Central California Coast Regional

Temperature Study Workplan



June 2022

This document was prepared by the Santa Clara Valley Water District's (Valley Water's) Environmental Mitigation and Monitoring Unit in coordination with Exponent, Stillwater Sciences, and the San Francisco Regional Water Quality Control Board (Region 2).

Cover photos by Valley Water.

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1. Introduction

In the past, the San Francisco Bay Regional Water Quality Control Board (Region 2, RWQCB) has utilized the EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003) as one line of evidence when assessing whether temperature requirements of aquatic life in a given water segment in the San Francisco Bay Region are being met. However, the Region 10 Guidance states (p. 2):

> Because this guidance reflects EPA's current analysis of temperature considerations for Pacific Northwest salmonid species, EPA intends to consider it when reviewing Pacific Northwest State and Tribal temperature WQS or promulgating federal temperature WQS in Idaho, Oregon, or Washington.[1]

The State Water Resources Control Board (SWRCB) Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List (2015) states (p. 25-26):

> Temperature water quality objectives shall be evaluated as described in sections 6.1.5.1 through 6.1.5.7. When "historic" [sic] or "natural" temperature data are not available, alternative approaches shall be employed to assess temperature impacts.
>
> In the absence of necessary data to interpret numeric water quality objectives, recent temperature monitoring data shall be compared to the temperature requirements of aquatic life in the water segment. In many cases, fisheries, particularly salmonids, represent the beneficial uses most sensitive to temperature. Information on current and historic [sic] conditions and distribution of sensitive beneficial uses (e.g., fishery resources) in the water segment is necessary, as well as recent temperature data reflective of conditions experienced by the most sensitive life stage of the aquatic life species. If temperature data from past (historic [sic]) periods corresponding to times

[1] As of March 2022, the EPA advises that although EPA 2003 states that it is applicable to Idaho, Oregon, and Washington, they do not believe the Region 10 Guidance is not applicable to other regions (Brian Thompson, personal communication, March 30, 2022).

when the beneficial use was fully supported are not available, information about presence/absence or abundance of sensitive aquatic life species shall be used to infer past (historic [sic]) temperature conditions if loss of habitat, diversions, toxic spills, and other factors are also considered.

> Determination of life stage temperature requirements of sensitive aquatic life species shall be based on peer-reviewed literature. Similarly, evaluation of temperature data shall be based on temperature metrics reflective of the temperature requirements for the sensitive aquatic life species, including but not limited to, the maximum weekly average temperature and upper lethal limit.

The Santa Clara Valley Water District (Valley Water), therefore, intends to coordinate with the RWQCB and interested stakeholders to complete a regional temperature study (RTS) that identifies available data, identifies data gaps, and develops scientific studies that can be used to refine protective temperature evaluation guidelines to support cold freshwater (COLD), migration (MIGR), fish spawning (SPWN), and related beneficial uses of the Central California Coast (CCC) steelhead (*Oncorhynchus mykiss*) distinct population segment (DPS).[2] The definitions of these beneficial uses are provided in Table 1.

The RTS will consist of two phases, described in Sections 3 and 4 of this workplan (Figure 1). This workplan describes the purpose of the RTS, explains the roles of the parties involved in the RTS, and outlines the phases and goals of the RTS. It is intended to facilitate coordination between Valley Water and the RWQCB and outline a path by which regionally appropriate temperature evaluation guidelines applicable to waterbodies supporting CCC steelhead may be best developed.

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[2] Information leading to the initiation of this study can be found in Exponent's technical memorandum "Evaluation of Proposed Temperature 303(d) Listing of Los Gatos Creek, CA" (2020) and the SWRCB's adopting resolution (Resolution 2020-0039). SWRCB Resolution 2020-0039, #14 states: "If the San Francisco Bay Regional Water Board determines the regional temperature study meets the requirements of the Listing Policy applicable to selecting an evaluation guideline to interpret the narrative water quality objectives, the San Francisco Bay Regional Board may use the study to re-assess the Los Gatos Creek temperature listing in a subsequent cycle." Refer to Exponent (2020) and SWRCB Resolution 2020-0039 for more information.

2. Regional Temperature Study

2.A. Deadline

The RTS is planned to be completed in January 2023.

2.B. Goals

The goal of the RTS is to develop an approach to refinement of regionally appropriate and scientifically rigorous temperature evaluation guidelines that support COLD, MIGR, and SPWN beneficial uses of CCC steelhead.

2.C. Implementation Structure

Valley Water will coordinate with stakeholders to assist with conducting the RTS by engaging scientific expertise from academic, public, and/or private sectors in the fields of salmonid biology and temperature tolerance, ecology of California fish and the San Francisco Estuary, physiology of California fish, salmonid habitat assessments and migratory passage, stream water temperature modeling, environmental stress tolerance, aquatic toxicology, the impact of introduced aquatic organisms, and other disciplines relevant to the derivation of temperature evaluation guidelines protective of MIGR, SPWN, and COLD beneficial uses.

Valley Water has engaged the San Francisco Estuary Institute (SFEI), an independent organization, to assemble and facilitate an impartial panel of experts (the Technical Review Panel, TRP) to provide technical recommendations and review the RTS design, data, and analyses. Valley Water, other participating stakeholders, and regulatory agencies will maintain open and transparent communication with TRP members and SFEI throughout the RTS process, consider the input of the TRP objectively, and avoid interfering with the independence of the TRP, their deliberations, or their scientific conclusions.

Technical Review Panel: The TRP will:

- Convene for approximately fifteen hours over multiple meetings between September 2021 and January 2023 (Table 2). Meeting dates are subject to change based on the RTS progress and availability of new information. Some meetings will have a portion of time devoted to questions and comments from the regulatory agencies, Valley Water, and Valley Water's consultants.
- Review data and/or documents provided through SFEI and provide feedback on the technical studies being done within, and data and information collected as a part of, the RTS in order to identify important biological endpoints[3] for CCC steelhead life stages and recommend study methodology to assess protective temperature considerations. If it is not possible to make temperature recommendations for the RTS based on existing data, then the TRP will recommend appropriate field or controlled studies or additional analyses which could reliably assist in answering these questions.
- In early 2023 the TRP, in coordination with SFEI, will provide a report (the TRP Recommendations Report) that includes the important water temperature considerations for each steelhead life stage, references relevant existing data/literature, and makes recommendations for additional data collection or study, as needed.

Regulatory Guidance: Staff from the RWQCB, California Department of Fish and Wildlife, National Oceanic and Atmospheric Administration/National Marine Fisheries Service, and Environmental Protection Agency (EPA) will be invited to attend a portion of the TRP meetings to receive progress updates and provide input. This will allow the TRP to consider the regulatory agencies' concerns and considerations when reviewing the RTS design, data, and analyses and making recommendations, if needed, on additional data collection or study such that the RTS conclusions can be used in accordance with the requirements of the Listing Policy

[3] Biological endpoints refer to biological properties of species and their habitat which can be objectively measured and are essential for successful completion of their life cycle. Endpoints represent biological attributes that, when adversely affected, lead to reduced fitness of individuals.

to assess temperature impairments in the region's surface waters.

Public Input: A portion of the RTS meetings will be open to the public to allow the TRP to hear and respond to stakeholder concerns.

Regional Water Quality Control Board: Valley Water has requested that the RWQCB review and advise on this RTS workplan, be invited to participate at the designated times in TRP meetings, and coordinate regularly with Valley Water and its consultants to help design an approach to assess protective temperature considerations for CCC steelhead and ultimately provide regionally-appropriate temperature guidelines.

Thus, it is important that the reader of this workplan, and the TRP in particular, understand the regulatory structure. In accordance with the implementation policy of the SWRCB Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List (2015) (p. 17):

> The Regional Water Boards and the State Water Board shall actively solicit all readily available data and information. The Regional Water Boards shall review all readily available data and information that has been submitted in response to the solicitation, including but not limited to data that is submitted by the Regional Water Boards, the State Water Board, and other sources,

and (p. 19):

> When evaluating narrative water quality objectives or beneficial use protection, the Regional Water Boards and the State Water Board shall identify evaluation guidelines that represent standards attainment or beneficial use protection.

Regarding the evaluation guideline selection process, the SWRCB Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List (2015) states (p. 19):

To select an evaluation guideline, the Regional Water Board or the State Water Board shall:

- Identify the water body, pollutants, and beneficial uses;
- Identify the narrative water quality objectives or applicable water quality criteria;
- Identify the appropriate interpretive evaluation guideline that potentially represents water quality objective attainment or protection of beneficial uses. If this Policy requires evaluation values to be used as one line of evidence, the evaluation value selected shall be used in concert with the other required line(s) of evidence to support the listing or delisting decision.

2.D. Study Activities and Products

It is the intent of the RTS to prepare a scientifically rigorous document which identifies important biological endpoints for CCC steelhead life stages and recommends study methodology to assess protective temperature considerations. This document (the TRP Recommendations Report) is meant to make the best available data and information for the CCC Region readily available and facilitate refinement of the RWQCB's assessment of temperature guidelines protective of beneficial uses (e.g., COLD, MIGR, SPWN) in the San Francisco Bay Region. Study activities are described in two phases. Phase 1 involves compiling and analyzing existing data to predict the probability of CCC steelhead occurrence based on temperature. The outcome of Phase 1 will include 1) a technical memorandum summarizing existing literature and data relevant to steelhead and temperature within the CCC DPS range, which was completed in June 2020 (Stillwater Sciences 2020, Appendix A[4]), and 2) a manuscript in a format suitable for publication in relevant scientific journals to be completed by Stillwater

[4] Note that page 1 of this report states that water bodies with temperatures that exceed a 7-day average of the daily maximum (7DADM) of 18°C are classified as impaired under Section 303(d) of the federal Clean Water Act. However, this is not always the case. The criteria used in the 303(d) listing of Los Gatos Creek are defined in the SWRCB Final Staff Report 2018 Integrated Report for Clean Water Act Sections 305(b) and 303(d) Adopted by the SWRCB on October 20, 2020 (SWRCB 2021). EPA (2003) recommends a summer maximum condition criteria of 18°C 7DADM for salmon/trout migration plus non-core juvenile rearing, and research permits issued to Valley Water typically require that electrofishing not occur if instantaneous water temperatures exceed 64°F (18°C).

Sciences by mid-2022. In Phase 2, the TRP will determine if suitable data exist, or identify additional studies or analyses which need to be conducted, to develop appropriate temperature evaluation guidelines protective of steelhead in the CCC Region. The outcome of Phase 2 will be the TRP Recommendations Report, due in early 2023.

3. Phase 1: Studies Based on Existing Data

Phase 1 is underway and will identify existing information on the presence or absence of *O. mykiss* as it relates to water quality, growth, and habitat data and predict the probability of CCC steelhead occurrence based on temperature. According to the EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality standards (EPA 2003), field studies that assess the probability of occurrence or density of a specific species based on maximum temperatures represent an independent line of evidence for defining upper optimal temperature thresholds and complement laboratory studies. Phase 1 will inform temperature tolerance of and an upper thermal limit for CCC steelhead, and using fish length/weight data, could help evaluate whether temperatures are associated with fish condition. More information on the RTS Phase 1 study is provided in Stillwater Sciences' Central California Coast Steelhead Temperature Tolerance Evaluation task order for Valley Water (Stillwater Sciences 2021).

Goal: Use existing data to evaluate how stream temperatures influence the presence and condition of CCC steelhead and identify existing information or recommend studies that could be used to develop one or more water temperature evaluation guidelines appropriate for CCC steelhead. Phase 1 is expected to inform the direction and focus of Phase 2.

Scale: The scale of Phase 1 was chosen to be the CCC steelhead DPS range because it would increase the sample size and range of habitats included in the study beyond the limits of Valley Water's service area (Santa Clara County), incorporating more temperature variability and increasing the ability to detect responses, while still being manageable given the existing resources and timeframe. Additionally, the National Marine Fisheries Service manages species population listings based on DPS designations, making it a logical study area.

Methods: Valley Water has contracted with Stillwater Sciences to perform the following tasks:

- Conduct a comprehensive literature review of steelhead temperature tolerance studies across their entire distribution.
- Determine quantity and quality of available data (which will include *O. mykiss* presence/absence, water temperature, and may include growth, habitat, and water quality data).
- Perform quantitative analyses to evaluate the probability of *O. mykiss* occurrence based on available temperature and presence/absence data compiled from agencies within the CCC steelhead DPS area.
- Evaluate fish condition using length and weight data collected during field surveys. Test for influences of temperature on fish condition to evaluate the potential for decreased growth resulting from higher temperatures.
- Determine which temperature guideline biological endpoint(s) may be addressed for CCC steelhead using available data and develop methodology for addressing those endpoints.
- Evaluate whether significant differences in temperature and steelhead presence/abundance can be identified within the CCC DPS area to determine if the same guidelines would be applicable to all subregions or diversity strata within the CCC DPS area.
- Determine an approach for supplementing available data to address appropriate temperature endpoints, as needed.

Timeline: Tasks including literature review, gathering of data, and recommendations for additional studies to fill data gaps that could limit the ability to develop new temperature evaluation guidelines have been implemented. Data analysis will be completed by early 2022 and preparation of a manuscript in a format suitable for publication in relevant scientific journals will be completed by mid-2022. The report will be posted online at Valley Water's website to make the report available to regulatory agencies and the public.

Limitations: Presence/absence surveys do not indicate temperatures associated with sublethal endpoints, and it may be difficult to separate the effects of temperature from other factors. The analyses described above will inform temperature tolerance of and an upper thermal limit for CCC steelhead. Fish length and weight data could help evaluate whether temperatures are suitable for growth based on fish condition, but these analyses will not define 'optimal' temperatures. Establishing optimal temperatures and thresholds for sublethal effects would require evaluating performance traits across a range of temperatures, which is best accomplished in controlled experiments. Evidence of optimal temperatures for CCC steelhead that is located within the literature (through controlled studies or otherwise) will be used to infer temperature optimum. The ability to predict upper thermal tolerance is based on the availability of data that include stream sites with warm temperatures. Existing data may not be suitable to evaluate growth or migration endpoints. The Phase 1 approach will provide information/evidence on the temperatures that could be limiting to growth, but it cannot be used to replace results from controlled studies to estimate optimal temperature ranges for growth.

4. Phase 2: TRP Recommendations Report

Phase 2 of the RTS will identify and design a supplemental study, or program of studies, to refine regionally appropriate temperature guidelines for CCC steelhead. Such studies would be conducted in partnership with regional stakeholders, including other interested water agencies, and in collaboration with the RWQCB. Potential supplementary studies to support the development of temperature guidelines could include, but are not limited to, evaluating historical water temperatures, conducting field studies, and/or conducting streamside experimental or laboratory studies.

Goal: Complete the TRP Recommendations Report, which will describe a study or program of studies to collect and develop scientifically sound data and recommendations to inform temperature evaluation guidelines appropriate for CCC steelhead life stages including spawning and egg incubation, juvenile rearing, and adult/juvenile migration that address the requirements of the Listing Policy applicable to selecting evaluation guidelines to interpret the narrative water quality objectives.

Scale: Based on Phase 1 findings and recommendations from the TRP, studies recommended in Phase 2 of the RTS could occur at a different spatial scale than Phase 1 studies, but will be designed to be applicable, but not necessarily limited to, streams supporting CCC *O. mykiss* in Santa Clara County.

Timeline: The TRP Recommendations Report is scheduled for completion in January 2023. Supplementary studies would occur after Phase 2 is complete and would be based on the final TRP Recommendations Report. The timeline for implementing supplementary studies will be refined with the assistance of the TRP and will be based on numerous factors including scope, schedule, permits/regulatory constraints, laboratory and organism availability, funding, etc.

Methods: The TRP Recommendations Report will address the following guiding questions:[5]

1) What key factors must be considered when determining protective temperatures that support CCC steelhead COLD, MIGR, and SPWN beneficial uses in the study area (e.g., life stages, thermal adaptation and acclimation, food availability, predation by and competition with other fish species, disease, seasonal habitat conditions, etc.)?

2) Valley Water, San Francisco Bay Regional Water Quality Control Board, and other regulatory agencies are seeking to improve the thresholds associated with protective temperatures that support CCC steelhead COLD, MIGR, and SPWN beneficial uses in the study area. What information or data currently exists that could improve the protective temperature thresholds?

[5] These are tentative questions based on the current understanding of the parties involved in the RTS regarding what will be needed to develop protective temperature evaluation guidelines for CCC steelhead. These questions may evolve over time as more information is gained through the RTS process.

3) What new data collection and/or experimental or modeled data analyses should be considered for providing information that could improve the protective temperature thresholds for CCC steelhead in the study area? How should the analyses be prioritized?

The TRP Recommendations Report may include references to studies that have already been conducted and which would be applicable to CCC steelhead and/or supplemental studies and methods that could be conducted to develop regionally appropriate temperature evaluation guidelines using the best available science.

The TRP's approach should use EPA (2003) as a starting point, meaning that the TRP should discuss the temperature considerations relevant to the life stages of spawning and egg incubation, juvenile rearing, and adult migration, similar to the summary of temperature considerations for salmon and trout life stages provided in EPA (2003), and reproduced here in Tables 3 - 5.[6] Other temperature considerations should include lethality, juvenile out-migration, and summer rearing specifically. The TRP should refer to pages 46 to 51 of the SWRCB 2018 Final Integrated Report (2020) for information on additional sources used to assess attainment of beneficial uses as a starting point for the TRP Recommendations Report. The TRP may recommend whether the temperature considerations in EPA (2003), and other papers cited in SWRCB (2020), should be retained, adjusted, or if there are other factors that should be considered, as well as identify the most sensitive life stage(s). Stillwater Sciences has completed a literature review relating temperature to CCC steelhead, and that memo is available to the TRP for reference. In regards to how rigid the existing temperature standards are, the RWQCB has stated that they look at outside sources for a narrative regarding beneficial uses, and that numeric interpretation of a narrative can be objective and dynamic; therefore, there is flexibility in the guidelines based on new information (Richard Looker, personal communication, November 19, 2021). Ultimately, the TRP should recommend studies that can

[6] The temperatures included in the EPA (2003) tables reproduced in this report are those that were selected for the Pacific Northwest and need not be considered as astarting point for determining appropriate temperatures for the CCC Region.

be conducted to develop scientifically sound temperature evaluation guidelines protective of steelhead life stages in the CCC DPS area.

Limitations: Ideally, the TRP would first identify existing studies that could be used to inform appropriate temperature evaluation guidelines for CCC steelhead. However, it will likely be necessary to collect additional field and/or experimental data to supplement currently available data. The TRP will provide recommendations for supplementary studies in the final TRP Recommendations Report, which marks the completion of Phase 2. Supplementary studies to be conducted after completion of Phase 2 will require assistance with study scope, schedule, permits/regulatory constraints, laboratory and organism availability, funding, etc. in addition to coordination with the parties involved in Phases 1 and 2 of the RTS.

References

Environmental Protection Agency [EPA]. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

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State Water Resources Control Board [SWRCB]. 2015. Water Quality Policy for Developing California's Clean Water Act Section 303(d) List. Adopted September 30, 2004. Amended February 3, 2015.

State Water Resources Control Board [SWRCB]. 2021. Final Staff Report 2018 Integrated Report for Clean Water Act Sections 305(b) and 303(d). Adopted by the State Water Resources Control Board on October 20, 2020.

Stillwater Sciences. 2020. Central California Coast Steelhead Temperature Threshold Review. Technical memorandum prepared for the Santa Clara Valley Water District.

Stillwater Sciences. 2021. Central California Coast Steelhead Temperature Tolerance Evaluation – Phase 2. Task Order No. SS09, Task Order Scope of Services, Valley Water On-call Consultant Agreement #A4278A.

Table 1. Definitions of aquatic life beneficial uses most relevant to this RTS (RWQCB 2019).

<u>FISH MIGRATION (MIGR):</u> *Uses of water that support habitats necessary for migration, acclimatization between fresh and salt water, and protection of aquatic organisms that are temporary inhabitants of waters within the region.* The water quality provisions acceptable to cold-water fish generally protect anadromous fish as well. However, particular attention must be paid to maintaining zones of passage. Any barrier to migration or free movement of migratory fish is harmful. Natural tidal movement in estuaries and unimpeded river flows are necessary to sustain migratory fish and their offspring. A water quality barrier, whether thermal, physical, or chemical, can destroy the integrity of the migration route and lead to the rapid decline of dependent fisheries. Water quality may vary through a zone of passage as a result of natural or human- induced activities. Fresh water entering estuaries may float on the surface of the denser salt water or hug one shore as a result of density differences related to water temperature, salinity, or suspended matter.
<u>FISH SPAWNING (SPWN):</u> *Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.* Dissolved oxygen levels in spawning areas should ideally approach saturation levels. Free movement of water is essential to maintain well-oxygenated conditions around eggs deposited in sediments. Water temperature, size distribution and organic content of sediments, water depth, and current velocity are also important determinants of spawning area adequacy.
<u>COLD FRESHWATER HABITAT (COLD):</u> *Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.* Cold freshwater habitats generally support trout and may support anadromous salmon and steelhead fisheries as well. Cold water habitats are commonly well-oxygenated. Life within these waters is relatively intolerant to environmental stresses. Often, soft waters feed cold water habitats. These waters render fish more susceptible to toxic metals, such as copper, because of their lower buffering capacity.

Table 2. Preliminary RTS Schedule of Activities.

RTS Milestones	
Stillwater to complete analysis of quantity/quality of available data, determine which temperature guideline endpoint(s) may be addressed for CCC steelhead using available data, and develop methodology for addressing those endpoints.	Summer 2022
TRP to review Phase 1 report and begin discussions regarding study design and methodology for additional data collection and/or laboratory studies to be conducted post-Phase 2, as needed, to determine evaluation temperatures for relevant biological endpoints.	Summer/Fall 2022
Coordinated effort among all parties to identify funding and stakeholders to conduct additional data collection and/or laboratory studies after completion of the RTS to support refinement of regionally protective temperature evaluation guidelines to support MIGR, COLD, SPWN and related beneficial uses.[5]	Fall/Winter 2022
TRP, with SFEI assistance, to complete RTS TRP Recommendations Report.	January 2023
TRP Meetings	
TRP Kick-off Meeting	September 2021
TRP Meeting #1	November 2021
TRP Meeting #2	March 2022
TRP Meeting #3	July 2022
TRP Meeting #4	January 2023

[5] Schedule for additional data collection and/or laboratory studies is dependent upon factors including but not limited to ability to obtain collection or electrofishing permits, laboratory capacity, availability of fish, and availability of funding.

Table 3. Summary of temperature considerations for salmon and trout life stages (reproduced from EPA 2003, Table 1).

Life Stage	Temperature Consideration	Temperature	Reference
Spawning and Egg Incubation	*Temp. range at which spawning is most frequently observed in the field	4 - 14°C (daily avg)	Issue Paper 1; pp 17-18 Issue Paper 5; p 81
	* Egg incubation studies - Results in good survival - Optimal range	4 - 12°C (constant) 6 - 10°C (constant)	Issue Paper 5; p 16
	*Reduced viability of gametes in holding adults	> 13°C (constant)	Issue Paper 5; pp 16 and 75
Juvenile Rearing	*Lethal temp. (1 week exposure)	23 - 26°C (constant)	Issue Paper 5; pp 12, 14 (Table 4), 17, and 83-84
	*Optimal growth - Unlimited food - Limited food	13 - 20°C (constant) 10 - 16°C (constant)	Issue Paper 5; pp 3-6 (Table 1), and 38-56
	*Rearing preference temp. in lab and field studies	10 - 17°C (constant) < 18°C (7DADM)	Issue Paper 1; p 4 (Table 2). Welsh et al. 2001.
	*Impairment to smoltification	12 - 15°C (constant)	Issue Paper 5; pp 7 and 57-65
	*Impairment to steelhead smoltification	> 12°C (constant)	Issue Paper 5; pp 7 and 57-65
	*Disease risk (lab studies) - High - Elevated - Minimized	> 18 - 20°C (constant) 14 - 17°C (constant) 12 - 13°C (constant)	Issue Paper 4, pp 12 – 23

Table 3. *Continued.*

Life Stage	Temperature Consideration	Temperature	Reference
Adult Migration	*Lethal temp. (1 week exposure) *Migration blockage and migration delay *Disease risk (lab studies) - High - Elevated - Minimized *Adult swimming performance - Reduced - Optimal * Overall reduction in migration fitness due to cumulative stresses	21- 22°C (constant) 21 - 22°C (average) > 18 - 20°C (constant) 14 - 17°C (constant) 12- 13°C (constant) > 20°C (constant) 15 - 19°C (constant) > 17-18°C (prolonged exposures)	Issue Paper 5; pp 17, 83 – 87 Issue Paper 5; pp 9, 10, 72-74. Issue Paper 1; pp 15 – 16 Issue Paper 4; pp 12 – 23 Issue Paper 5; pp 8, 9, 13, 65 - 71 Issue Paper 5; p 74

Table 4. Recommended uses and criteria that apply to summer maximum temperatures (reproduced from EPA 2003, Table 3).

Salmonid Uses During the Summer Maximum Conditions	Criteria
Bull Trout Juvenile Rearing	12°C (55°F) 7DADM[6]
Salmon[7]/Trout[8] "Core" Juvenile Rearing *(Salmon adult holding prior to spawning, and adult and subadult bull trout foraging and migration, may also be included in this use category)*	16°C (61°F) 7DADM
Salmon/Trout Migration plus Non-Core Juvenile Rearing	18°C (64°F) 7DADM
Salmon/Trout Migration	20°C (68°C) 7DADM, plus a provision to protect and, where feasible, restore the natural thermal regime

Table 5. Other recommended uses and criteria (reproduced from EPA 2003, Table 4).

Salmonid Uses	Criteria
Bull Trout Spawning	9°C (48°F) 7DADM[7]
Salmon[8]/Trout[9] Spawning, Egg Incubation, and Fry Emergence	13°C (55°F) 7DADM
Steelhead Smoltification	14°C (57°F) 7DADM

[7] "7DADM" refers to the Maximum 7-day Average of the Daily maximums.
[8] "Salmon" refers to Chinook, coho, sockeye, pink, and chum salmon.
[9] "Trout" refers to steelhead and coastal cutthroat trout.

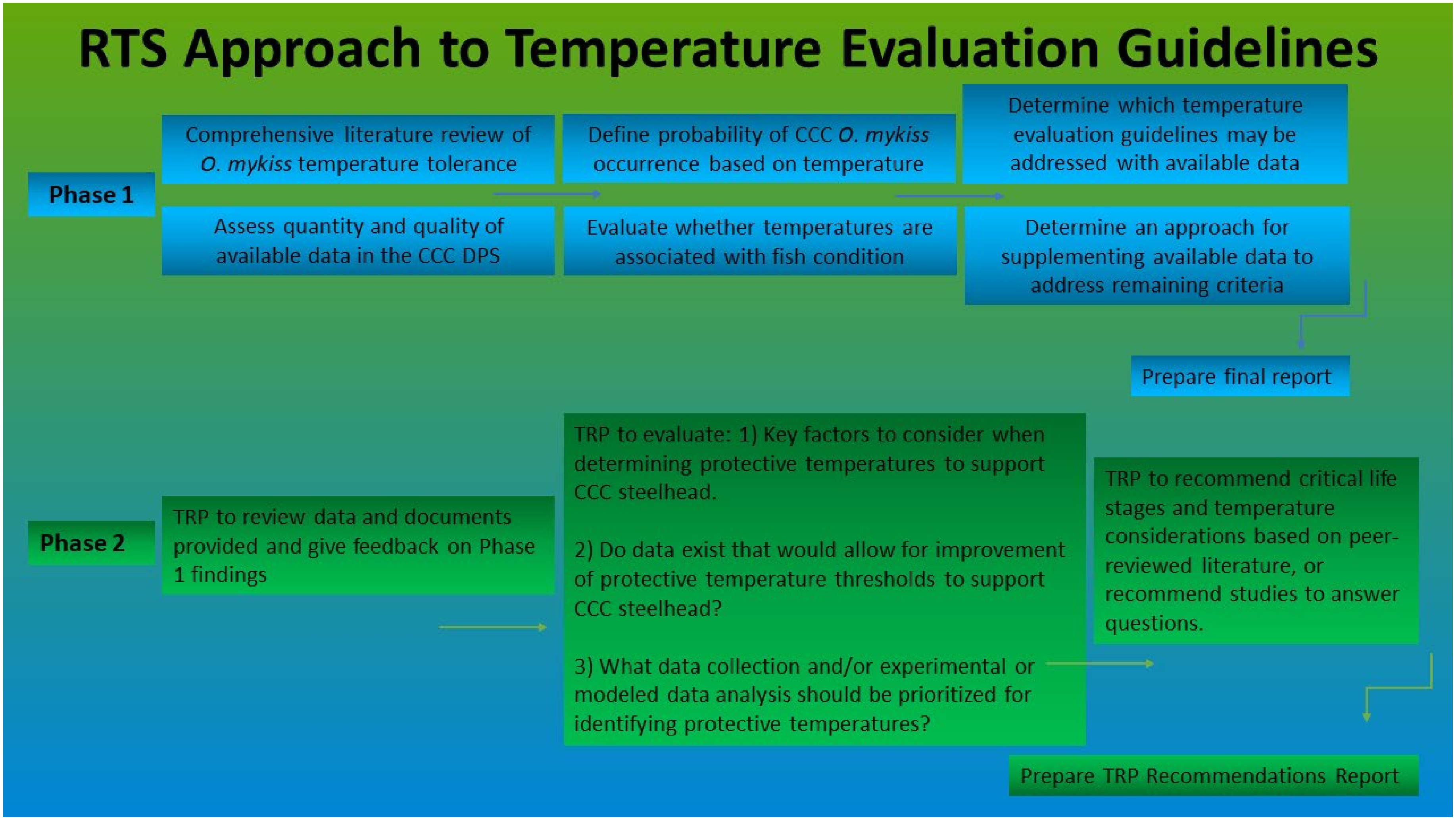

Figure 1. Conceptual RTS approach to ultimately refining temperature evaluation guidelines for the CCC Region.

Appendix A
Central California Coast Steelhead Temperature Threshold Review

Stillwater Sciences
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TECHNICAL MEMORANDUM

DATE: June 30, 2020

TO: Santa Clara Valley Water District

FROM: Stillwater Sciences

SUBJECT: Central California Coast Steelhead Temperature Threshold Review

Santa Clara Valley Water District (Valley Water) has requested assistance from Stillwater Sciences to investigate and prepare a report on temperature thresholds that potentially limit the occurrence of Central California Coast (CCC) steelhead (*Oncorhynchus mykiss irideus*). Currently, Valley Water has temperature restrictions which limit their ability to collect data on steelhead (electrofishing/tagging standards), and potentially unrealistic instream temperature standards that are based on research in the Pacific Northwest. Valley Water would like to assess the potential to identify more appropriate temperature threshold standards for the CCC Steelhead Distinct Population Segment (DPS).

To support Valley Water's goals for evaluating CCC steelhead temperature tolerance, Stillwater recommended a phased approach. Phase 1 included: (a) summarize existing literature and data; (b) coordinate with other stakeholder groups in the CCC DPS region; and (c) provide recommendations for analyses or additional data collection. The technical memo presented herein is the deliverable under Phase 1.

1 BACKGROUND

Steelhead (*Oncorhynchus mykiss*) are generally considered a cold-water species, but despite this, steelhead are known to tolerate wide temperature ranges and occur across a broad latitudinal temperature gradient from the Bering Sea south to the Northern Baja California. At the southern extent of their distribution in central and southern California, steelhead populations have generally been declining due to numerous factors but mainly habitat loss and climate change. Declines in steelhead numbers have led to federal listing of Central California Coast (CCC), Central California (CC), South-Central California Coast (SCC), and Southern California Coast (SC) Steelhead DPSs as either endangered (CCC and SC) or threatened (CC and SCC) under the Endangered Species Act (NMFS 2006). As a consequence of their federal listing and to reduce negative impacts on steelhead, water bodies with temperatures that exceed a 7-day average of the daily maximum (7-DADM) of 18°C, an upper temperature limit originally established for steelhead in the Pacific Northwest, are classified as impaired under section 303(d) of the federal Clean Water Act (USEPA 2003). Impaired water bodies due to high temperatures require development of Total Maximum Daily Loads (TMDLs), which involve quantitative assessments of high temperature sources and temperature thresholds (i.e., temperatures that protect cold-water fish) in the watershed, as well as development of a plan to restore healthy water quality. In addition to developing TMDLs following designation of an impaired water body, sampling waters for steelhead using many traditional methods (e.g., electrofishing, trapping, tagging) is only permitted by NMFS when the water temperature is below the designated 18°C maximum, which can limit research and recovery efforts in the CCC DPS where water frequently exceeds this upper temperature limit.

A central question is whether the regulatory standard derived from northern populations of steelhead is applicable to steelhead in their southern distribution. The 18°C regulatory standard was derived from an extensive literature review by McCollough (1999) focused on physiological effects of temperature on salmonids. In their review, McCollough (1999) addressed the potential for intraspecific thermal tolerances in steelhead (and other salmonids) and generally found studies did not support biologically relevant differences in temperature tolerance among populations (and even among species within the salmonid family). However, interspecific variability in thermal performance has been shown for salmonids (Cech and Myrick 1999, Myrick and Cech 2001, Richter and Kolmes 2005, Eliason et al. 2011, Chen et al. 2013, Verhille et al. 2016), and the need for incorporating population specific information into fishery management has been noted (Gayeski et al. 2018). At the time of McCollough (1999, 2001) reviews, few studies were available that evaluated temperature tolerances of central and southern California steelhead populations or that evaluated population-specific thermal physiology. Almost two decades later, additional studies have provided evidence that steelhead at their southern distribution can tolerate much higher temperatures (Verhille et al. 2016, Sloat & Osterback 2013). However, regulatory standards for sampling below 18°C are still applied in central and southern California.

To evaluate the current state of knowledge on temperature tolerances of steelhead in the CCC DPS, we collected existing information on steelhead temperature tolerance with a focus on steelhead populations within the CCC DPS. In addition to assembling peer-reviewed and grey literature, we contacted water districts, government agencies, and other stakeholders that operate within CCC DPS watersheds for data and reports relating steelhead presence to temperature (a summary of all agencies and stakeholders contacted is provided in Table A-1). Below we provide a summary of the information and data available, identify data gaps, and provide recommendations for future analysis and studies. We begin with a brief review of the effects of temperature on fish.

1.1 Temperature and Salmonids

Temperature affects fish directly through its regulation of metabolic rate (Fry 1948) and indirectly by influencing ecological interactions (e.g., competition and predation) and food availability. Thus, temperature influences salmonids across life stages including growth and development, and timing of life history events such as smoltification and emergence from the redd (Groot et al. 1995). Metabolic rate, and thus oxygen demand, increases with increasing temperature to a point after which the capacity to supply oxygen becomes limited and anaerobic metabolism takes over (Portner & Farrell 2008). Aerobic scope, defined as the increase in oxygen consumption from resting to maximal (Brett 1971), supports animal function including growth, digestion, movement, and reproduction. As temperature increases or decreases away from an optimal temperature, the amount of energy available for these functions decreases due to narrowing aerobic scope. Thus, fish have a range of temperatures they can tolerate, an optimal temperature range where performance is maximized, and critical temperatures when normal body function is no longer supported, and survival becomes time dependent. Because of the effects of temperature on fish metabolism and performance, species (and population) thermal tolerances are adaptations to thermal regimes that vary over biogeographical scales. However, temperature tolerance is also heavily influenced by a fish's prior thermal history (acclimation).

Understanding upper temperature limits of fish has long been of interest, having recently received considerable attention due to predicted increases in aquatic temperatures because of climate change. Lethal temperature limits exist for fish, but sub-lethal temperature stress occurs at above-optimal temperatures and can become lethal if chronic exposure occurs. Sub-lethal temperature stress influences physiology (e.g., ionoregulation, immune function), growth, energetics, and performance (e.g., swimming ability). Fish can acclimate to higher temperatures but can also respond behaviorally to above optimal temperatures by locating thermal refuge in microclimates (Li et al. 1994) or migrating to cooler waters (Nielsen et al. 1994). When additional food is available, fish can also increase feeding to meet increased metabolic demands imposed by above optimal temperatures, and growth rates can be higher under warmer conditions (Wurtsbaugh & Davis 1977). However, increased feeding can only allow fish to survive at higher temperatures to a point, beyond which there is no longer capacity for digestion and activity due to the collapse of aerobic scope. It should be noted that different performance traits can have different thermal optimum, and temperature influences biotic conditions (e.g., prey density) and species interactions (Reeves et al. 1987). Thus, ecologically realized thermal niches can differ from those measured for a single trait.

1.2 Temperature Thresholds

Descriptors of the temperature tolerance of fish reported in the literature are many and varied, and include "optimum" (or "optimal"), "preferred," "suitable," "tolerance," "stressful," "maximum," and "lethal". Very few studies use comparable evaluation methods or produce equivalent thresholds, but some of the most common thresholds are described as.

Optimal – temperatures that maximize performance metrics, such as swimming ability, oxygen consumption, or growth rate.

Preferred – temperatures selected by fish when ranges of temperature is available. Note that preferred and optimal temperatures can differ due to multiple factors such as prey availability.

Suitable (or within range of tolerance) – temperature range that fish can tolerate for extended periods of time.

Sub-lethal – temperatures that result in stress and can lead to mortality if exposure is over extended periods of time.

Lethal – temperatures that cause acute mortality

Each metric for assessing temperature tolerance has different implications and applications. For example, optimal temperatures, which are typically evaluated under controlled laboratory settings, are evaluated in reference to a specific biological trait such as growth rate. Of note, optimal temperatures can vary among biological traits, and fish do not necessarily select optimal temperatures within an environment due to interacting factors such as competition or predation. Field-based observations have been used to infer suitable temperatures based on presence/absence of fish across a range of temperatures. In one study, field observations were used to estimate in-situ thermal niche occupied by *O. mykiss* (Huff et al. 2005). Indeed, due to temperature influences on stream biotic and abiotic conditions and species interactions (Reese & Harvey 2002), realized thermal-niche of species in the natural environment are often different from optimal temperatures identified in controlled laboratory experiments.

The temperature thresholds above are commonly evaluated using specific tests in controlled settings that are described below for reference.

Incipient lethal temperature (ILT) - temperature that is lethal for 50% of the population (upper ILT referred to as UILT).

Aerobic scope - the absolute difference between maximum metabolic rate (MMR) and routine metabolic rate (RMR) or the amount of energy available for activities beyond resting.

Critical thermal maximum (CT_{max}) - the thermal point at which locomotion becomes disorganized and the animal loses its ability to escape from conditions that will promptly lead to its death.

Measures of lethal temperature, such as ILT, are difficult to estimate because it requires more test specimens and mortality is necessarily an experiment endpoint, which limits its application to at-risk populations. In contrast, CT_{max} and aerobic scope requires fewer test organisms and mortality is not necessarily an experimental endpoint. In contrast to UILT and CT_{max}, which only provide estimates of upper temperature limits, aerobic scope is perhaps the most biologically meaningful because it estimates of the percent of energy available to complete biological needs (e.g., digestion, growth) above basic survival over a range of temperatures.

In addition to these common temperature tolerance metrics described above, direct physiological stress from temperature can also be measured in a variety of ways. For example, stress hormone levels and ion concentrations respond to temperature stress and can be measured from blood plasma samples. Molecular techniques, such as microarray or quantitative real-time polymerase chain reactions (qRT-PCR), can also be used to assess temperature effects by measuring cellular level stress responses such as increased expression of heat shock proteins and genes related to stress, immune function, osmoregulation and metabolic processes. Increased pathogen loads are also associated with temperature stress and could be proximate mechanisms of mortality in many cases due to increased pathogenicity, immunosuppression, or both. Pathogen presence and loads can be identified through histological or molecular approaches.

1.3 Temperature Characterization and Standards

The above thresholds and metrics are designed to evaluate temperature tolerance of fish, whereas in-situ temperatures are characterized by various indices. Temperature standards are then developed based on temperature thresholds and indices and are applied based on achieving specific objectives. Short-term temperature standards are generally developed to protect against acute effects (i.e., mortality), whereas long-term standards address chronic, sub-lethal effects such as reduced growth or reduced gamete viability. Commonly encountered temperature indices and standards are summarized below.

Daily average temperature is the average temperature for a single 24-hour period based on regular and periodic measurements.

Daily maximum temperature is the maximum instantaneous temperature in a single 24-hour period based on regular and periodic measurements.

Seasonal average temperature is the average temperature for the entirety of a designated seasonal period. An alternative time period of concern (e.g., the duration of a fish life stage) may often be used in place of season.

Annual maximum temperature is the maximum daily temperature that occurs each year. The annual maximum temperature index is typically used to develop temperature standards to protect against short-term temperature increases that can result in direct mortality.

Maximum weekly average temperature, or ***MWAT***, is the maximum 7-day running average of the daily mean temperatures for the period of record or a time period of concern (e.g., a salmonid life stage) (Brungs and Jones 1977). The date of the 7-day averaging period may be any day in the period, but is typically the midpoint or end of the period. This threshold reflects the average temperatures that an organism experiences over the course of any 7-day period during the time period of concern, but may not account for short-term maxima that may approach or exceed lethal limits. Although fish can generally tolerate short-term exposure to critically high temperatures, repeated or prolonged exposure may negatively affect growth, fitness, or survival.

Maximum weekly maximum temperature (MWMT), or ***7-day average of the daily maximum temperatures (7-DADM)***, is the maximum value in a moving (running) 7-day average of the daily maximum temperatures. This index reflects a stream's maximum temperatures without undue bias by the temperature of a single day (USEPA 2003). This index, however, due to its emphasis on maximum temperatures that often occur only for short periods, may not accurately characterize chronic temperature conditions that affect growth. Therefore, MWMT (or 7-DADM) is best suited for use as part of a temperature standard that protects against acute (i.e., lethal) effects. This is the standard applied to streams to evaluate whether systems are impaired under 303(d).

Perhaps the most widely used and commonly accepted long-term water temperature standard is MWAT. The use of MWAT was first proposed by the National Academy of Sciences (NAS and NAE) in 1972 (NAS and NAE 1973) as a long-term standard for preventing chronic sub-lethal effects for a variety of fish species. MWAT is currently a convenient way to compare the results of researchers and is the threshold most commonly used for establishing temperature standards for salmonids (e.g., Armour 1991, NMFS and USFWS 1997, Sullivan et al. 2000). The objective of the MWAT is to provide an upper temperature threshold that is protective of a particular salmonid life stage, typically during the summer season.

The scientific rationale for using MWAT as a temperature standard is based on experimental observations that fish can tolerate moderate temperature fluctuations as long as the ILT is not exceeded for prolonged periods (Sullivan et al. 2000). The use of MWAT also assumes that optimal temperatures are not necessary or realistic at all times to sustain viable fish populations (NAS and NAE 1973), and thus allows some environmental variability around any daily threshold value.

In contrast to MWAT, the 7-DADM (or MWMT) is the temperature standard applied by the USEPA (2003) for designating impaired waters to protect salmonids against acute temperature effects. The use of MWMT rather than MWAT is due to the tendency of the MWAT standard to underestimate maximum temperatures, especially when there are large daily temperature fluctuations. The most biologically appropriate temperature standard (MWAT versus MWMT) for protecting salmonids is subject to debate (McCollough 2010).

2 APPROACH

As a first step towards evaluating CCC steelhead temperature tolerance, we located peer-reviewed literature and unpublished reports that related temperature to CCC steelhead. Literature searches were performed with Google Scholar using combinations of keywords including "steelhead," "temperature," and "thermal." Titles and abstracts of studies in search results were reviewed to identify relevant literature for additional review. Relevant studies were reviewed further, and references were cross-checked to identify additional studies missing from Google Scholar results.

Regional agencies and stakeholders were contacted to identify additional information on CCC steelhead and temperature in the form of data collected and unpublished reports not identified in web-based searches. Unpublished reports were reviewed to identify data that could be used in future evaluations, and additional coordination among stakeholders was used to further identify relevant data sets. While this literature and data collection step does not include a detailed evaluation of temperature tolerance, we provide a preliminary summary of relevant information from the literature.

Peer-reviewed literature searches focused on CCC steelhead studies, but as relatively few studies are specific to CCC steelhead, studies on CC, SCC, and SC steelhead were incorporated to provide additional insights into region-specific thermal tolerance. Literature from outside of central and southern California that specifically addressed high thermal tolerance of steelhead were also incorporated, when appropriate. Studies that examined resident rainbow trout populations within steelhead waters (historical or current) were also considered because resident rainbow trout share genetics with steelhead even when resident populations exist above barriers (Clemento et al. 2009). However, hatchery stocking practices could influence population genetics of resident populations (and thus temperature tolerance, e.g., Myrich and Cech 2000), and populations without immigration could experience localized adaptation.

3 RESULTS

3.1 Literature Searches

In total, we located and reviewed 29 peer-reviewed studies that were of specific interest for evaluating temperature tolerance of steelhead populations at the southern end of their distribution (Table A-2). In addition to the peer-reviewed literature, we located and reviewed six government reports, one book chapter, three academic theses, and over 30 unpublished reports (Table A-2, Table A-3). Unpublished reports were located through various water manager's websites or through personal communications with water managers. The number of unpublished reports reviewed herein does not accurately reflect the total number of available reports. For example, many water managers publish annual reports, and in these cases, we selected reports that summarized multiple years of data or selected reports from a few different years to review consistency of methods and reporting. Below we summarize the locations, timing, methodologies, and results from these studies. This is not intended to be a comprehensive review, rather a preliminary assessment of the information available to identify gaps and inform our recommendations for future qualitative and quantitative studies.

Literature searches were focused on studies on steelhead at the southern end of their range, but as anticipated, most peer-reviewed studies were from northernly populations. Web-based literature searches only identified six peer-reviewed studies that related temperature to CCC steelhead

(Table 1). Peer-reviewed studies on CC (n = 4), SCC (n = 2), and SC (n = 5) steelhead were also identified through web-based searches. Other relevant peer-reviewed studies that specifically addressed higher thermal tolerance of certain strains or populations were from northern California (n = 9), Oregon (n =2), and Australia (n = 1). Of interest, the study from Australia not only evaluated upper temperature limits of *O. mykiss*, but also involved *O. mykiss* introduced from a Central California population, which is why it was considered of specific interest. In addition to the peer-reviewed literature, nine reports in the form of academic theses and water manager reports were located that specifically related steelhead to temperature in streams within the CCC Steelhead DPS (Table 1). Note, that we located and reviewed numerous other unpublished reports that monitor steelhead and temperature, but only a subset of these reports specifically related temperature to steelhead, which is why many unpublished reports were not included in Table 1. These additional reports are documented in Table A-3 and referenced with respect to our summary of available data (see Section 3.2 below for more details).

Table 1. Summary of identified literature that evaluates the influence of temperature on steelhead within the CCC Steelhead DPS. Literature includes peer-reviewed studies, academic theses, and unpublished reports. All identified literature including studies from outside the CCC Steelhead DPS is summarized in Table A-2.

Reference	Document Type	Study Region or DPS	Study Location	Life Stage	Summary of Temperature Effects
Beakes et al. 2010	Peer-reviewed; experimental	Central Coast California, Northern California	Scott Creek, upper Sacramento River	juvenile	Increased growth in warmer temperatures (~4°C warmer than cooler temperatures), but more so for Northern population than Central Coast population.
Dockam 2016	M.S. thesis	Central Coast California	Dry Creek	juvenile	Growth and relative condition increased at higher temperatures from 13 – 15°C.
Hayes et al. 2008	Peer-reviewed; field observation	Central Coast California	Scott Creek	juvenile	Estuarine fish grew larger and faster despite warmer temperatures (15 – 24°C) compared to the upper watershed (14 – 18°C), presumably due to higher prey availability in estuary.
Kubicek & Price 1976	Peer-reviewed; field observation	Central Coast California	Big Sulphur and Squaw Creek	juvenile	Young of the year rear in geothermally warmed waters until temperatures reach marginal (26.5 – 28° C) or lethal (>28° C) in May or June. Juvenile rearing occurs in sub-lethal temperatures (20 – 26.5° C).
Leicester & Smith. 2014	Report; field observation	Central Coast California	Coyote Creek	juvenile	Highest densities observed in location with higher water temps. Growth reduced at higher temps during summer (20 – 21°C)

Reference	Document Type	Study Region or DPS	Study Location	Life Stage	Summary of Temperature Effects
Matsubu 2019	Ph.D. thesis	Central Coast California	Russian River estuary	juvenile	The depth of fish in the water column is regulated in part by temperature with deeper depths occupied when temperatures were high. Energetic costs of high temperatures in the upper reaches of the estuary are moderated by the consumption of energy dense prey.
Matsubu et al. 2017	Peer-reviewed; field observation	Central Coast California	Russian River estuary	juvenile	Fish will voluntarily choose habitats with high temperatures (~ 20° C) when habitats with lower temperatures are available.
NCRCD 2003c	Report; field observation	Central Coast California	Sulphur Creek Watershed	juvenile	Temperatures > 20°C recorded during habitat surveys where steelhead were present.
NCRCD 2014	Report; field observation	Central Coast California	Pope Creek	juvenile	Average temp was 20°C with max of 22.5°C. Observed 10 – 15 steelhead, and concluded presence of a small population despite high temperatures.
SCWA 2003	Report; field observation	Central Coast California	Russian River	juvenile	Steelhead observed at 22°C and 22.5°C.
Seghesio 2011	M.S. thesis	Central Coast California	Russian River estuary	juvenile	Simulated temperature increases indicate growth rate plateaus at 13 – 16°C then decreases as temperatures rise.
Smith, J. 2018	Report; field observation	Central Coast California	San Lorenzo River, Soquel Creek, Aptos Creek and	juvenile	Estuary temps were high in mid-October when steelhead observed at temps >22.8°C

Reference	Document Type	Study Region or DPS	Study Location	Life Stage	Summary of Temperature Effects
			Estuary, Pajaro River Estuary		
Sogard et al. 2012	Peer-reviewed; field observation	Central Coast California, Central California	Scott Creek, Soquel Creek, American River, Mokulmne River	juvenile	Did not specifically test for temperature effects, although temperature and food availability were thought to influence results showing different growth rates and life history patterns of steelhead in coastal and central California streams.
Stillwater Sciences 2007a	Report; field observation	Central Coast California	Napa River	juvenile	Temperatures generally within range for optimal growth (<18°C), but temps > 20°C observed with no effects on growth

Limited information on temperature tolerance for southern steelhead populations was included in reviews used to establish current EPA guidelines (USEPA 2003). Studies on CCC steelhead in the peer-reviewed literature spanned from 1976 – 2017. With the exception of a single study published in 1976 (Kubicek & Price 1976), all other peer-reviewed CCC studies were published after reviews by McCollough (1999, 2001), which were used to establish the current EPA temperature guidelines. Furthermore, there were only two peer-reviewed studies (i.e., Matthews & Berg 1997, Railsback & Rose 1999) on steelhead temperature tolerance from southern populations (SC and CC, respectively) available to be included in seminal reviews by McCollough (1999, 2001). We also did not locate any unpublished reports relating CCC steelhead to temperature prior to reviews by McCollough (1999, 2001). McCollough (2001) did note, however, that population-specific thermal tolerance was a possibility but did not find evidence to support this. The lack of studies on southern populations is likely due to limited numbers of fish available to study, and regulatory protections of existing fish.

Among the literature reviewed, the majority were field-based, observational studies (n = 14) followed by controlled experiments (n = 8). We also identified eight literature reviews in the form of peer-reviewed studies and government reports. Field observation studies commonly used *O. mykiss* surveys paired with continuous temperature monitoring to relate temperature to *O. mykiss* presence/absence, growth, feeding rates, species interactions, and behavioral responses. Experimental studies commonly assessed the effects of temperature on performance metrics such as growth and metabolic rate, and experimental approaches were also applied to define temperature tolerance thresholds using CT_{max} (Myrich and Cech 2005) and aerobic scope (Verhille et al. 2016). Thus, experimental studies tended to be better at evaluating upper temperature thresholds due to the ability to manipulate temperature in a controlled setting. Growth is a fundamental biological factor for steelhead life-history decisions and survival, hence why growth was commonly assessed across both field and lab studies.

3.2 CCC Steelhead Temperature Summary

Results from the literature specific to temperature tolerance of CCC steelhead are summarized in Table 1. Studies suggest juvenile steelhead can tolerate and even benefit from increased growth in temperatures greater than the regulatory standard of 18°C. Steelhead were routinely observed at temperatures above 20°C (Leicester & Smith. 2014, Matsubu et al. 2017, NCRCD 2003c) with presence commonly reported near 22°C (SCWA 2003, NCRCD 2014, Smith, J. 2018) and in some cases reported as high as 24 – 26°C (Kubicek & Price 1976, Hayes et al. 2008). These measures of temperature and fish presence likely define a zone of tolerance rather than optimal temperatures for growth. In addition to finding presence of steelhead at temperatures higher than 18°C, one study found juvenile steelhead densities were actually higher in warmer temperatures (exact temperatures not clear but presumably above 21°C; Leicester & Smith 2014). In another study, steelhead selected habitat with higher temperatures despite cooler temperatures being available (Matsubu et al. 2017) presumably because warmer temperatures impart growth advantages or better feeding opportunities. Most of these studies were not designed to evaluate a specific upper temperature threshold, but in one study, CCC steelhead were no longer observed in surveys when temperature was ≥ 26°C (Kubicek & Price 1976).

Numerous studies on CCC steelhead also noted increased growth of juveniles exposed to warmer temperatures (Beakes et al. 2010, Dockam 2016, Hayes et al. 2008), although temperature ranges where increased growth was reported varied among studies. For example, Beakes et al. (2010) exposed steelhead to two temperature regimes, 'warm' and 'cool,' that mimicked environmental temperatures (including seasonal variations) from streams and found higher growth rates of fish in the ‘warm’ treatment. Temperatures in the ‘warm’ treatment were on average 4°C higher than the ‘cool’ treatment and reached >18°C but varied considerably over the course of the study. Although Beakes et al. (2010) found evidence of higher growth rate in warmer temperatures, their study was not designed to evaluate upper temperature limits for growth. In another study, steelhead growth was reduced in an upper watershed during warm (14 – 18°C) summer months compared to cool (7 – 12°C) winter months, but increased growth was observed at warmer temperatures (15– 24°C) in the estuary (Hayes et al. 2008). The author of this study attributed reduced growth in upper watershed at warmer temperatures to a lack of productivity, whereas the warmer estuary environment was highly productive to offset metabolic costs.

3.3 Non-CCC Steelhead Temperature Summary

Results from studies on other southern populations of steelhead outside of the CCC steelhead DPS coincided with findings from within the CCC, mainly that steelhead temperature tolerance varies based on population, and higher (>18°C) temperature tolerance is observed in many locations, but there is much variability across studies. Temperatures limiting presence of steelhead that were reported from field surveys ranged from mean temperatures >21°C (Matthews & Berg 1997, Thomson 2012) to maximum temperatures >30°C (Sloat and Osterback 2013). Behavioral avoidance was observed at temperatures from 23 – 28°C (Nielsen et al. 1994, Brewitt & Danner 2014, Wang et al. 2020), but in one study, fish selected warmer (>20°C) habitat when the habitat provided increased feeding opportunities (Smith & Li 1983). Signs of sub-lethal physiological stress were detected when fish were exposed to long-term temperatures >18°C and short-term temperatures >20 – 25°C (Werner et al. 2005, Kammerer & Heppell 2013). Experimental studies showed CT_{max} of CC steelhead ranged from 27.5 – 29.6°C depending on acclimation temperature (Myrich and Cech 2005). Interestingly, a Central California *O. mykiss* population that was introduced to warmer streams in Australia had a measured CT_{max} of 29°C, demonstrating the potential for population-specific temperature adaptations/acclimation. In another study on CC steelhead, fish maintained 95% of peak aerobic scope over a broad thermal window (17.8 – 24.6°C) (Verhille et al. 2016). Upper optimal temperatures for growth rate from studies outside of the CCC steelhead DPS were commonly reported at 19°C (Myrich and Cech 2000, 2004, 2005). One study reported reduced growth at temperatures >15°C, but noted reduced growth was likely related to limited prey availability (McCarthy et al. 2009).

3.4 Steelhead Thermal Tolerance Summary

Based on our preliminary review of the literature, steelhead in the southern range of their distribution have the potential to tolerate and even thrive in temperatures above the current 18°C regulatory standard. Population-level differences were observed across study locations (Myrick & Cech 2000, Beakes et al. 2010). A question is whether thermal tolerance differences observed across geographic scales and at the population level are due to local adaptation or acclimation to higher temperatures. Regardless of the mechanism, it appears that steelhead are capable of not only tolerating temperatures >18°C, but in some cases, benefit from higher temperature due to increased growth rates as long as food is available to compensate for increased metabolic costs.

3.5 Available Data

We identified available data through communications with various water districts/agencies that operate within the CCC steelhead watersheds and by reviewing unpublished reports from water districts and other sources. Several types of data were consistently identified that could be used to evaluate CCC steelhead temperature thresholds. We only included summaries for data from sources that indicated they were willing to share the data. Common types of data that could be made available include:

O. mykiss survey data **-** snorkel and electrofishing surveys were common in streams with seining in some estuaries.

Continuous temperature monitoring data – collected using data loggers. In some cases, can be paired with *O. mykiss* presence/absence data from surveys.

Growth data **-** *O. mykiss* growth data either from scale samples or from size measurements repeated through time. In some cases, growth data can be paired with continuous temperature monitoring data.

Movement data **-** telemetry data or other movement-based monitoring (e.g., downstream migrant traps).

Discrete temperature data – temperature measurements at the time and location of *O. mykiss* surveys or at locations where fish are detected or captured. In many cases, *O. mykiss* surveys are timed to avoid times of the day when there are high temperatures, and thus these discrete temperature measures may not accurately represent actual temperature experience of fish.

Additional data that was identified that could be useful included: invertebrate data, water quality data (e.g., dissolved oxygen), and physical habitat data. Invertebrate data is of specific interest because it could help test the hypothesis that fish are able to tolerate higher temperatures when enough prey is available to offset the increased metabolic demands, but these data are likely only available in a few locations (e.g., Dry Creek, Russian River estuary) and are not continuously collected. Water quality and physical habitat data could be useful to include as covariates in models predicting *O. mykiss* presence/absence. These data are routinely collected during *O. mykiss* surveys and may be widely available.

Table A-2 summarizes available data from various sources and includes location and temporal resolution of the available data. The data covers a large spatial extent of the CCC region, although it was noted in communications with data sources, that many of the locations may not experience elevated temperatures. For example, Joe Sullivan (East Bay Regional Parks), Bert Mulchaey (East Bay Municipal Utilities District), and Eric Ettlinger (Marin Municipal Water District) all noted that the maximum temperatures experienced in their watersheds were generally lower than 18°C. Others, however, noted that the temperatures in their watershed where *O.mykiss* occur are greater than 18-20° C including in the Russian River watershed and streams monitored by Valley Water, Napa County Resource Conservation District, and San Francisco Public Utilities Commission. Of specific interest, biologists from Sonoma County Water Agency (Gregg Horton) expressed willingness to share data and are in the process of gathering and formatting data to send. In addition, Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) is willing to share their data upon request and has collected eight years of continuous temperature monitoring data throughout sites within the Santa Clara Valley. Based on a preliminary review of locations for SCVURPPP temperature data and Valley Water *O. mykiss* survey data, many sites can be reasonably paired together for analyses. Overall, there is data available across a large spatial coverage within the CCC steelhead DPS that is available for analyses. We discuss our recommendations for how to analyze this data below in Section 4.

To provide an example of the range of temperatures where *O. mykiss* are observed within the Valley Water service area, we evaluated *O. mykiss* survey data provided by Valley Water that was collected from 1997-2002. *O. mykiss* surveys were conducted using a range of techniques including trapping, seining, and backpack electrofishing surveys. Temperature measurements were included for each fish 'detection.' A total of 1,076 records were included in this data set. Temperatures ranged from 9 – 26°C (mean ± SD = 16.5 ± 4.2°C) (Figure 1). Approximately one third (33%) of the temperatures recorded were above the 18°C regulatory standard when fish were observed. These data clearly indicate that *O. mykiss* in these watersheds can tolerate short-term exposure to temperatures up to 26°C.

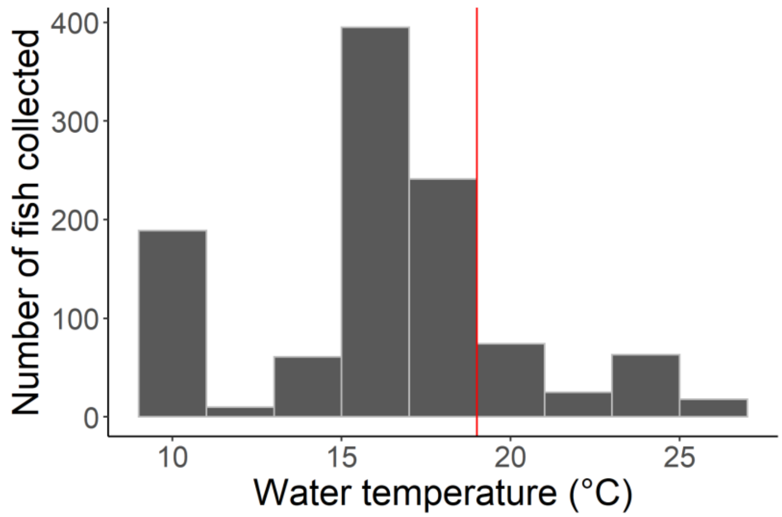

Figure 1 Number of *O. mykiss* detected in surveys across a range of water temperature. Each bar represents water temperatures in 2˚C bins. The vertical red line represents the 18˚C regulatory standard.

3.6 Knowledge and Data Gaps

Our review of existing information revealed several knowledge gaps that could limit the ability to reevaluate regulatory standards. These knowledge gaps include:

- A small number of peer-reviewed studies relating temperature to CCC steelhead.
- A small number of peer-reviewed studies relating temperature to southern steelhead populations (e.g., CC, SCC, SC).
- Life stage specific temperature effects (as noted in Myrick & Cech 2004) such as during incubation, rearing, and smoltification for CCC steelhead; all existing peer-reviewed CCC studies are on the juvenile life history stage.
- Studies evaluating links between temperature, growth, and food availability

4 RECOMMENDATIONS

Below we describe a series of studies and data collection efforts that we recommend for evaluating the temperature tolerance of CCC steelhead and ultimately for encouraging a reevaluation of regulatory standards. For each study, we describe the approach and anticipated outcomes. Each of these approaches have their own merits, challenges, and limitations, which are discussed for each study. The strongest approach for evaluating steelhead temperature tolerance would include a combination of literature review, field-based, and laboratory studies, with the aim of submitting results to peer-reviewed scientific journals. In addition to our recommended studies, we also include recommendations for additional studies to consider based on funding availability and collaboration opportunities.

4.1 Literature Review and Synthesis

Our preliminary literature searches located many recent peer-reviewed studies published over the last two decades (i.e., since publications reviewed by McCollough 1999, 2001) that could be used to evaluate temperature tolerance of steelhead at the southern end of their distribution. Moreover, results from these studies suggest interspecific variation in thermal performances and higher temperature tolerance of steelhead populations at the southern end or their distribution compared to northern populations. A formal literature review would update existing reviews with recent studies and provide additional context on population-specific thermal tolerance of steelhead, as well as provide updated recommendations for upper thermal tolerance based on the geographic location of the population.

The largest anticipated challenge will be establishing defensible recommendations based on a limited number of studies on CCC steelhead. Including studies from other southern locations would provide additional data to inform this qualitative evaluation. The literature review would include studies on southern and more northern populations for comparisons and specifically evaluate whether temperature limits established for northern populations apply to more southern population. The review would be submitted for peer-review as either a stand-alone review, or in combination with the data analysis described below in Section 4.2.

4.2 Data Analysis – Predicting Probability of Occurrence Based on Temperature

Defining an ecological thermal niche, a range of temperatures in which an organism can persist, for salmonids has been done by measuring in-situ environmental temperatures to ultimately define upper thermal tolerance to aid in restoration (Welsh et al. 2001, Hines and Ambrose 2000). We recommend a quantitative analysis using existing data from CCC steelhead DPS for evaluating temperature tolerance of steelhead at the southern end of their distribution. This analysis would use continuous temperature monitoring data that can be paired with steelhead (and resident *O. mykiss*) presence/absence across the CCC DPS. We recommend using presence/absence data rather than density data because presence/absence is more readily available and not influences as much by sampling techniques. Based on our communications with water agencies, these types of data sets are available for many locations within the CCC DPS. This analysis could be further expanded to include data collected at other southern locations, such as within the SC steelhead DPS, to increase samples sizes and test for additional population-specific thermal tolerance. This analysis would be presented as either a stand-alone study for peer-review or would be combined with the literature review described above. We recommend the latter because it would include empirical data to test temperature tolerance values reported in the literature.

Temperature metrics including MWMT and MWAT would be calculated from continuous monitoring data and used to predict the probability of steelhead occurrence using logistic regression. The analysis would focus on summer temperatures and juvenile rearing life stage. The result from this analysis would establish probabilities of steelhead occurring for any given temperature. Interpretations from this analysis would form recommendations for thermal limits based on in-situ field observations. For example, results might indicate that there is a 10% probability that steelhead are present when temperature is greater than some value and a 90% probability that steelhead are present when temperature is less than some value. Other instream habitat variables, such as physical habitat data, could also be included in models to account for their effects on steelhead presence, although this is dependent on the availability and consistency of this type of data.

We anticipate the largest challenge for this data analysis will be collecting data from water districts. The water districts have expressed willingness to share data but have also expressed concerns that organizing data in a format that can be shared presents challenges in terms of effort by their staff.

4.3 Data Collection – *O. mykiss* surveys Paired with Continuous Temperature Monitoring

To bolster sample sizes, we also recommend deployment of continuous temperature data loggers at locations that correspond with fish surveys in a randomized spatial design within the watersheds managed by Valley Water. This data could be added to the analysis described in Section 4.2.

4.4 Additional Studies to Consider

We recommend considering the following studies based on available funding, collaboration opportunities, and logistical feasibility.

Data analysis – growth rate

Growth rate is among the most important biological factors because it is predictive of life history pathways (e.g., smoltification), survival and fitness. Temperature and food availability are two critical components for predicting growth rates, and it has been shown that increased food availability can offset increased metabolic costs associated with higher temperatures. Many of the *O. mykiss* surveys that would be used in the analyses described in Section 4.2 above include data collected on fish growth through collection of scales or by repeated measurements of fish size from the population that can be used to track growth rates of age classes of fish over time. Growth rate measurements collected in the field could be related to continuous temperature monitoring metrics (MWAT and MWMT) to evaluate temperatures limiting to growth. If invertebrate or stream productivity data is also collected, these could also be incorporated into analyses. The major anticipated challenge with this analysis is locating large enough sample sizes of growth data that can be paired with limited continuous temperature monitoring data.

Controlled experiments

A limitation of data collected in the field is the inability to disentangle the effects of multiple, potentially interacting factors that could influence fish presence or growth rate. For example, temperatures in a stream could be suitable for a species, but other environmental conditions, such as habitat availability or the presence of predators, limit that species presence. Controlled experiments can be used to study factors of specific interest and complement results from field-based studies. In some cases, controlled experiments can be performed in the field (e.g., $CT_{max,}$ aerobic scope) and there is no need to have access to laboratory facilities. A challenge can be the time and cost of running these experiments, but collaboration with academic labs could reduce cost.

CT_{max} tests are a rapid method to determine upper temperature tolerance of fish that require fewer sample sizes and mortality is not the experiment endpoint. CT_{max} tests involve acclimating fish to one temperature and then increasing temperature at a uniform rate until loss of equilibrium is observed. These tests can be performed streamside, and thus, do not require access to a laboratory. However, obtaining necessary permits can be challenging if the population in question is within anadromous waters. There are a number of *O. mykiss* populations above barriers within the CCC DPS (e.g, Upper San Leandro Creek) that are not included in federally protected steelhead populations. We recommend targeting above-barrier *O. mykiss* populations to perform CT_{max} tests while also collecting continuous temperature data. There is potential to collaborate on this research with academic researchers. Dr. Erika Eliason (University of California, Santa Barbara; UCSB) and Dr. Nann Fangue (University of California, Davis; UCD) are two professors with specific focus on understanding thermal tolerance of salmonids including steelhead. Both professors have labs equipped to conduct this type of research and expressed interest in future collaboration.

As discussed in the background section, upper temperature thresholds can be evaluated using CT_{max} or UILT tests, but these do not evaluate temperature that are biologically meaningful for optimal fish performance. Evaluating aerobic scope of a fish provides a range of temperatures over which energy is available for biological function above resting (e.g., digestion, growth, feeding, etc.). Aerobic scope studies require more time and investment than CT_{max} studies but are recommended because of the insights they provide into thermal physiology. Swim tunnel respirometers used to measure aerobic scope can be set up in the field (e.g., see Verhille et al. 2016), but access to steelhead for this research may be limited due to permitting constraints. We suggest exploring opportunities for collaboration with the academic labs mentioned previously at UCSB or UCD.

Finally, perhaps the most robust studies on temperature tolerance would involve controlled hatchery experiments. These types of experiments would involve collection of steelhead gametes in the field followed by fertilization and rearing in the lab. Hatchery reared fish could be exposed to temperature treatments to test hypotheses about population level adaptation, acclimation, growth, and survival. These studies would require the most cost and effort and should be considered a ‘pie in the sky’ if funding and collaboration opportunities allowed.

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6 APPENDICES

Table A-1 Summary of agencies and stakeholders identified within the CCC Steelhead DPS region. The table indicates whether contact was made, if data is available, and includes a summary of potential data and willingness to collaborate.

Agency/Stakeholder	Contact	Contacted	Data available?	Comments
CalTrout	Patrick Samuel; psamuel@caltrout.org	20-Apr	Possibly	CDFW Pescadero Lagoon Monitoring data available and publication provided.
CDFW	Sean Cochran, CDFW; Sean.Cochran@wildlife.ca.gov	N	N/A	Not yet contacted
CDFW	Jon Jankovitz, CDFW; Jon.Jankovitz@wildlife.ca.gov	N	N/A	Not yet contacted
Dr. Erika Eliason (UCSB)	eliason@ucsb.edu	1-Feb	N	Fish physiologist with specific interest in steelhead temperature thresholds. Does research examining *O. mykiss* thermal tolerance in So Cal.
Dr. Jerry Smith (San Jose St)	frogs_and_fish@yahoo.com	20-Apr	Y	Lots of data on temperature and steelhead from streams within Santa Clara Valley Water District
Dr. Nann Fangue (Cal Davis)	Nann A Fangue; nafangue@ucdavis.edu	1-Feb	Possibly	Fish physiologist with specific interest in steelhead temperature thresholds. Does research examining *O. mykiss* thermal tolerance in central California. Dr. Fangue is supportive of the project and willing to provide input as needed. Also

Agency/Stakeholder	Contact	Contacted	Data available?	Comments
				recently submitted m/s on Chinook temperature tolerance.
Dr. Stephanie Carlson (UC Berkeley)	smcarlson@berkeley.edu	4-May	N/A	Contacted, but no response.
East Bay Municipal Utilities District (EBMUD)	Barnard, Denise; denise.barnard@ebmud.com	4-Jun	Y	Mokelumne River, from Camanche dam to the confluence with the San Joaquin. Consistent rotary screw trap data and at least a couple continuous monitoring gauges close to sampling sites
East Bay Municipal Utilities District (EBMUD)	Bert Mulchaey; bert.mulchaey@ebmud.com	12-May	Y	Data provided, from a single sampling site in Upper Pinole Creek that has continous monitoring data paired with *O. mykiss* suvyes. Temperature rarely >18°C.
East Bay Regional Parks District	Joe Sullivan; jsullivan@ebparks.org	12-May	Y	Few resident rainbow trout streams that are sampled using efising in late summer. They find fish can survive in pools if they are deep and temp is low – mostly under 18°C is found in the area so probably not temperature limited
FISHBIO	Jim Inman; jiminman@fishbio.com	N	N/A	Not contacted
Hagar Environmental	Jeffery Hagar; jmhagar@sbcglobal.net	N	N/A	Not contacted

Agency/Stakeholder	Contact	Contacted	Data available?	Comments
Marin Municipal Water District	Eric Ettlinger; (eettlinger@marinwater.org)	12-May	Y	Indicated they are willing to share data, but few sites were temperatures >18°C.
Napa County	Jeremy Sarrow; jeremy.sarrow@countyofnapa.org	N	N/A	Not contacted
Napa River Resource Conservation District	Jonathan Koehler; jonathan@naparcd.org	20-Apr	Y	Directed to review reports to locate specific data that could be useful
NMFS	Joel Casagrande, NMFS; joel.casagrande@noaa.gov	N	N/A	Not yet contacted
NMFS	Joseph D. Kiernan, NMFS; joseph.kiernan@noaa.gov	N	N/A	Not yet contacted
NMFS	Haley Ohms, NMFS; haley.ohms@noaa.gov	N	N/A	Not yet contacted
NMFS	Josh Fuller - NMFS Santa Rosa; joshua.fuller@nmfs.gov	N	N/A	Not yet contacted
NMFS Santa Cruz lab	Ann Marie Osterbeck	N	N/A	Not yet contacted
San Francisco Public Utilities Commission	Brian Sak; bsak@sfwater.org	27-Apr	Y	Lots of temperature and steelhead monitoring data collected and available. Indicated it would be time consuming to provide data, but willing to provide specific data requested.

Agency/Stakeholder	Contact	Contacted	Data available?	Comments
Santa Clara Valley Urban Runoff Pollution Prevention Program	Paul Randall; prandall@eoainc.com	4-Jun	Y	Lots of continous temperature data collected in streams within Santa Clara Valley Water District.
Santa Clara Valley Water District	Jennifer Watson; JenniferWatson@valleywater.org	N/A	Y	Primary contact for project and source for Valley Water data.
Sonoma County Water Agency	Gregg Horton; gregg.horton@scwa.ca.gov	27-Apr	Y	Lots of existing data that is being provided. Continous temperature montitoring paired at locations near *O. mykiss* surveys.
Stillwater Sciences	Matt Drenner; mdrenner@stillwatersci.com	N/A	Y	Data available on Napa River and in Southern California on Santa Paula Creek within Santa Clara River
UC Cooperative Extension	Mariska Obedzinski; mobedzinski@ucsd.edu	N/A	N/A	Contact provided by Patrick Samuel, but not contacted
US EPA	Robert A. Leidy; Leidy.Robert@epa.gov	N/A	N/A	Not yet contacted
Zone 7	Elke Rank; erank@zone7water.com, Tami Church; tchurch@zone7water.com	N/A	N/A	Not contacted due to lack of *O. mykiss* in watershed, but will contact if temperature data is needed

Table A-2. All identified literature relating temperature to steelhead with specific relevance to high temperature tolerance. Literature includes peer-reviewed studies, academic theses, government reports, and unpublished reports.

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
Beakes et al. 2010	Peer-reviewed; experimental	Central Coast California, Northern California	Scott Creek and upper Sacramento River	juvenile	Increased growth in warmer temperatures (~4°C warmer than cooler temperatures), but more so for Northern population than Central Coast population.
Boughton et al. 2007	Peer-reviewed; field manipulation	Southern California	Lion Creek	juvenile	When food is not limiting variable cool temperatures have a stronger effect on growth compared to stable warm temperatures.
Boughton et al. 2009	Peer-reviewed; field observation	Southern California	Arroyo Seco River	juvenile, adult	Winter spawning and summer rearing habitats are concentrated in different parts of the watershed. Substantial spawning occurred in intermittent tributaries; however adults were most common in cooler perennial tributaries, rare in warmer mainstem.
Boughton et al. 2015	Peer-reviewed; modeling	Southern California	Santa Ynez River	juvenile	Simulations indicate coastal river is "thermally suitable" (mean daily <25° C and max daily <29° C) during hot summers, even though nearly every day is "thermally stressful" (any time >21° C).
Brewitt & Danner 2014	Peer-reviewed; field observation	Northern California	Kalamath River	juvenile	Juvenile steelhead moved into refuges when mainstem temperatures reached 22–23°C, and all fish moved in by 25°C.

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
Carter 2005	Government report; literature review	Broad geographic area	Broad geographic area	all	Review of temperature requirements of steelhead with implications specific to Klamath Basin
Chen et al. 2015	Peer-reviewed; experimental	Australia	population origin from Central California	juvenile	T_{opt} at 15°C, T_{pejus} at 20°C, 40% of aerobic scope at 25°C, CT_{max} around 29°C; fh_{max} peak at 24 C
Dockam 2016	M.S. thesis	Central Coast California	Dry Creek	juvenile	Growth and relative condition increased along a temperature gradient from 13 – 15°C.
Harvey et al. 2002	Peer-reviewed; field observation	Northern California	Eel River	juvenile, adult	Warmer temperature habitat had more invasive fish and fewer steelhead compared to cool habitats (MWAT range from 17 – 24°C).
Hayes et al. 2008	Peer-reviewed; field observation	Central Coast California	Scott Creek	juvenile	Estuarine fish grew larger and faster despite warmer temperatures (15 – 24°C) compared to the upper watershed (14 – 18°C)
Huff et al. 2005	Peer-reviewed; modeling and field observation	Oregon	Oregon - many locations	juvenile, adult	*O. mykiss* had the largest difference in realized thermal niche between ecoregions (16.9 – 22.4 C). *O. mykiss* had a warmer thermal niche in the South Coastal basin (16.6°C) than in the North Coastal basin (14.0°C)
Kammerer & Heppell 2013	Peer-reviewed; experimental	Oregon	Maupiin, Oregon	juvenile	Physiological threshold at about 23°C for steelhead. Steelhead had lower growth rates and elevated heat shock protein 70 levels at temperatures ≥

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
					25◦C relative to fish exposed to 23◦C and 15◦C.
Kubicek & Price 1976	Peer-reviewed; field observation	Central Coast California	Big Sulphur and Squaw Creek	juvenile	Young of the year rear in geothermally warmed waters until temperatures reach marginal (26.5 – 28° C) or lethal (>28° C) in May or June. Juvenile rearing occurs in sub-lethal temperatures (20 – 26.5° C).
Leicester & Smith. 2014	Report; field observation	Central Coast California	Coyote Creek	juvenile	Highest densities observed in location with higher water temps. Growth reduced at higher temps during summer (20 – 21°C)
Matsubu 2019	Ph.D. thesis	Central Coast California	Russian River estuary	juvenile	The depth of fish in the water column is regulated in part by temperature with deeper depths occupied when temperatures were high. Energetic costs of high temperatures in the upper reaches of the estuary are moderated by the consumption of energy dense prey.
Matsubu et al. 2017	Peer-reviewed; field observation	Central Coast California	Russian River estuary	juvenile	Fish will voluntarily choose habitats with high temperatures (~ 20° C) when habitats with lower temperatures are available.
Matthews & Berg 1997	Peer-reviewed; field observation	Southern California	Sespe Creek	juvenile, adult	No trout observed when temps exceeded 21°C

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
McCarthy et al. 2009	Peer-reviewed; modeling and field observation	Northern California	South Fork Trinity River, CA	juvenile	Reduced growth during summer when temps >15°C possibly related to increased metabolic demands and lower prey availability due to low flows/high temps
McCullough et al. 1999	Government report; literature review	Broad geographic area	Broad geographic area	all	Reviewed literature on temperature effects on salmonids with specific focus on Chinook.
McCullough et al. 2001	Government report; literature review	Broad geographic area	Broad geographic area	all	Literature review of the role temperature exerts on the physiology of various salmonids.
Myrick & Cech 2000	Peer-reviewed; experimental	Northern California	Shasta Strain RBT and Eagle Lake RBT	juvenile	Food consumption increased from 10-19°C, decreased from 19 – 25°C. Growth rates increased as temps increased from 10 – 19°C but were near zero from 19 – 25°C. Data demonstrate that rainbow trout are capable of growing well at temperatures near 22°C but that growth rates declined rapidly as temperatures approach 25°C
Myrick & Cech 2001	Report; literature review	Central California	Central Valley	all	Adult chronic lethal temp 25°C but can withstand temps up to 29.6°C for short durations. CT_{max} for juvenile rearing dependent on acclimation temperature but as hgih as >30°C. Optimal egg survival from 7 – 10°C. Smoltification from 6 – 10°C

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
Myrick & Cech 2004	Peer-reviewed; literature review	Central California	San Joaquin River - Central Valley	all considered	Growth reduced at temperatures > 19°C
Myrick & Cech 2005	Peer-reviewed; experimental	Central California	American River, Central Valley	juvenile	Highest growth rate observed at 19°C compared to 11 and 15°C. CT_{max} increased from 27.5°C for 11°C acclimated fish to 29.6°C for fish acclimated to 19°C.
Nakamoto 1994	Peer-reviewed; field observation	Northern California	New River -- Trib to Trinity	adult	No significant relationship between fish density and mean hourly pool temp (8.7 – 26.6°C)
NCRCD 2003c	Report; field observation	Central Coast California	Sulphur Creek Watershed	juvenile	Temperatures > 20°C recorded during habitat surveys, did not appear to impact steelhead population
NCRCD 2014	Report; field observation	Central Coast California	Pope Creek	juvenile	Average temp was 20°C with max of 22.5°C. Observed 10 – 15 steelhead, and concluded presence of a small population despite high temps
Nielsen et al. 1994	Peer-reviewed; field observation	Northern California	Eel River	juvenile, adult	Juvenile steelhead moved into stratified pools during periods of high ambient stream temperatures (23 – 28°C). Summer-run steelhead adults were found in deep stratified pools on the Middle Fork Eel River throughout summer when midday ambient stream temperatures ranged from 26 to 29°C and coldwater pockets averaged 3.5°C cooler.
Railsback & Rose 1999	Peer-reviewed; modeling and field observation	Central California	Tule River	juvenile	Summer temps not found to be important for growth, but likely due to temps being < 21°C

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
Reese & Harvey 2002	Peer-reviewed; experimental	Northern California	Eel River	juvenile	When Sacramento pikeminnow (*Ptychocheilus grandis*) are present and water temperature is 20 – 23°C *O. mykiss* growth is reduced >50%. *O. mykiss* growth was unaffected by Sacramento pikeminnow in water 15 – 18° C.
Ritcher & Kolmes 2005	Peer-reviewed; literature review	Broad geographic area	Broad geographic area	all	Literature review to summarize temp effects across life stage of different salmonid species.
SCWA 2003	Report; field observation	Central Coast California	Russian River	juvenile	Steelhead observed at 22°C and 22.5°C
Seghesio 2011	M.S. thesis	Central Coast California	Russian River estuary	juvenile	Simulated temperature increases indicate growth rate plateaus at 13 – 16° C then decreases as temperatures rise.
Sloat and Osterback 2013	Peer-reviewed; field observation	Southern California	Santa Paula Creek	juvenile	Fish present when maxima temperature ≤30°C. Feeding stopped at 29°C.
Smith & Li 1983	Book chapter	South Central Coast	Uvas Creek, trib of Pajaro River	juvenile	Selection of higher velocity habitat that had more food available when temperature increased to 20.5°C
Smith, J. 2018	Report; field observation	Central Coast California	San Lorenzo River, Soquel Creek, Aptos Creek and Estuary, Pajaro River Estuary	juvenile	Estuary temps were high in mid-October when steelhead observed at temps >22.8°C

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
Sogard et al. 2012	Peer-reviewed; field observation	Central Coast California, Central California	Scott Creek, Soquel Creek, American River, Mokulmne River	juvenile	Did not specifically test for temperature effects, although temperature and food availability were thought to influence results showing different growth rates and life history patterns of steelhead in coastal and central California streams.
Spina 2007	Peer-reviewed; field observation	Southern California	Arroyo Sequit, Solstice Creek and Topanga Creek	juvenile	Fish near the southern extent of the species range experienced high-water temperatures (17.4 – 24.8°C). Visual observation indicated normal fish behavior within these high temperatures and little or no thermal refugia.
Stillwater Sciences 2007a	Report; field observation	Central Coast California	Napa River	juvenile	Temperatures generally within range for optimal growth, but temps > 20°C observed with no effects on growth
Stillwater Sciences 2007b	Report; field observation	Southern California	Santa Paula Creek	juvenile	Data suggests upper thermal limits for *O. mykiss* in Santa Paula Creek to be between 31.5 – 33°C
Thomson 2012	Peer-reviewed; field observation	South Central Coast	Salinas River	juvenile	Sites with steelhead had maximum and mean water temperatures that were 6.1°C and 3.1°C cooler, respectively, than sites without steelhead. No steelhead were observed at sites where the mean and maximum temperature exceeded 21.5°C and 26°C, respectively.
USEPA 2003	Government report; literature review	Broad geographic area	Broad geographic area	all	Recommends that 7-DADM should not exceed 18°C in waters where both adult salmonid migration and juvenile

Reference	Document type	Study Region or DPS	Study location	Life stage	Summary of temperature effects
					rearing occur during the period of summer maximum temperatures
Verhille et al. 2016	Peer-reviewed; experimental	Central California	lower Tuolumne River, California	juvenile	95% of peak aerobic scope was maintained over a broad thermal window (17.8 – 24.6°C)
Wang et al. 2020	Peer-reviewed; field observation	Northern California	Eel River	juvenile	fish avoided temperatures greater than 24°C, but were found at 20 – 22°C despite cooler temperatures available
Werner et al. 2005	Peer-reviewed; experimental	Northern California	Navarro River	juvenile	Showed thermal stress, as evidenced by increased heat shock protein expression, under high temperatures from 18 – 19°C in terms of both short- and long-term averages and 20 – 22.5°C in terms of daily maximum averages

Table A-3. Summary of data collected by various stakeholders within the CCC Steelhead DPS. Information was gathered from reviewing reports or by personal communications with water managers.

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
Smith, J. 2019	Technical Report	Stevens Creek	2013–2019	• Temperature data loggers in 5 locations from May–November 2019. • Electrofishing surveys at 5 sites during October • Fish size and scale data	None
Leicester & Smith. 2014	Technical report	Coyote Creek	2014	• Temp loggers at 5 locations • Depletion efishing at 3 sites – presence/absence & density data • Scale samples taken for growth, fin clips for genetics • Temperatures recorded during efishing	• Highest densities observed in location with higher water temps • Growth reduced at higher temps during summer (20 – 21°C)
Smith, J. 2018	Technical report	Penitencia Creek	2018	• Temperature loggers at 4 sites in Upper Penitencia Creek at four locations over summer • Efishing at 5 sites in October • Scale data taken for growth	• Recorded temps are high (>21°C) during summer, but these temps were not related specifically to fish presence in the report
Alley, D.W. & Associates. 2019	Technical report	San Lorenzo River, Soquel Creek, Aptos Creek and Estuary, Pajaro River Estuary	2018	• Efishing to determine fish abundance at sites • Seining in estuary • Presumably, temperatures recorded during efishing • Temps taken in estuary	• Estuary temps were high in mid-October when steelhead observed at temps >22.8°C
SCWA (Sonoma County Water Authority) 2003	Technical Report	Russian River	2002	• Snorkel surveys in summer • Habitat assessment and temperature recorded in survey segments	• Steelhead observed at 22°C and 22.5°C

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
				• Temperature monitoring stations within same reaches	• Highest temps were 24 – 25°C, but behavior not discussed • The distribution of steelhead was correlated with water temperatures
SCWA and California Sea Grant. 2019	Technical Report	Russian River Watershed	2015–2019	• Electrofishing surveys • DIDSON • PIT tagging • No temperature data described, but presumably, discrete temperature measures taken during surveys	None
SCWA Draft EIR report - Chapter 4.3	Technical report	Russian River Watershed	draft	• Modeled temperature changes based on changes in flow • Related temperature changes to effects on steelhead	• Proposed how predicted temperature changes would affect steelhead
NCRCD (Napa County Resource Conservation District). 2005a, 2006a, 2007a	Technical Reports	Napa River	2004–2007	• Spawner surveys • Snorkel survey in May 2007 • Presumably, discrete temperature measures taken during surveys	None
NCRCD. Annual reports 2009–2013, 2016–2019	Technical Reports	Napa River	2009–2019	• Rotary screw trapping (RST) in spring 2009–2019 • Temperature data loggers summer 2009, spring 2012, 2013 • Spawner surveys 2011–2013, 2015–2019 • Snorkel surveys in spring 2012, 2013 • PIT tagging 2013–2019	None

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
NCRCD. Annual reports 2006b, 2007b, 2008.	Technical Reports	Napa Creek	2006–2008	• Stream habitat assessment • Temperature data logger from June 2006–December 2007, early 2008–? • Spawner surveys in November 2006, December 2007, and April 2008	• 2008 report suggests high temperatures limit successful rearing
NCRCD. 2014.	Technical Report	Pope Creek	2014	• Stream habitat assessment in May • Snorkel survey in May • Pool temperature differential in two pools	• Average temp was 20°C with max of 22.5°C • Observed 10 – 15 steelhead, and concluded presence of a small population despite high temps
NCRCD. 2003a.	Technical Report	Carneros Creek Watershed	2002	• Stream habitat assessment in September • Temperature data loggers at 2 sites from July–October	None
NCRCD. 2003b.	Technical Report	Wooden Valley Creek, White Creek	2002	• Stream habitat assessment in June	None
NCRCD. 2003c.	Technical Report	Sulphur Creek Watershed	2002	• Stream habitat assessment in August–September • Temperature data loggers at 2 sites from July–October	• Temperatures > 20°C recorded during habitat surveys, did not appear to impact steelhead population
NCRCD and Prunuske Chatham, Inc. 2012.	Technical Report	Northern Napa River sub–watersheds	2011	• Stream habitat assessment in summer and fall	None
NCRCD. 2005b.	Technical Report	Central Napa River sub–watersheds	2003–2004	• Stream habitat assessment in summer 2004 • Temperature data loggers at 10 sites from August 2003–October 2004 • Spawner surveys in November–December 2004	• Temperatures were high and observed few steelhead during snorkel survey

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
				• Snorkel surveys in summer 2004	
NCRCD. 2009.	Technical Report	Southern Napa River sub–watersheds	2006–2007	• Stream habitat assessment in summer and fall • Temperature data loggers at 11 sites from August 2006–December 2007 • Spawner survers (at a sub–set of sites) in 2007	None
SFPUC (San Francisco Public Utilities Commission). 2009a.	Technical Report	San Antonio Creek, Indian Creek and Arroyo Hondo	2005	• Temperature data loggers at 6 sites from January–June 2005 • Upstream migrant trapping late January–early April 2005 • Downstream migrant trapping February–mid–June 2005	• Majority of downstream moving adults were trapped in mid–March when temps were higher than prior weeks • Downstream movement of YOY more related to increases in temp than a specific temp range
SFPUC. 2009b.	Technical Report	Alameda Creek, Calaveras Creek, La Costa Creek, Indian Creek, and Arroyo Hondo	2007	• Temperature loggers at 24 locations from April–December 2007 • Snorkel surveys, August 2007 (Alameda, Calaveras, Arroyo Hondo) • Electrofishing surveys in October • Spawner surveys in February–April	• Temperature reaches 30°C at some sites, but average temperatures are < 20°C
EBMUD (East Bay Municipal Utility District)	Technical Report (HCP)	Upper San Leandro Creek and Pinole Creek watersheds	2015-2019	• Temperature loggers in 17 reaches year-round 2015-2019 • Habitat assessments in spring 2019 • Electrofishing surveys in May creeks from 2015-2019	• Temperature described but rarely exceed 20°C, and never exceed 23°C so not thought to be limiting
CDFW (California	Technical Report	Pescadero Creek Lagoon	2018	• Fish sampling with seine and PIT tagging, bimonthly July-October	• Suggest increased growth rate due to increased

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
Department of Fish and Wildlife)				• Temperature recorded weekly during water quality testing • Temperature logged hourly at 2 lagoon sites, 21 May 2018-13 January 2019	temperatures (19 – 26°C) during September-October
SCVURPPP 2019	Technical Report	Stevens Creek Guadalupe Creek Alamitos Creek Coyote Creek Upper Penitencia	2014 – 2019	• Temperature loggers at a minimum of least 8 sites each year	• Temperatures exceeded both acute lethal (24°C) and MWAT (17°C) thresholds
SCVW (Jennifer Watson)	Personal communication & data	Guadalupe Creek Coyote Creek Stevens Creek	1990s – present	• Temperature loggers deployed over summer (Guadalupe, Stevens creeks) • Juvenile surveys • PIT telemetry data • Vaki Riverwatcher data • Outmigrant trapping	• Fish observed a temperatures higher than 18°C threshold • Surveys limited in some years due to high temp >18°C
East Bay Regional Parks District (Joe Sullivan)	Personal communication	Alameda Creek	n/a	• Adult rescue operations • Resident rainbow trout streams sampled in late summer	• Temperatures rarely above 18°C
East Bay MUD (Bert Mulchaey)	Personal communication	Pinole Creek San Leandro Creek Upper San Leandro Creek San Pablo Creek	2007 – present	• Efishing surveys • Redd surveys • Temperature monitoring at three sites on Pinole Ck, in pool below Chabot dam in San Leandro Ck, and in upper San Leandro Ck	• Pinole ck - temp approach 21 – 22°C. YOY - Growth rates in higher water temps based on YOY size. • San Leandro Ck –temp can get as high as 23°C, but difficult to survey for steelhead • Upper San Leandro Ck - Cold spring fed creeks – but

Citation	Information type	Location	Years of data collection	Data Summary	Noted temperature effects
					may approach 20°C in summer
Sonoma County WA (Gregg Horton)	Personal communication	Russian River including tribs and estuary	2000 - present	• Snorkel surveys (spatially balanced) • Downstream migrant trapping • Temperature loggers • Invertebrate data (Dry Creek, RR estuary) • Growth data (Dry Creek, RR estuary)	• Above 18°C temperatures observed in locations with steelhead present
Marin Municipal Water District (Eric Ettlinger)	Personal communication	Lagunitas Creek San Geronimo Creek	n/a	• *O. mykiss* surveys • Growth data from late summer • Temperature monitoring	• Temperatures do not exceed 18°C in their locations
Stillwater Sciences and Dietrich 2002	Technical report	Napa River and Ritchie Creek	2001 – 2002	• Temperature loggers • Growth data	• Temperatures were above 20°C in some monitoring locations • Negative growth observed suggesting food not available to meet metabolic demands
Stillwater 2007	Technical report	Napa River	2005 – 2006	• *O. mykiss* growth from mark-recapture surveys • Invertebrate data • Temperature monitoring	• Temperatures generally within range for optimal growth, but temps > 20°C observed with no effects on growth