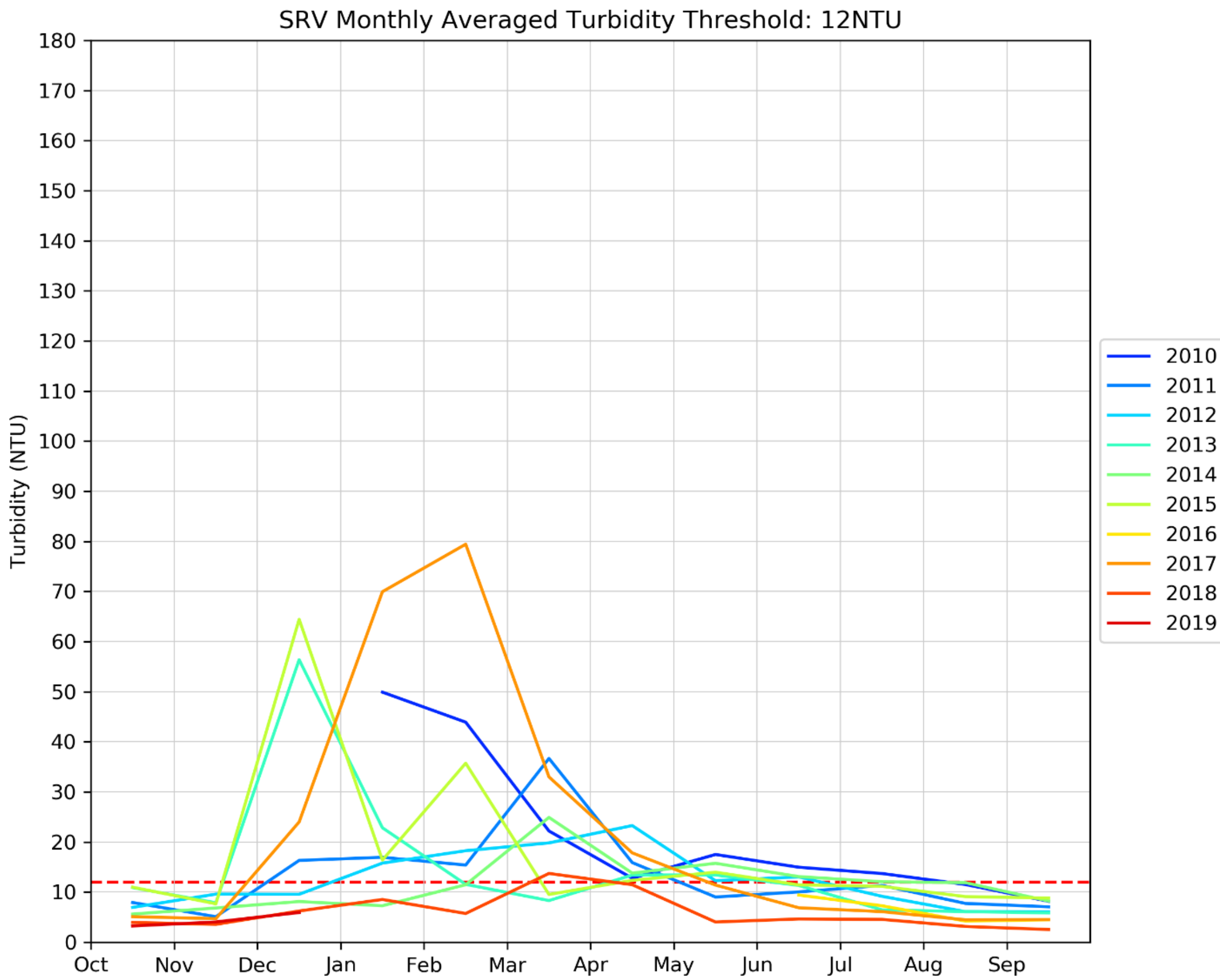

Figure 184. Monthly Average Turbidity for the Period of Record at Station SRV – Sacramento River at Rio Vista

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

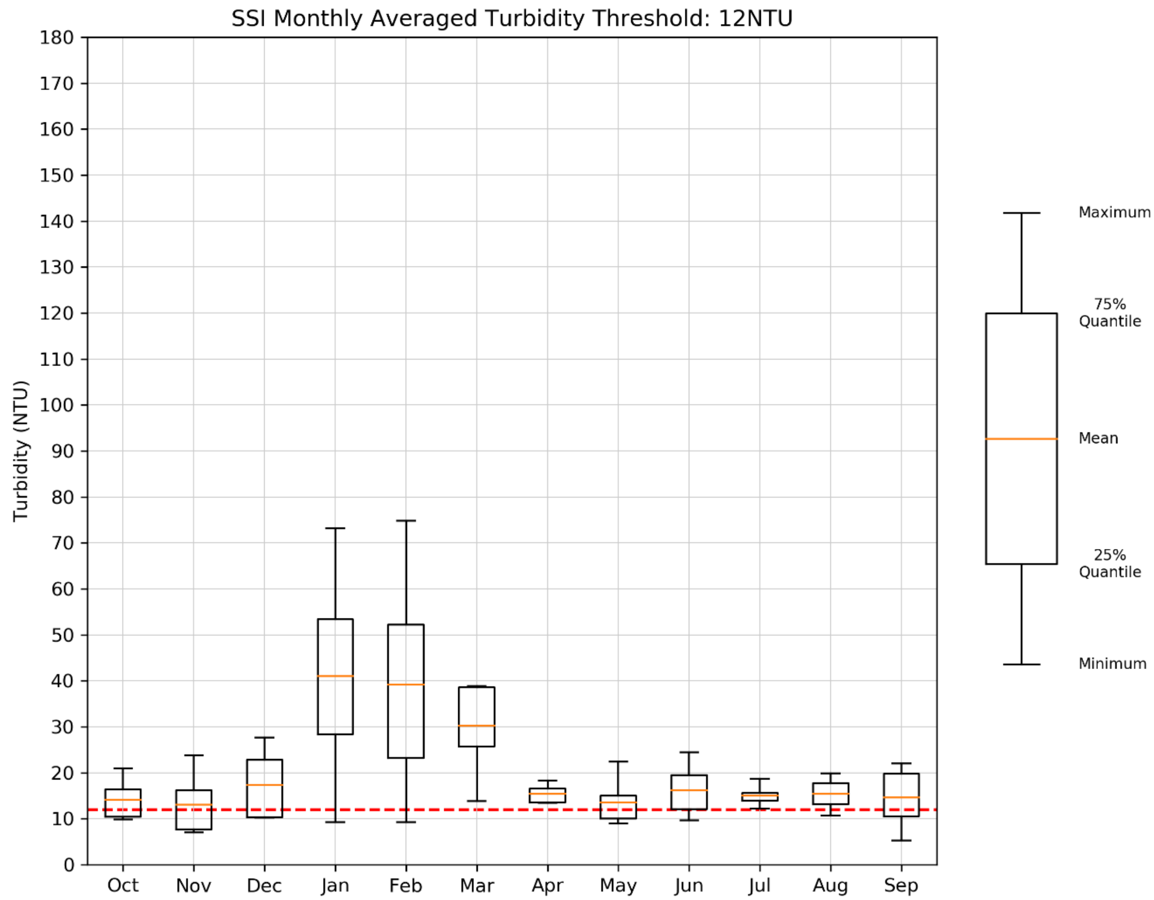

Figure 185. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station SSI – Sacramento River near Sherman Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

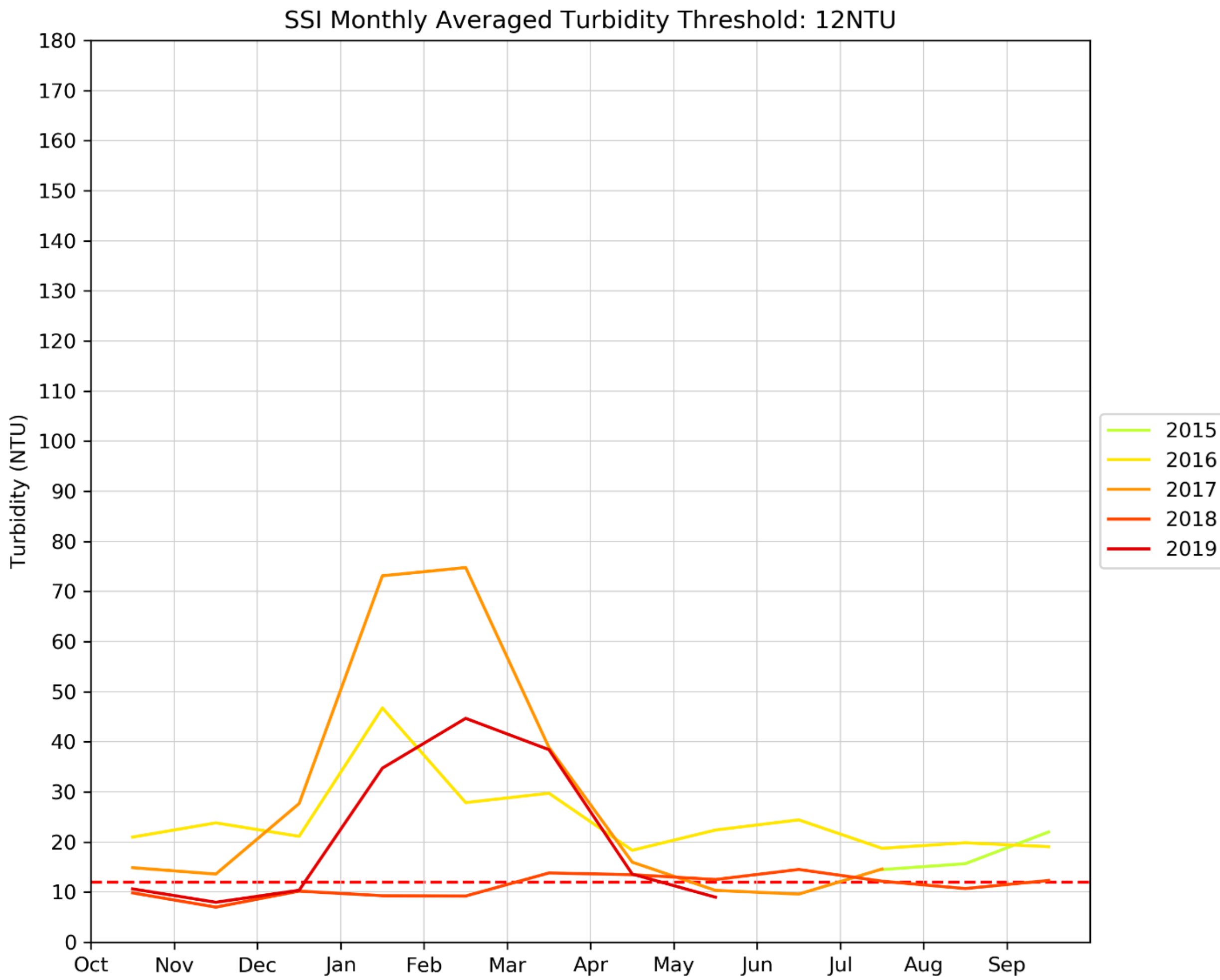

Figure 186. Monthly Average Turbidity for the Period of Record at Station SSI – Sacramento River Near Sherman Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

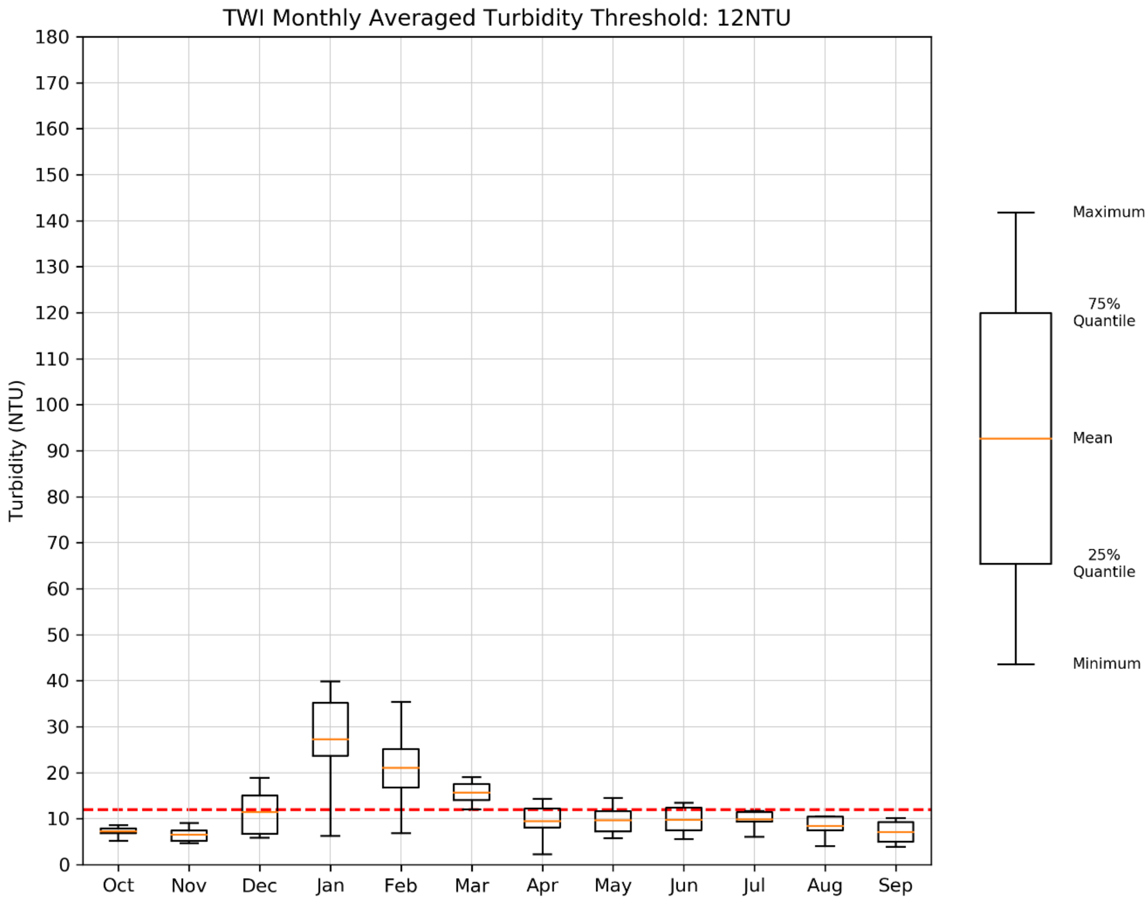

Figure 187. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station TWI - San Joaquin River at Twitchell Island

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

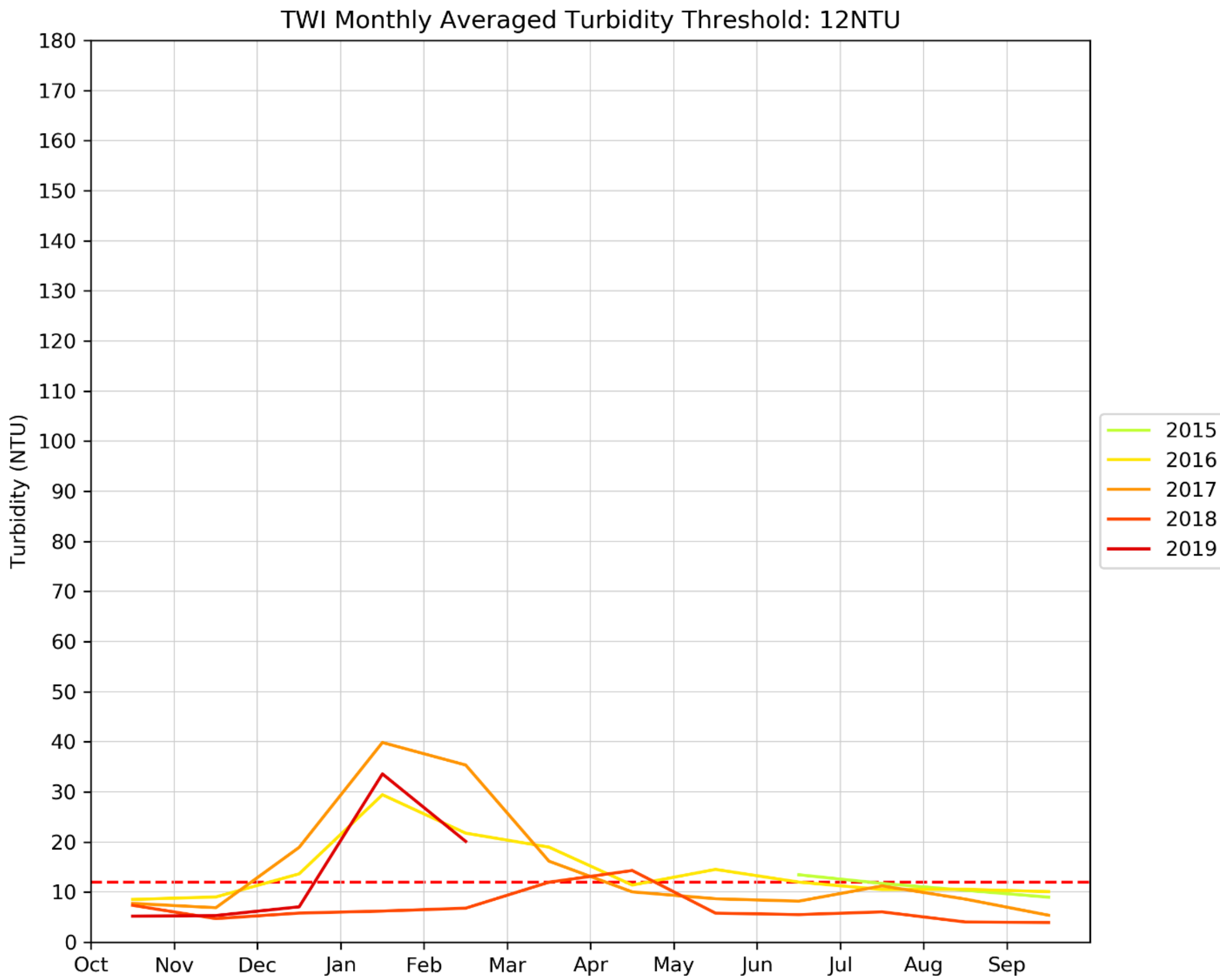

Figure 188. Monthly Average Turbidity for the Period of Record at Station TWI – San Joaquin River at Twitchell Island

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

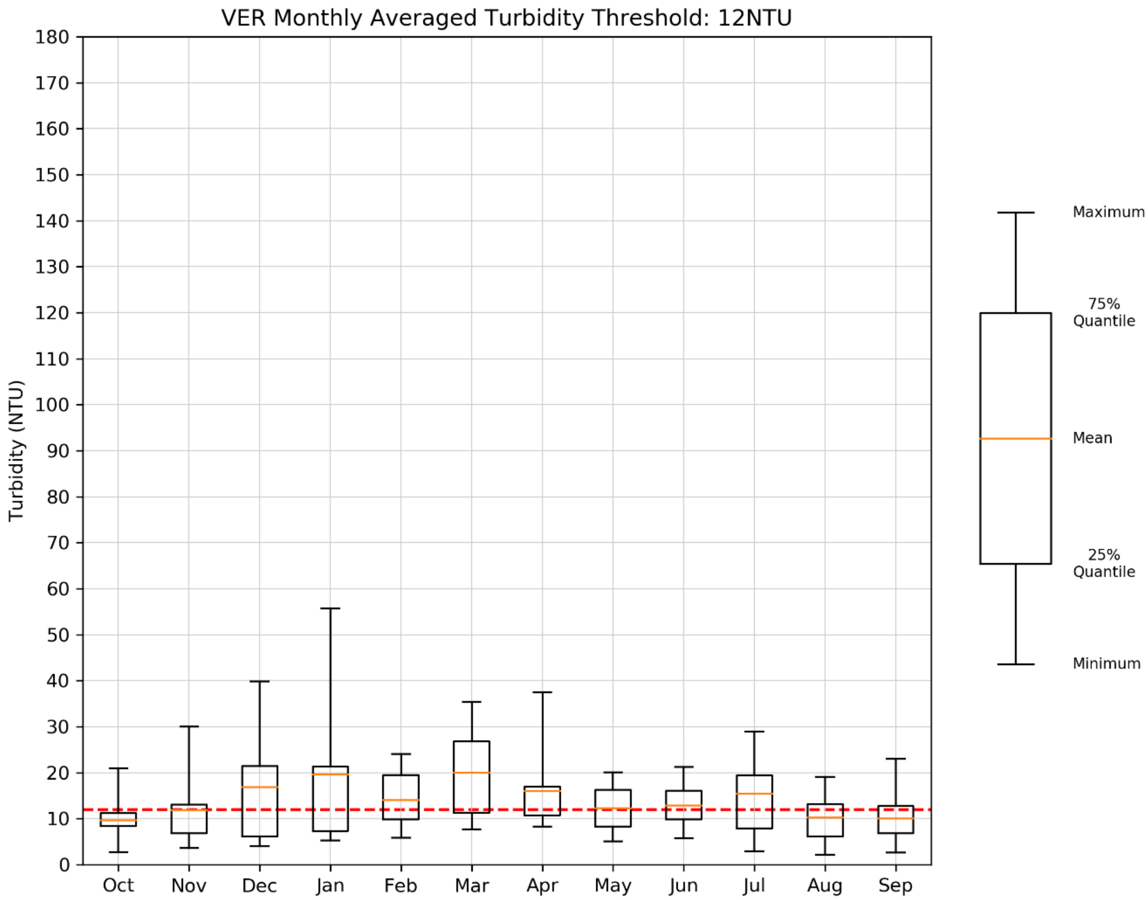

Figure 189. Bar and Whisker Plot Summarizing Range of Monthly Averaged Turbidity at Station VER – San Joaquin River near Vernalis

Figure shows data plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis. An explanatory box and whisker plot on the right explains the plotting convention: red line is the mean; top and bottom portions of the box are 75% and 25% quantiles, respectively; and top and bottom portions of the whisker are maximum and minimum, respectively.

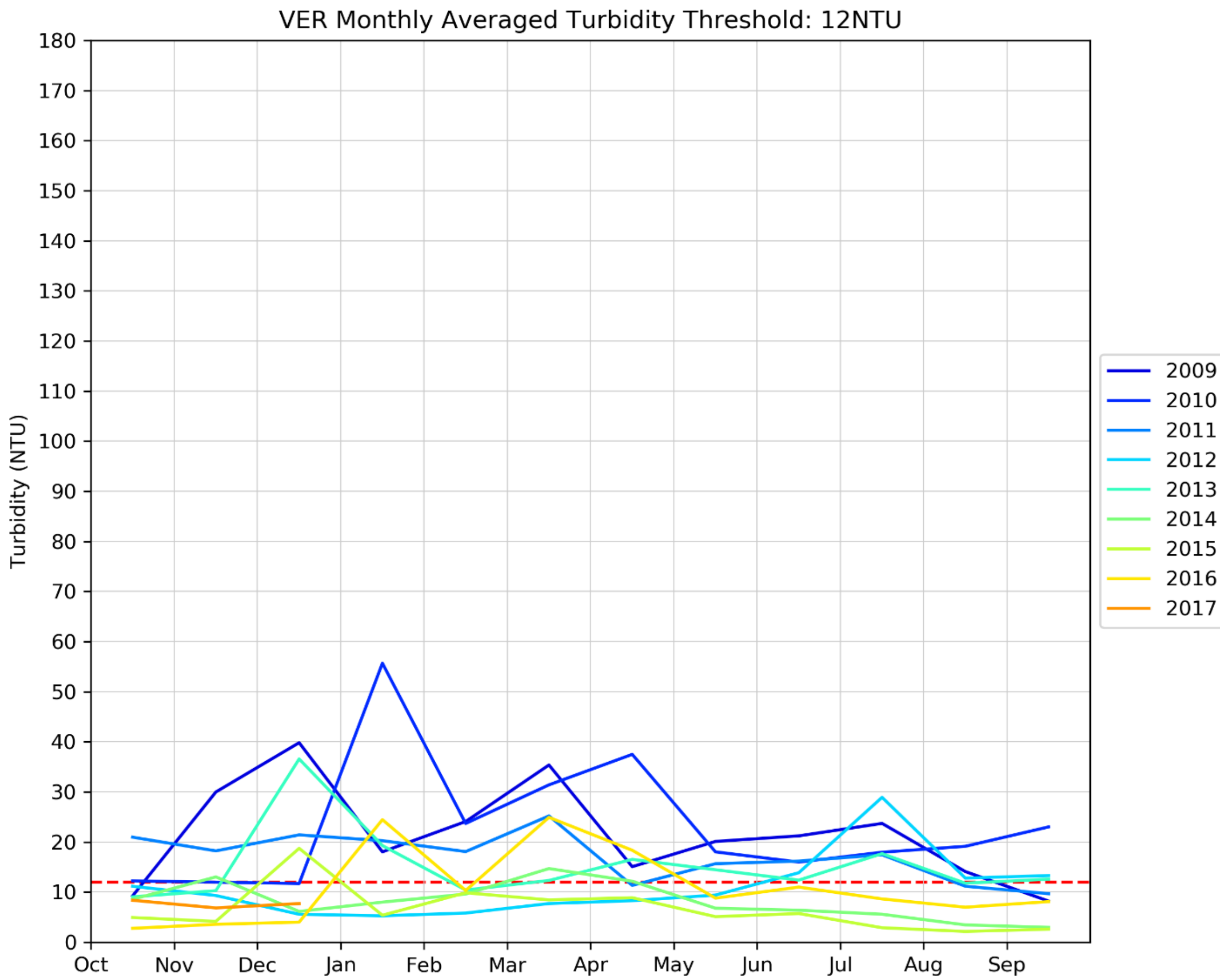

Figure 190. Monthly Average Turbidity for the Period of Record at Station VER – San Joaquin River Near Vernalis

Figure shows yearly data (symbolized by colored lines) plotted by time (in months) on the x-axis and turbidity (in NTU) on the y-axis.

Appendix B
RMA Modeling Results

Appendix B
Delta and Estuary Habitat Results, Anticipated Biological and Environmental Outcomes

Detailed seasonal results for each species are tabulated in the following sections.

B.1 Delta Smelt Habitat

Table 1. Delta Region – Delta Smelt Spring and Summer-Fall Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Delta Smelt Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Spring 1976	23875.2	36252.4	44071.9	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1976	6842.2	12494.1	16656.2	6873.7	12505.8	16589.1	0.5%	0.1%	-0.4%
Spring 1977	23875.1	36252.4	44071.9	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1977	6467.1	11948.4	16110.4	6523.9	11911.5	15994.7	0.9%	-0.3%	-0.7%
Spring 1978	23875.1	36252.4	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1978	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1979	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1979	7197.1	12849.1	17011.1	7220.6	12852.8	16936.0	0.3%	0.0%	-0.4%
Spring 1980	23875.2	36252.5	44072.1	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1980	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1981	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1981	7010.1	12662.0	16824.1	7128.3	12760.5	16843.7	1.7%	0.8%	0.1%
Spring 1982	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1982	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1983	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1983	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1984	23875.2	36252.5	44072.1	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1984	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1985	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1985	6849.9	12478.6	16640.7	6956.0	12578.5	16661.7	1.5%	0.8%	0.1%
Spring 1986	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1986	7288.6	12940.6	17102.7	7289.8	12922.0	17005.2	0.0%	-0.1%	-0.6%
Spring 1987	23875.1	36252.4	44071.9	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1987	6884.1	12531.8	16693.8	7018.4	12650.6	16733.8	2.0%	0.9%	0.2%
Spring 1988	23875.2	36252.4	44071.9	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1988	6486.3	12096.5	16258.5	6489.0	12025.0	16108.2	0.0%	-0.6%	-0.9%
Spring 1989	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1989	6838.9	12454.6	16616.6	6974.0	12592.7	16675.9	2.0%	1.1%	0.4%
Spring 1990	23875.2	36252.4	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall 1990	6434.4	11955.3	16117.4	6421.4	11874.3	15957.5	-0.2%	-0.7%	-1.0%
Spring 1991	23875.1	36252.4	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Spring all	23875.2	36252.5	44072.0	25976.4	38361.1	47921.8	8.8%	5.8%	8.7%
Summer-Fall all	6982.8	12607.6	16769.7	7022.9	12618.9	16702.1	0.6%	0.1%	-0.4%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 2. Suisun Region – Delta Smelt Spring and Summer-Fall Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Delta Smelt Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Spring 1976	23666.3	23666.3	23666.3	25217.6	25217.6	25217.6	6.6%	6.6%	6.6%
Summer-Fall 1976	1056.0	1069.9	1074.4	1340.9	1354.9	1359.4	27.0%	26.6%	26.5%
Spring 1977	16665.3	16665.3	16665.3	18602.1	18602.1	18602.1	11.6%	11.6%	11.6%
Summer-Fall 1977	485.0	498.9	503.4	317.1	320.2	320.2	-34.6%	-35.8%	-36.4%
Spring 1978	34685.8	34685.8	34685.8	35403.2	35403.2	35403.2	2.1%	2.1%	2.1%
Summer-Fall 1978	22488.9	22502.9	22507.4	24410.9	24424.8	24429.3	8.5%	8.5%	8.5%
Spring 1979	34267.6	34267.6	34267.6	35165.2	35165.2	35165.2	2.6%	2.6%	2.6%
Summer-Fall 1979	11682.0	11695.9	11700.4	12356.4	12370.3	12374.8	5.8%	5.8%	5.8%
Spring 1980	34298.1	34298.1	34298.1	35181.3	35181.3	35181.3	2.6%	2.6%	2.6%
Summer-Fall 1980	22281.5	22295.4	22299.9	23433.6	23447.5	23452.0	5.2%	5.2%	5.2%
Spring 1981	32222.3	32222.3	32222.3	33596.0	33596.0	33596.0	4.3%	4.3%	4.3%
Summer-Fall 1981	11449.7	11463.7	11468.2	13893.5	13907.4	13911.9	21.3%	21.3%	21.3%
Spring 1982	34686.2	34686.2	34686.2	35403.4	35403.4	35403.4	2.1%	2.1%	2.1%
Summer-Fall 1982	30052.2	30066.2	30070.7	30903.1	30917.1	30921.6	2.8%	2.8%	2.8%
Spring 1983	34686.2	34686.2	34686.2	35403.4	35403.4	35403.4	2.1%	2.1%	2.1%
Summer-Fall 1983	33776.1	33790.0	33794.5	34519.6	34533.5	34538.0	2.2%	2.2%	2.2%
Spring 1984	33760.1	33760.1	33760.1	34601.3	34601.3	34601.3	2.5%	2.5%	2.5%
Summer-Fall 1984	27217.8	27231.7	27236.2	28108.3	28122.3	28126.8	3.3%	3.3%	3.3%
Spring 1985	30525.3	30525.3	30525.3	31940.9	31940.9	31940.9	4.6%	4.6%	4.6%
Summer-Fall 1985	6827.7	6841.6	6846.1	9261.9	9275.8	9280.3	35.7%	35.6%	35.6%
Spring 1986	34365.5	34365.5	34365.5	35191.3	35191.3	35191.3	2.4%	2.4%	2.4%
Summer-Fall 1986	25712.7	25726.7	25731.2	26968.8	26982.8	26987.3	4.9%	4.9%	4.9%
Spring 1987	30287.4	30287.4	30287.4	31723.7	31723.7	31723.7	4.7%	4.7%	4.7%
Summer-Fall 1987	6210.4	6224.3	6228.8	8772.9	8786.9	8791.4	41.3%	41.2%	41.1%
Spring 1988	26168.1	26168.1	26168.1	27574.8	27574.8	27574.8	5.4%	5.4%	5.4%
Summer-Fall 1988	4695.4	4709.3	4713.8	5372.8	5386.7	5391.2	14.4%	14.4%	14.4%
Spring 1989	33629.1	33629.1	33629.1	34498.4	34498.4	34498.4	2.6%	2.6%	2.6%
Summer-Fall 1989	6775.6	6789.5	6794.0	9462.5	9476.5	9481.0	39.7%	39.6%	39.5%
Spring 1990	25101.2	25101.2	25101.2	26411.3	26411.3	26411.3	5.2%	5.2%	5.2%
Summer-Fall 1990	2186.3	2200.3	2204.8	2532.0	2546.0	2550.5	15.8%	15.7%	15.7%
Spring 1991	31122.4	31122.4	31122.4	31635.7	31635.7	31635.7	1.6%	1.6%	1.6%
Spring all	30633.6	30633.6	30633.6	31721.8	31721.8	31721.8	3.6%	3.6%	3.6%
Summer-Fall all	14193.1	14207.1	14211.6	15443.6	15456.8	15461.0	8.8%	8.8%	8.8%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 3. Suisun + Delta Region – Delta Smelt Spring and Summer-Fall Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Delta Smelt Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Spring 1976	47541.4	59918.7	67738.2	51194.0	63578.7	73139.4	7.7%	6.1%	8.0%
Summer-Fall 1976	7898.1	13564.1	17730.6	8214.6	13860.7	17948.4	4.0%	2.2%	1.2%
Spring 1977	40540.4	52917.6	60737.1	44578.5	56963.2	66523.9	10.0%	7.6%	9.5%
Summer-Fall 1977	6952.1	12447.3	16613.8	6841.0	12231.7	16314.9	-1.6%	-1.7%	-1.8%
Spring 1978	58561.0	70938.3	78757.8	61379.5	73764.3	83325.0	4.8%	4.0%	5.8%
Summer-Fall 1978	29777.6	35443.5	39610.0	31700.7	37346.9	41434.6	6.5%	5.4%	4.6%
Spring 1979	58142.8	70520.1	78339.6	61141.5	73526.3	83087.0	5.2%	4.3%	6.1%
Summer-Fall 1979	18879.1	24545.0	28711.5	19577.0	25223.1	29310.8	3.7%	2.8%	2.1%
Spring 1980	58173.3	70550.6	78370.2	61157.6	73542.4	83103.1	5.1%	4.2%	6.0%
Summer-Fall 1980	29570.1	35236.0	39402.6	30723.4	36369.5	40457.2	3.9%	3.2%	2.7%
Spring 1981	56097.5	68474.8	76294.3	59572.3	71957.1	81517.8	6.2%	5.1%	6.8%
Summer-Fall 1981	18459.8	24125.7	28292.2	21021.8	26667.9	30755.7	13.9%	10.5%	8.7%
Spring 1982	58561.3	70938.6	78758.2	61379.8	73764.6	83325.3	4.8%	4.0%	5.8%
Summer-Fall 1982	37340.9	43006.8	47173.3	38192.9	43839.1	47926.8	2.3%	1.9%	1.6%
Spring 1983	58561.3	70938.6	78758.2	61379.8	73764.6	83325.3	4.8%	4.0%	5.8%
Summer-Fall 1983	41064.7	46730.6	50897.2	41809.4	47455.5	51543.2	1.8%	1.6%	1.3%
Spring 1984	57635.3	70012.6	77832.2	60577.7	72962.4	82523.1	5.1%	4.2%	6.0%
Summer-Fall 1984	34506.4	40172.3	44338.9	35398.1	41044.3	45132.0	2.6%	2.2%	1.8%
Spring 1985	54400.5	66777.8	74597.3	57917.2	70302.0	79862.7	6.5%	5.3%	7.1%
Summer-Fall 1985	13677.5	19320.3	23486.8	16217.9	21854.3	25942.0	18.6%	13.1%	10.5%
Spring 1986	58240.7	70618.0	78437.6	61167.7	73552.4	83113.1	5.0%	4.2%	6.0%
Summer-Fall 1986	33001.4	38667.3	42833.8	34258.7	39904.8	43992.5	3.8%	3.2%	2.7%
Spring 1987	54162.5	66539.8	74359.3	57700.1	70084.8	79645.6	6.5%	5.3%	7.1%
Summer-Fall 1987	13094.5	18756.1	22922.7	15791.3	21437.5	25525.2	20.6%	14.3%	11.4%
Spring 1988	50043.2	62420.5	70240.0	53551.2	65935.9	75496.6	7.0%	5.6%	7.5%
Summer-Fall 1988	11181.7	16805.8	20972.3	11861.7	17411.7	21499.4	6.1%	3.6%	2.5%
Spring 1989	57504.3	69881.6	77701.1	60474.8	72859.5	82420.3	5.2%	4.3%	6.1%
Summer-Fall 1989	13614.5	19244.1	23410.7	16436.5	22069.1	26156.8	20.7%	14.7%	11.7%
Spring 1990	48976.4	61353.7	69173.2	52387.6	64772.4	74333.1	7.0%	5.6%	7.5%
Summer-Fall 1990	8620.7	14155.6	18322.2	8953.4	14420.2	18508.0	3.9%	1.9%	1.0%
Spring 1991	54997.6	67374.8	75194.4	57612.1	69996.8	79557.5	4.8%	3.9%	5.8%
Spring all	54508.7	66886.0	74705.5	57698.2	70083.0	79643.7	5.9%	4.8%	6.6%
Summer-Fall all	21175.9	26814.7	30981.2	22466.6	28075.8	32163.2	6.1%	4.7%	3.8%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 4. Bay Region – Delta Smelt Spring and Summer-Fall Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

Simulation Season	Delta Smelt Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Spring 1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1978	27700.6	27700.6	27700.6	29991.9	29991.9	29991.9	8.3%	8.3%	8.3%
Summer-Fall 1978	206.6	206.6	206.6	212.7	212.7	212.7	2.9%	2.9%	2.9%
Spring 1979	1245.5	1245.5	1245.5	1647.4	1647.4	1647.4	32.3%	32.3%	32.3%
Summer-Fall 1979	0.0	0.0	0.0	18.4	18.4	18.4	0.0%	0.0%	0.0%
Spring 1980	21600.9	21600.9	21600.9	21717.1	21717.1	21717.1	0.5%	0.5%	0.5%
Summer-Fall 1980	87.6	87.6	87.6	108.6	108.6	108.6	24.0%	24.0%	24.0%
Spring 1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1981	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1982	60801.3	61520.8	61520.8	61331.4	62163.8	62163.8	0.9%	1.0%	1.0%
Summer-Fall 1982	486.2	694.7	694.7	498.0	691.5	691.5	2.4%	-0.5%	-0.5%
Spring 1983	69620.1	73113.7	73113.7	69690.4	73230.9	73230.9	0.1%	0.2%	0.2%
Summer-Fall 1983	13020.0	17105.4	17105.4	13069.5	17231.0	17231.0	0.4%	0.7%	0.7%
Spring 1984	4178.7	4178.7	4178.7	4477.2	4477.2	4477.2	7.1%	7.1%	7.1%
Summer-Fall 1984	28.1	28.1	28.1	38.5	38.5	38.5	37.3%	37.3%	37.3%
Spring 1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1986	33611.8	34266.2	34266.2	34011.4	34708.7	34708.7	1.2%	1.3%	1.3%
Summer-Fall 1986	101.8	101.8	101.8	117.6	117.6	117.6	15.6%	15.6%	15.6%
Spring 1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1989	748.8	748.8	748.8	1101.7	1101.7	1101.7	47.1%	47.1%	47.1%
Summer-Fall 1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Summer-Fall 1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring 1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%
Spring all	13719.2	14023.5	14023.5	13998.0	14314.9	14314.9	2.0%	2.1%	2.1%
Summer-Fall all	928.7	1214.9	1214.9	937.6	1227.9	1227.9	1.0%	1.1%	1.1%

Most restrictive, mean, and least Restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

B.1.1 Longfin Smelt Habitat

Table 5. Delta Region – Longfin Smelt Spring-Summer Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows) Scenarios

	Longfin Smelt Habitat Area (ac)		Habitat Area % Change from Baseline
Simulation Season	Baseline	VA	VA
Spring-Summer 1976	64053.7	67262.0	5.0%
Spring-Summer 1977	64053.7	67262.0	5.0%
Spring-Summer 1978	64053.7	67262.0	5.0%
Spring-Summer 1979	64053.8	67262.0	5.0%
Spring-Summer 1980	64053.8	67262.0	5.0%
Spring-Summer 1981	64053.7	67262.0	5.0%
Spring-Summer 1982	64053.7	67262.0	5.0%
Spring-Summer 1983	64053.7	67262.0	5.0%
Spring-Summer 1984	64053.8	67262.0	5.0%
Spring-Summer 1985	64053.7	67262.0	5.0%
Spring-Summer 1986	64053.8	67262.0	5.0%
Spring-Summer 1987	64053.7	67262.0	5.0%
Spring-Summer 1988	64053.7	67262.0	5.0%
Spring-Summer 1989	64053.7	67262.0	5.0%
Spring-Summer 1990	64053.7	67262.0	5.0%
Spring-Summer 1991	64053.7	67262.0	5.0%
Spring-Summer all	64053.7	67262.0	5.0%

Percent change from baseline is reported for VA scenario in the right column. These results were based on the CalSim II operations model.

Table 6. Suisun Region – Longfin Smelt Spring-Summer Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows) Scenarios

	Longfin Smelt Habitat Area (ac)		Habitat Area % Change from Baseline
Simulation Season	Baseline	VA	VA
Spring-Summer 1976	26718.7	27960.1	4.6%
Spring-Summer 1977	25115.2	26607.8	5.9%
Spring-Summer 1978	33552.7	34356.0	2.4%
Spring-Summer 1979	33009.2	33834.6	2.5%
Spring-Summer 1980	33474.4	34250.8	2.3%
Spring-Summer 1981	31351.5	32808.4	4.6%
Spring-Summer 1982	33950.7	34687.1	2.2%
Spring-Summer 1983	34686.2	35403.4	2.1%
Spring-Summer 1984	33450.4	34228.1	2.3%
Spring-Summer 1985	31314.5	32746.7	4.6%
Spring-Summer 1986	33261.5	34130.9	2.6%
Spring-Summer 1987	31142.5	32558.3	4.5%
Spring-Summer 1988	29640.8	30676.9	3.5%
Spring-Summer 1989	31563.9	32939.5	4.4%
Spring-Summer 1990	27355.3	28508.7	4.2%
Spring-Summer 1991	29059.0	29417.9	1.2%
Spring-Summer all	31165.4	32194.7	3.3%

Percent change from baseline is reported for VA scenario in the right column. These results were based on the CalSim II operations model.

Table 7. Delta and Suisun Region – Longfin Smelt Spring-Summer Average Habitat Areas for the Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows) Scenarios

Simulation Season	Longfin Smelt Habitat Area (ac)		Habitat Area % Change from Baseline
	Baseline	VA	VA
Spring-Summer 1976	90767.9	95217.5	4.9%
Spring-Summer 1977	89164.4	93865.2	5.3%
Spring-Summer 1978	97601.9	101613.4	4.1%
Spring-Summer 1979	97058.5	101092.0	4.2%
Spring-Summer 1980	97523.6	101508.3	4.1%
Spring-Summer 1981	95400.7	100065.8	4.9%
Spring-Summer 1982	97999.9	101944.5	4.0%
Spring-Summer 1983	98735.4	102660.9	4.0%
Spring-Summer 1984	97499.6	101485.5	4.1%
Spring-Summer 1985	95363.7	100004.2	4.9%
Spring-Summer 1986	97310.7	101388.3	4.2%
Spring-Summer 1987	95191.7	99815.7	4.9%
Spring-Summer 1988	93690.0	97934.3	4.5%
Spring-Summer 1989	95613.1	100196.9	4.8%
Spring-Summer 1990	91404.5	95766.1	4.8%
Spring-Summer 1991	93108.1	96675.3	3.8%
Spring-Summer all	95214.6	99452.1	4.5%

Percent change from baseline is reported for VA scenario in the right column. These results were based on the CalSim II operations model.

Table 8. Bay Region – Longfin Smelt Spring-Summer Average Habitat Areas for the Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows) Scenarios

Simulation Season	Longfin Smelt Habitat Area (ac)		Habitat Area % Change from Baseline
	Baseline	VA	VA
Spring-Summer 1976	0.0	0.0	0.0%
Spring-Summer 1977	0.0	0.0	0.0%
Spring-Summer 1978	30110.1	31335.9	4.1%
Spring-Summer 1979	9976.5	11494.4	15.2%
Spring-Summer 1980	21673.8	22735.2	4.9%
Spring-Summer 1981	2121.1	2477.9	16.8%
Spring-Summer 1982	43202.0	43639.6	1.0%
Spring-Summer 1983	66166.5	66271.3	0.2%
Spring-Summer 1984	13386.2	13788.9	3.0%
Spring-Summer 1985	472.1	844.3	78.8%
Spring-Summer 1986	27660.0	28353.8	2.5%
Spring-Summer 1987	1147.9	1391.9	21.3%
Spring-Summer 1988	0.0	0.0	0.0%
Spring-Summer 1989	10309.6	11731.9	13.8%
Spring-Summer 1990	0.0	0.0	0.0%
Spring-Summer 1991	1323.3	1319.8	-0.3%
Spring-Summer all	14221.8	14711.6	3.4%

Percent change from baseline is reported for VA scenario in the right column. These results were based on the CalSim II operations model.

B.1.2 Salmonid Rearing Habitat

Table 9. Delta Region – Salmonid Rearing Winter-Spring Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Salmonid Rearing Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Winter-Spring 1976	6023.4	6044.2	6044.4	6343.5	6363.9	6364.1	5.3%	5.3%	5.3%
Winter-Spring 1977	5997.1	6022.6	6022.8	6313.0	6336.2	6336.4	5.3%	5.2%	5.2%
Winter-Spring 1978	6167.1	6175.0	6175.2	6519.4	6527.5	6527.7	5.7%	5.7%	5.7%
Winter-Spring 1979	6105.1	6118.1	6118.3	6420.5	6432.8	6433.0	5.2%	5.1%	5.1%
Winter-Spring 1980	6266.9	6274.7	6274.9	6616.2	6623.4	6623.6	5.6%	5.6%	5.6%
Winter-Spring 1981	6071.1	6091.7	6091.9	6394.3	6413.9	6414.1	5.3%	5.3%	5.3%
Winter-Spring 1982	6381.5	6388.1	6388.3	6763.9	6770.1	6770.2	6.0%	6.0%	6.0%
Winter-Spring 1983	6059.8	6061.5	6061.7	6568.5	6569.6	6569.8	8.4%	8.4%	8.4%
Winter-Spring 1984	6310.0	6322.5	6322.7	6681.4	6693.6	6693.7	5.9%	5.9%	5.9%
Winter-Spring 1985	6109.2	6128.7	6128.9	6439.1	6457.6	6457.8	5.4%	5.4%	5.4%
Winter-Spring 1986	6001.8	6009.8	6010.0	6430.6	6437.9	6438.0	7.1%	7.1%	7.1%
Winter-Spring 1987	6135.1	6152.1	6152.3	6463.9	6479.8	6480.0	5.4%	5.3%	5.3%
Winter-Spring 1988	6129.8	6147.4	6147.6	6450.7	6467.0	6467.2	5.2%	5.2%	5.2%
Winter-Spring 1989	6134.7	6156.4	6156.6	6478.3	6498.4	6498.6	5.6%	5.6%	5.6%
Winter-Spring 1990	6091.3	6116.0	6116.3	6417.2	6438.9	6439.1	5.3%	5.3%	5.3%
Winter-Spring 1991	6096.0	6118.4	6118.6	6416.2	6436.3	6436.5	5.3%	5.2%	5.2%
Winter-Spring all	6130.0	6145.5	6145.6	6482.3	6496.7	6496.9	5.7%	5.7%	5.7%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 10. Suisun Region – Salmonid Rearing Winter-Spring Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Salmonid Rearing Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Winter-Spring 1976	3121.3	3121.3	3121.3	3540.0	3540.0	3540.0	13.4%	13.4%	13.4%
Winter-Spring 1977	3124.7	3124.7	3124.7	3540.6	3540.6	3540.6	13.3%	13.3%	13.3%
Winter-Spring 1978	3064.3	3064.3	3064.3	3500.0	3500.0	3500.0	14.2%	14.2%	14.2%
Winter-Spring 1979	3099.3	3099.3	3099.3	3522.8	3522.8	3522.8	13.7%	13.7%	13.7%
Winter-Spring 1980	3042.7	3042.7	3042.7	3483.5	3483.5	3483.5	14.5%	14.5%	14.5%
Winter-Spring 1981	3110.7	3110.7	3110.7	3531.9	3531.9	3531.9	13.5%	13.5%	13.5%
Winter-Spring 1982	2992.5	2992.5	2992.5	3453.4	3453.4	3453.4	15.4%	15.4%	15.4%
Winter-Spring 1983	2894.7	2894.7	2894.7	3377.9	3377.9	3377.9	16.7%	16.7%	16.7%
Winter-Spring 1984	3045.8	3045.8	3045.8	3486.3	3486.3	3486.3	14.5%	14.5%	14.5%
Winter-Spring 1985	3108.1	3108.1	3108.1	3536.8	3536.8	3536.8	13.8%	13.8%	13.8%
Winter-Spring 1986	2995.7	2995.7	2995.7	3454.2	3454.2	3454.2	15.3%	15.3%	15.3%
Winter-Spring 1987	3103.2	3103.2	3103.2	3537.2	3537.2	3537.2	14.0%	14.0%	14.0%
Winter-Spring 1988	3103.4	3103.4	3103.4	3534.1	3534.1	3534.1	13.9%	13.9%	13.9%
Winter-Spring 1989	3098.8	3098.8	3098.8	3531.6	3531.6	3531.6	14.0%	14.0%	14.0%
Winter-Spring 1990	3111.1	3111.1	3111.1	3541.0	3541.0	3541.0	13.8%	13.8%	13.8%
Winter-Spring 1991	3107.6	3107.6	3107.6	3539.7	3539.7	3539.7	13.9%	13.9%	13.9%
Winter-Spring all	3070.2	3070.2	3070.2	3506.9	3506.9	3506.9	14.2%	14.2%	14.2%

Most Restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 11. Delta and Suisun Region – Salmonid Rearing Winter-Spring Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Salmonid Rearing Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Winter-Spring 1976	9144.7	9165.5	9165.7	9883.5	9903.9	9904.1	8.1%	8.1%	8.1%
Winter-Spring 1977	9121.8	9147.3	9147.5	9853.5	9876.8	9876.9	8.0%	8.0%	8.0%
Winter-Spring 1978	9231.4	9239.3	9239.5	10019.4	10027.5	10027.7	8.5%	8.5%	8.5%
Winter-Spring 1979	9204.5	9217.5	9217.7	9943.3	9955.7	9955.9	8.0%	8.0%	8.0%
Winter-Spring 1980	9309.6	9317.5	9317.6	10099.7	10106.9	10107.1	8.5%	8.5%	8.5%
Winter-Spring 1981	9181.9	9202.4	9202.6	9926.2	9945.8	9946.0	8.1%	8.1%	8.1%
Winter-Spring 1982	9374.0	9380.6	9380.7	10217.2	10223.4	10223.6	9.0%	9.0%	9.0%
Winter-Spring 1983	8954.5	8956.2	8956.3	9946.4	9947.5	9947.7	11.1%	11.1%	11.1%
Winter-Spring 1984	9355.7	9368.2	9368.4	10167.7	10179.9	10180.1	8.7%	8.7%	8.7%
Winter-Spring 1985	9217.3	9236.8	9237.0	9975.8	9994.4	9994.6	8.2%	8.2%	8.2%
Winter-Spring 1986	8997.4	9005.5	9005.6	9884.8	9892.1	9892.2	9.9%	9.8%	9.8%
Winter-Spring 1987	9238.2	9255.3	9255.4	10001.1	10017.0	10017.2	8.3%	8.2%	8.2%
Winter-Spring 1988	9233.2	9250.8	9251.0	9984.8	10001.2	10001.3	8.1%	8.1%	8.1%
Winter-Spring 1989	9233.5	9255.2	9255.3	10009.9	10030.1	10030.3	8.4%	8.4%	8.4%
Winter-Spring 1990	9202.4	9227.2	9227.4	9958.1	9979.9	9980.1	8.2%	8.2%	8.2%
Winter-Spring 1991	9203.6	9226.1	9226.3	9956.0	9976.0	9976.2	8.2%	8.1%	8.1%
Winter-Spring all	9200.2	9215.7	9215.9	9989.2	10003.6	10003.8	8.6%	8.5%	8.5%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.

Table 12. Bay Region – Salmonid Rearing Winter-Spring Average Habitat Areas for Baseline (Baseline Habitat with Baseline Flows) and VA (VA Habitat with VA Flows)

	Salmonid Rearing Habitat Area (ac)						Habitat Area % Change from Baseline		
	Baseline			VA			VA		
Simulation Season	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive	Most Restrictive	Mean	Least Restrictive
Winter-Spring 1976	20187.2	20187.2	20187.2	20189.4	20189.4	20189.4	0.0%	0.0%	0.0%
Winter-Spring 1977	20225.4	20225.4	20225.4	20227.7	20227.7	20227.7	0.0%	0.0%	0.0%
Winter-Spring 1978	20087.5	20087.5	20087.5	20088.1	20088.1	20088.1	0.0%	0.0%	0.0%
Winter-Spring 1979	20161.0	20161.0	20161.0	20161.8	20161.8	20161.8	0.0%	0.0%	0.0%
Winter-Spring 1980	20038.3	20038.3	20038.3	20042.2	20042.2	20042.2	0.0%	0.0%	0.0%
Winter-Spring 1981	20173.8	20173.8	20173.8	20173.9	20173.9	20173.9	0.0%	0.0%	0.0%
Winter-Spring 1982	19871.6	19871.6	19871.6	19875.7	19875.7	19875.7	0.0%	0.0%	0.0%
Winter-Spring 1983	19657.7	19657.7	19657.7	19664.1	19664.1	19664.1	0.0%	0.0%	0.0%
Winter-Spring 1984	19952.7	19952.7	19952.7	19955.6	19955.6	19955.6	0.0%	0.0%	0.0%
Winter-Spring 1985	20082.7	20082.7	20082.7	20083.4	20083.4	20083.4	0.0%	0.0%	0.0%
Winter-Spring 1986	19843.8	19843.8	19843.8	19848.7	19848.7	19848.7	0.0%	0.0%	0.0%
Winter-Spring 1987	20028.4	20028.4	20028.4	20030.2	20030.2	20030.2	0.0%	0.0%	0.0%
Winter-Spring 1988	20054.9	20054.9	20054.9	20058.1	20058.1	20058.1	0.0%	0.0%	0.0%
Winter-Spring 1989	20048.6	20048.6	20048.6	20048.8	20048.8	20048.8	0.0%	0.0%	0.0%
Winter-Spring 1990	20066.4	20066.4	20066.4	20069.2	20069.2	20069.2	0.0%	0.0%	0.0%
Winter-Spring 1991	20061.9	20061.9	20061.9	20065.0	20065.0	20065.0	0.0%	0.0%	0.0%
Winter-Spring all	20033.9	20033.9	20033.9	20036.4	20036.4	20036.4	0.0%	0.0%	0.0%

Most restrictive, mean, and least restrictive results cover the range of possible values. Percent change from baseline is reported in the right three columns. These simulations were performed with CalSim II operations model results.