Oregon
Kate Brown, Governor

Department of Environmental Quality
Environmental Solutions Division
700 NE Multnomah Street, Suite 600
Portland, OR 97232
(503) 229-5696
FAX (503) 229-5675
TTY 711

March 18, 2020

Kim Kratz
Assistant Regional Administrator
Oregon and Washington Coastal Office
National Marine Fisheries Service
1201 Northeast Lloyd Boulevard, Suite 1100
Portland, OR 97232

RE: Submittal of Cold-Water Refuge Report for the Lower Willamette River to Address RPA

Dear Mr. Kratz,

The Oregon Department of Environmental Quality is pleased to submit the attached Lower Willamette River Cold Water Refuge Report.

This report is submitted to satisfy a reasonable and prudent alternative (RPA) from the 2015 National Marine Fisheries Service Biological Opinion on the U.S. EPA approval of Oregon's 2003 water temperature standards for the Lower Willamette migration corridor. The RPA addresses the jeopardy decision for threatened and endangered Upper Willamette and Lower Columbia River Chinook salmon (*Oncorhynchus tshawytscha*), and Upper Willamette and Lower Columbia River steelhead trout (*Oncorhynchus mykiss*) identified in the Biological Opinion. The purpose of this RPA is to interpret the cold-water refuge (CWR) narrative provision in order to allow for implementation of the criterion through DEQ's Clean Water Act authorities. The lower 50 miles of the Willamette River is designated a salmon and steelhead migration corridor for purposes of Oregon's water temperature standard. The CWR study identifies the source, location, and levels of use of CWR habitat available to adult and juvenile life stages of these populations, with emphasis on the support of migrating adult salmon and steelhead.

The Oregon DEQ agreed to develop the cold-water refuge study, with oversight from the U.S. EPA and NMFS, for the lower 50 miles of the Willamette River. The study evaluates whether there is sufficient cold-water refuge to support the listed salmon and steelhead populations, and therefore, whether the narrative criterion is being met. The study also identifies data gaps and uncertainties. Finally, the report recommends that the existing cold-water refuge habitat within the designated migration corridor be protected through regulatory or voluntary actions.

In order to complete this study, DEQ convened and consulted with an external scientific panel of experts from federal, state, local, and academic institutions with experience in cold-water refuge identification or salmon and steelhead biology and conservation specific to the Willamette River. This included biologists from ODFW, NMFS, USGS, U.S. EPA, U.S. FWS, the University of Idaho, Oregon State University, and the City of Portland. This study reflects the best data and scientific expertise available for documenting cold-water habitat availability and use by salmon and steelhead for this reach of the Willamette River.

If you have questions regarding this submittal or would like additional information, please contact me or have your staff contact Debra Sturdevant, Water Quality Standards Program Lead, at 503-299-5384.

Sincerely,

Jennifer Wigal

Jennifer Wigal
Water Quality Program Deputy Administrator

Cc: Anne Mullan, NOAA-NMFS
Mark Liverman, NOAA-NMFS
John Palmer, U.S. EPA
Hanh Shaw, U.S. EPA
Rochelle Labiosa, U.S. EPA
Connie Dou, ODEQ

Enclosure:
Lower Willamette River Cold Water Refuge Study

Lower Willamette River Cold-Water Refuge Narrative Criterion Interpretation Study

Submitted to: NOAA — National Marine Fisheries Service

By: Oregon Department of Environmental Quality – Division of Water Quality Standards and Assessment

March 2020

Water Quality Standards and Assessment
700 NE Multnomah St.
Suite 600
Portland, OR 97232
Phone: 503-229-5696
800-452-4011
Fax: 503-229-5850
Contact: Debra Sturdevant or James McConaghie
www.oregon.gov/DEQ

DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon’s air, land and water.

DEQ
State of Oregon
Department of Environmental Quality

This report prepared by:
Department of Environmental Quality
700 NE Multnomah Street, Suite 600
Portland, OR 97232
1-800-452-4011
www.oregon.gov/deq

Contacts:
James McConaghie, PhD
Mcconaghie.james@deq.state.or.us
503-229-5619

Debra Sturdevant, Program Lead
Sturdevant.debra@deq.state.or.us
503-229-6691

DEQ can provide documents in an alternate format or in a language other than English upon request. Call DEQ at 800-452-4011 or email deqinfo@deq.state.or.us.

About This Document

This document contains results and conclusions from analysis of data to apply Oregon’s cold water refugia narrative criterion in the migration corridor reach of the Willamette River. This is to satisfy the Reasonable and Prudent Alternative (RPA) in the National Marine Fisheries Services Endangered Species Act Biological Opinion on the Environmental Protection Agency's Proposed Approval of Certain Oregon Water Quality Standards Including Temperature and Intergravel Dissolved Oxygen (2015).

Acknowledgements

DEQ appreciates the significant contributions from the following individuals and institutions in the preparation of this document:

Melissa Brown and Julia Bond, City of Portland Bureau of Environmental Services and Krista Jones, USGS Oregon Water Science Center – for providing valuable water temperature datasets that were critical for identifying cold-water sources in the lower Willamette River.

Stanley Gregory, Oregon State University and Thomas Friesen, Oregon Department of Wildlife – for access to unpublished datasets on fish presence, abundance, and behavior in the lower Willamette River.

The Oregon Department of Fish and Wildlife and Pacific General Electric for providing raw data from their databases of daily fish passage counts.

Peter Leinenbach, U.S. EPA for NorWeST modeling of tributary water temperatures in the Willamette Basin.

And Matthew Keefer, University of Idaho, for access to unpublished datasets and draft reports, and his multiple thoughtful reviews of this work, which greatly improved the scientific robustness of the report.

Table of contents

List of figures

List of Tables

Executive summary

Purpose of this study

The Lower Willamette River cold-water refuge study addresses a jeopardy decision of the 2015 National Marine Fisheries Service (NMFS) Endangered Species Act Biological Opinion on the Environmental Protection Agency's Proposed Approval of Certain Oregon Water Quality Standards Including Temperature and Intergravel Dissolved Oxygen. In the 2015 Biological Opinion, NMFS found jeopardy on the U.S. EPA's approval of Oregon's 2003 water temperature criterion for migration corridors. NMFS questioned the protectiveness of the 20°C criterion relative to the Salmon and Trout Rearing and Migration criterion of 18°C, because DEQ had not demonstrated how to interpret the CWR narrative provision. The CWR narrative provision supplements the numeric criterion of 20°C to protect migrating populations of salmon and steelhead, including threatened and endangered Upper Willamette and Lower Columbia River Chinook salmon (*Oncorhynchus tshawytscha*), and Upper Willamette and Lower Columbia River steelhead trout (*Oncorhynchus mykiss*) that pass through the designated migration corridor to reach their spawning streams.

This study satisfies the reasonable and prudent alternative identified in the Biological Opinion as a means to interpret the cold-water refuge (CWR) narrative provision in Oregon's temperature standard in order to allow for implementation of the criterion through DEQ's Clean Water Act authorities. The Oregon DEQ agreed to develop a cold-water refuge study for the lower 50 miles of the Willamette River in order to interpret the narrative criterion and evaluate whether there is sufficient cold-water refuge (CWR) and identify what regulatory or voluntary actions could be taken, should DEQ find that the narrative is not being met.

Oregon's temperature criteria for salmon and steelhead migration corridors

The designated beneficial use in Oregon's water quality standards for the lower 50-mile reach of the Willamette River is "salmon and steelhead migration corridor." Oregon designated the migration corridor use for large lower mainstem river reaches where the primary and most sensitive aquatic life use is for adult salmon and steelhead migration during the summer, and where lesser or no use for salmonid rearing occurs in the months of July and August. In addition, it is unlikely that the natural thermal conditions of these large lower mainstem reaches would ever have maintained water temperatures below 18°C throughout the summer.

The temperature criteria that apply to migration corridors are a 7-day average of maximum temperature at 20°C (68.0 degrees Fahrenheit) and the narrative criterion for CWR. The narrative criterion states that these water bodies must have sufficiently distributed CWR that allow salmon and steelhead migration without significant adverse effects from a rolling weekly average of daily maximum water temperatures up to 20°C.

The narrative criterion calls for CWR that are sufficiently distributed so that salmon and steelhead migration can occur without significant adverse effects from warmer water temperatures in the main stem Willamette River. The narrative is supplemental to the 20°C biologically based numeric criterion (BBNC) and was structured to work in conjunction with either the BBNC or the natural conditions criterion (NCC) that was effective at that time the standard was adopted. By “warmer” temperatures, the narrative refers to temperatures above 18°C– the BBNC that applies to protect salmon and steelhead rearing and migration in main stems and tributaries upstream of the migration corridors.

Available Information and Professional Judgement

A number of stakeholder groups and State and Federal agencies have conducted studies and surveys to identify CWR in the Willamette Basin. However, at this time, determining whether CWR are sufficiently distributed to allow salmon and steelhead migration without impairment must rely primarily on professional judgment. There are no studies, objective measures, or methods currently available from which to determine the volume and distribution of CWR needed to support a given population size of salmon or steelhead. Therefore, DEQ’s conclusions about refuge sufficiency are based on a combination of data analysis using the best available data and information, and the input of regional experts with specific knowledge of the study area.

DEQ collaborated with an external scientific expert panel in conducting this study. An overview of our external scientific expert panel is in Section 1.3. Where necessary, DEQ highlights the uncertainty around whether existing information can be used to determine that the CWR narrative is being met, or what additional information is needed to make a determination.

DEQ evaluated CWR availability and sufficiency under two sets of conditions:

1. at water temperatures up to and including the 20°C migration corridor numeric criterion.
2. This addresses the core of the RPA to interpret the CWR narrative to protect migration in conditions up to the 20°C criterion.
3. at times when water temperatures exceed the 20°C migration corridor numeric criterion.
4. This addresses the ability of CWR to offset risks from conditions when the waterbody is warmer than the numeric criterion. In the lower Willamette River, current and expected natural condition temperatures exceed 20°C for a portion of most summers.

Summary of Findings

1. A detailed analysis of temperature data for identifying CWR in the migration corridor, a map of CWR locations, and a list of existing CWR features is provided in Chapter 3.
2. The Lower Willamette CWR study identified a total of 48 CWR locations within the migration corridor.
3. The study identified 20 of these refuges as large CWR suitable for use by migrating adult salmon and steelhead.
4. The study identified an additional 27 small-scale cold-water inflows suitable for rearing and migrating juvenile salmon and steelhead but likely too small to accommodate adults.
5. The current distribution of CWR is accessible to individual adult Chinook and steelhead moving at the median of observed migratory swim speeds observed in this river.
6. A detailed analysis of fish passage data at Willamette Falls and North Fork dam, fish survey data, and a review of existing studies of adult salmon and steelhead migration behavior, thermal exposure, and habitat use is in Chapter 4

7. Adult UWR and LCR winter steelhead populations currently avoid exposure to temperatures expected to trigger CWR use during migration through their migration timing. DEQ considers the current distribution of CWR sufficient for these populations due to apparent lack of need for use.
8. Over the last 10 years, a range of 99% - 57%, with an average of 91% of the spring chinook population passes through the migration corridor reach before water temperatures exceed 20°C.
9. In any given year within the last 10 years, a minority of the listed adult spring Chinook populations with a range of 10-48% per year, with an average of 14%, pass through the migration corridor reach before water temperatures exceed 18°C; the lowest temperature expected to trigger CWR use.
10. During years that warm earlier than average, the observed behavioral response of UWR spring Chinook salmon is to begin migration earlier. UWR spring Chinook are also observed to increase migration rate and reduce residence time when they encounter warming water temperatures and/or lower river flows during their migration period.
11. **During water temperatures up to and including the 20°C criterion,** available evidence suggests the current availability and distribution of CWR is sufficient to meet the needs of UWR spring Chinook due to lack of observed use during migration.
12. The currently available data suggests UWR Chinook do not delay their migration to hold in the available CWR habitat when river temperatures are at 18-20°C. This addresses the primary objective of the RPA related to the CWR narrative facilitating migration in temperatures up to the 20°C migration corridor criterion.
13. **During water temperatures when the 20°C criterion is exceeded,** DEQ is unable to conclude at this time whether the current availability and distribution of CWR is sufficient to meet the needs of migrating adult UWR spring Chinook and LCR spring/fall Chinook populations.
14. **Under conditions when the 20°C criterion is both attained or exceeded,** DEQ is unable to conclude at this time whether the current availability and distribution of CWR is sufficient to meet the needs of migrating adult LCR fall Chinook and UWR spring Chinook that spawn in the Clackamas Basin. There is a lack of population-specific data for timing and abundance of these populations in the migration corridor and entry to the Clackamas River.
15. There are significant knowledge gaps about fish behavior and CWR habitat use due to restrictions on fish handling or tagging when water temperatures exceed 18°C.
16. DEQ is unable to conclude at this time whether the current availability and distribution of CWR is sufficient to meet the needs of the out-migrating juvenile UWR or LCR spring Chinook or juvenile and kelt UWR or LCR winter steelhead populations.
17. There are significant knowledge gaps and uncertainty about juvenile and kelt abundance, migration timing, and habitat use during elevated temperatures in the migration corridor.
18. Although juveniles have broader temperature tolerance than the adult life stages, juveniles are present in the migration corridor at times of year with additional risk of exposure to high temperatures relative to migrating adults of the same species.
19. The data and studies available on juvenile habitat use in temperatures up to 20°C show juveniles dispersed throughout the various habitats in the lower river and did not find a higher abundance of juveniles in cold-water sites.

Interpretation of the narrative CWR criterion for the listed populations of migrating adult salmon and steelhead.

	Population segment or ESU	Conditions attaining 20°C	Conditions exceeding 20°C
Below Willamette Falls (RM 0 –26.7)	UWR Chinook	Attained	Insufficient data
	UWR steelhead	Attained	N/A
	LCR Chinook	Insufficient data	Insufficient data
	LCR steelhead	Attained	N/A
Above Willamette Falls (RM 26.7–50.8)	UWR Chinook	Attained	Insufficient data
	UWR steelhead	Attained	Insufficient data

Summary of Conclusions

1. DEQ did not find evidence that additional CWR in the migration corridor is needed at this time. However, there are not enough studies that measured CWR habitat use at times when the migration corridor is warmer than the criterion.
2. The largest CWR by volume is the area of the Clackamas River – Meldrum Bar near Willamette Falls, and this site is one of the few CWR with evidence of regular use by migrating salmon and steelhead given the current limitations in data. Maintaining access and the quality of this CWR should be a priority.
3. The existing thermal heterogeneity in the lower Willamette mainstem identified in this report should be maintained and protected in order to support potential use by migrating adult and juvenile salmon and steelhead.
4. Implement existing temperature TMDLs to address temperature reductions in CWR tributaries on the 303(d) list to maintain and enhance existing CWR from these tributaries.
5. NPDES permits for discharges must evaluate and prohibit thermal impacts to CWR under the authority of OAR 340-041-0053 (d). Evaluation of impacts to the CWR identified in this report makes it possible to apply thermal plume limitations where necessary in NPDES discharge permits.

1. Introduction

1.1 Objectives of the cold-water refuge study

The purpose of the CWR study is to adequately interpret Oregon's "cold water refugia" narrative to determine whether sufficient refuge is available, and allow for implementation of the criterion through DEQ's Clean Water Act authorities.

1. Gather and synthesize readily available data, information, and professional opinion.
2. Characterize current distribution and use of CWR.
3. Assess whether the current spatial and temporal extent of CWR present is sufficient to meet the CWR narrative criterion.
4. If DEQ concludes that the CWR criterion is not being met, characterize, to the maximum extent possible, the extent of additional CWR needed to attain the criterion.
5. Identify and prioritize actions to protect, enhance, or restore CWR necessary to attain the narrative criterion.
6. Identify scientific uncertainties and any additional research needed to fully implement the cold-water narrative.

Because DEQ is not allocated resources to conduct primary research or monitoring within the timeframe required for this study, DEQ compiled and synthesized readily available data and information collected by other state and federal agencies, academic researchers, and organizations to address the objectives of the RPA. DEQ hopes this study will contribute to better understanding of the thermal refuge requirements of migrating salmon and steelhead in the lower Willamette River to protect existing CWR and determine whether there is a need for additional restoration or enhancement of CWR.

1.2 Project scope

1.2.1 Authority

The authority for DEQ to produce this study is derived from state statute designating DEQ to implement the Clean Water Act and associated federal regulation (ORS 468B). The study is in response to the Reasonable and Prudent Alternatives (RPA's) developed by the National Marine Fisheries Service in their biological opinion[1] on the approval of Oregon's water temperature standards by the U.S. EPA. DEQ is undertaking this study under the supervision of the National Marine Fisheries Service and the U.S. EPA.

1.2.2 Geographic scope

The Lower Willamette River CWR Study addresses the lower 50 river-miles of the main stem of the Willamette River. One of the beneficial uses designated for this reach of the river is as a salmon and

---

[1] NOAA-National Marine Fisheries Service, Endangered Species Act Biological Opinion on the Environmental Protection Agency's Proposed Approval of Certain Oregon Water Quality Standards Including Temperature and Intergravel Dissolved Oxygen. November 3, 2015.

steelhead migration corridor for the protection of aquatic life. The project area for this study extends from the mouth of the Willamette River at the confluence with the Columbia River (river mile 0) to the confluence of the Willamette River and Chehalem Creek in the area of the Newberg pool (river mile 50.8) downstream to the confluence. The geographic scope includes the mouth and lower reaches of tributaries to the Willamette River that function as CWR to the main stem.

1.2.3 Biological scope

The Lower Willamette River CWR Study focuses on refuge use and behavior of migrating individuals from naturally propagating populations of listed evolutionarily significant units (ESUs) identified in the RPA of the National Marine Fisheries Service Biological Opinion on Oregon's Water Temperature Standards (NMFS 2015). These are Upper Willamette River (UWR) spring Chinook salmon (*Oncorhynchus tshawytscha)*, UWR winter steelhead trout (*Oncorhynchus mykiss)* (anadromous Coastal Rainbow Trout), Lower Columbia River (LCR) Chinook salmon and LCR winter steelhead trout that migrate through the all or a portion of the lower 50 miles of the Willamette River. Non-native or non-listed populations are outside the scope of the RPA and will not be directly evaluated in this study.

1.3 External Coordination

DEQ leveraged existing resources, information, and expertise in the Willamette Basin necessary to complete all aspects of the RPA. DEQ compiled and synthesized data and information collected by other state and federal agencies, researchers, and organizations to address the RPA objectives. In addition, DEQ formed an expert peer review panel comprised of experts on Willamette River salmon and steelhead migration behavior and CWR function.

DEQ's ability to fully identify and evaluate the sufficiency of CWR is limited by the nature of available data and information. However, we are encouraged by the broad interest in cold-water refuge and the work being done by multiple parties on this topic. For this study, DEQ employed the professional expertise of the many individuals and organizations that already have invested resources in identifying cold-water refuges.

1.3.1 Agencies and institutions consulted:

- City of Portland, Bureau of Environmental Services (BES)
- NOAA, National Marine Fisheries Service (NMFS)
- Oregon Dept. of Fish and Wildlife (ODFW)
- Oregon State University
- University of Idaho
- University of Oregon
- U.S. Environmental Protection Agency, Region 10
- U.S. Environmental Research Laboratory - Corvallis
- U.S. Geological Survey, Oregon Water Science Center

Additionally, DEQ's lower Willamette Basin Coordinator contacted DMAs within the study area to request any available temperature or fish survey data that could be used to identify CWR.
DEQ maintained regular contact with NMFS and the U.S. EPA by participating in regular meetings to monitor and review progress of both the Lower Willamette and the Columbia River cold-water refuge studies. The NOAA staff contact for this RPA was Dr. Anne Mullan, PhD. The U.S. EPA project lead was John Palmer.

The USGS was a primary source of data and maintained river gages at several locations within the lower Willamette migration corridor. USGS also collected shorter-term datasets specifically for cold-water refuge. The U.S. EPA and other partners in the NorWeST stream temperature project provided modeled stream temperatures for tributaries throughout the Willamette basin. NorWeST is a highly accurate spatial stream network (SSN) model of water temperature developed by the U.S. Forest Service[2]. This work provides the primary data sources that DEQ used to identify cold-water refuges, in consultation with these agencies, for developing this study. The USGS, Oregon State University, University of Oregon, Portland BES, and ODFW also continue to working cooperatively to collect, assemble and analyze information on cold-water refuges in the Willamette Basin. DEQ consulted with experts from these agencies to inform and review this CWR study.

1.3.2 External scientific expert panel input and review

In order to assess the availability, fish use, benefits and risks, and sufficiency of cold-water refuge in the Lower Willamette, Oregon DEQ relied on input from an external scientific panel of experts on cold-water refuges and Chinook salmon and steelhead biology and ecology in the Willamette River.

Table Expert review panel

Name	Affiliation
Julia Bond	City of Portland, Bureau of Environmental Services
Melissa Brown	City of Portland, Bureau of Environmental Services
Joseph Ebersol	U.S. Environmental Protection Agency
Thomas Friesen	Oregon Department of Fish and Wildlife
Stanley Gregory	Oregon State University, Department of Fisheries and Wildlife
Krista Jones	U.S. Geological Survey
Matthew Keefer	Department of Fish and Wildlife Sciences, College of Natural Resources, University of Idaho
Anne Mullan	NOAA- National Marine Fisheries Service
Brook Silver	U.S. Fish and Wildlife Service
Marcía Snyder	U.S. Environmental Protection Agency

---

[2] http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

This panel of experts reviewed our data sources and analysis, provided guidance, additional information, and expert opinion on the quality, uncertainty, and action-ability of this report's conclusions. This includes DEQ's interpretation of the available data to determine whether cold-water refuge is used, beneficial, and sufficiently distributed and abundant to meet the needs of listed populations of adult Chinook salmon and steelhead in the migration corridor.

DEQ consulted with the expert panel to review three sequential drafts of the Lower Willamette Cold Water Refuge study in January 2019, August 2019, and January 2020. In addition, the panel reviewed the conclusions for each chapter in November 2019. After each review, DEQ responded to the panel's comments and incorporated their input into this document.

Two panel meetings were convened in person and by phone, in January and February 2019, for deliberation of DEQ's analysis and conclusions. DEQ also communicated individually with panel members as needed on questions related to their specific research or expertise.

The analysis and conclusions expressed in this study are DEQ's own. DEQ relied on the expertise of its own staff for matters of interpretation of Oregon's water quality standards and regulations.

1.3.3 U.S. Environmental Protection Agency coordination

Region 10 of the U.S. EPA is conducting a cold-water refuge study for the Columbia River to address additional RPAs in the 2015 NMFS Biological Opinion. Region 10 is providing oversight to DEQ on the development of the Lower Willamette refuge study. The U.S. EPA is ultimately responsible for implementation of the RPAs, including this study.

EPA Region 10 is coordinating with the following agencies in the Northwest Power and Conservation Council and Federal Caucus to update federal agencies on the Columbia River and the Lower Willamette CWR studies as appropriate:

- U.S. Environmental Protection Agency
- U.S. Army Corps of Engineers
- Bonneville Power Administration
- Bureau of Reclamation
- U.S. Geological Survey
- U.S. Forest Service
- Bureau of Indian Affairs
- U.S. Fish and Wildlife Service
- NOAA National Marine Fisheries Service

The EPA will work with the Federal Caucus to secure assistance and participation from federal agencies on identified tasks and workshops and to coordinate the findings of the cold-water refuge studies with other related federal projects.

2. Background

2.1 Objectives of this section:

1. Provide an overview of the project and relevant background information, including the history of Oregon's water temperature standard, Endangered Species Act (ESA) consultation, and the development and content of the NMFS Biological Opinion (BiOp) and Reasonable and Prudent Alternatives (RPAs).
2. Provide background information on temperature impacts to migrating salmon and steelhead and the potential role of cold-water refuge based on the scientific literature.

2.2 Regulatory history

2.2.1 History of Oregon's water temperature standards in the lower Willamette River

In 1996, the Oregon Environmental Quality Commission (EQC) adopted a major revision of the state's water temperature criteria following a 3-year review by the agency. The new standard primarily protected specific salmon and steelhead life stages and species, and other species where appropriate, where they are the most sensitive aquatic life in waterbodies. The 1996 standard limited temperature increases due to anthropogenic activity and when water temperatures exceeded trigger values expressed as a seven-day average daily maximum metric.

In July 1999, the U.S. Environmental Protection Agency (EPA), with one exception, approved the revised criteria with conditions following Endangered Species Act (ESA) consultation with the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS). EPA initially disapproved the temperature criteria of 68 degrees Fahrenheit (20°Celsius) for the Lower Willamette River at that time.

In December 2003, the EQC adopted further revisions to the temperature standard. In the revisions the 68°F (20°C) criterion for the lower Willamette and Columbia Rivers was retained. DEQ designated these reaches as migration corridors to reflect that the primary salmon and steelhead fish use is transitory during the warm summer months, and that these reaches are not likely, even absent human impact, to maintain water temperatures less than 20°C throughout the summer. DEQ added the thermal refuge narrative criterion for migration corridors to protect migrating salmon and steelhead life stages and species. The numeric and narrative criteria together make up the current water quality standard that is applied to the Lower Willamette migration corridor.

In March of 2004, EPA approved the revised migration corridor criteria for salmon, steelhead, bull trout (*Salvelinus confluentus*), and the beneficial use designations following ESA consultation with the USFWS and NMFS. Litigation of EPA's approval of Oregon's criteria for temperature and dissolved oxygen led to re-consultation on the listed populations of salmon, steelhead, bull trout, eulachon (*Thaleichthys pacificus)* and Oregon chub (Oregonichthys crameri). The 2015 NMFS Biological Opinion was the second ESA consultation and resulted in a jeopardy decision and reasonable and prudent alternative (RPA) for the migration corridor criteria. This cold-water refuge study addresses that RPA.

2.2.2 The cold-water refuge narrative criterion

The purpose of the CWR narrative criterion within the temperature standard is to supplement the numeric migration corridor criterion. The 20°C numeric criterion for migration corridors is set at a low-risk, rather than a no-risk, level of aquatic life protection. This results in ecologically relevant standards that reflect the natural thermal regime of Oregon's large rivers. In many cases, the natural thermal potential of Oregon's large rivers is for peak summer conditions warmer than 20°C. The intent of the cold-water refuge narrative was to ensure that 20°C was a protective numeric criterion for the migration corridors if attained. The intent was not that CWR would function as a primary remedy for protecting aquatic life from water temperatures that are warmer than what naturally occurred.

The cold-water refuge narrative applies to water bodies designated as migration corridors. Migration corridors are often river channels that are too large to be cooled by shading vegetation and groundwater inflow, although these factors can be important to maintaining fine-scale refuge in these systems. The narrative directs that sufficient cold-water refuge be available within the warmer waters of migration corridors. As the temperature of corridors approach 20°C, the role of CWR was expected to enable fish to migrate to upstream and downstream destinations beyond the water body without impairment. Fish may move into CWR if the temperature of the main corridor flow becomes too warm. A second part of the narrative requires protection and restoration of natural seasonal thermal patterns in the Columbia and Snake Rivers. This provision does not apply to the Lower Willamette.

Implementation of narrative criteria occurs as part of the development of TMDLs and in 401 certifications for hydroelectric dams. Implementation steps identified in TMDLs include surveys to identify existing CWRs and modeling to identify potential for restoring or creating new CWRs.

Existing refuges may be protected by:

1. maintaining or enhancing vegetation for shade
2. protecting the watersheds of cold tributaries
3. protecting channel features that create cold water flows from physical alteration
4. protecting sources of groundwater inflows
5. removing or prohibiting barriers to fish access in areas of cold water

Potential cold-water refuge could be restored by improving access or enhancing characteristics that form cold-water refuge where they have been altered by human activity. Implementation pertaining to non-point source activities occurs through coordination by DEQ's Basin Coordinators and Designated Management Agencies (DMAs). DEQ can implement controls for point source activities that degrade cold water sources through National Pollutant Discharge Elimination System (NPDES) permits. DEQ's regulations restrict point source thermal discharges in locations where they will degrade or destroy cold-water refuge.

2.2.2.1 Migration corridor rule language

The Cold Water Refuge narrative is in Division 41 of Oregon's Administrative Rules (OARs).

OAR 340-041-0028

(4)(d): The seven-day-average maximum temperature of a stream identified as having a migration corridor use on subbasin maps and tables OAR 340-041-0101 to 340-041-0340: Tables 101B, and 121B, and Figures 151A, 170A, 300A, and 340A, may not exceed 20.0 degrees Celsius (68.0 degrees

Fahrenheit). In addition, these water bodies must have cold water refugia that are sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body. Finally, the seasonal thermal pattern in Columbia and Snake Rivers must reflect the natural seasonal thermal pattern.

2.2.2.2 Rule definitions

OAR 340-041-0002
(10) "Cold Water Refugia" means those portions of a water body where, or times during the day when, the water temperature is at least 2 degrees Celsius colder than the daily maximum temperature of the adjacent well-mixed flow of the water body.
[…]
(37) "Migration corridor" means those waters that are predominantly used for salmon and steelhead migration during the summer and have little or no anadromous salmonid rearing in the months of July and August. These uses are designated on the following subbasin maps set out at OAR 340-041-0101 to 340-041-0340: Tables 101B and 121B, and Figures 151A, 170A and 340A.

2.2.3 Willamette main stem temperature 303(d) listing and TMDL

The Lower Willamette is designated as a salmon and steelhead migration corridor from river mile 0 (the mouth at the confluence with the Columbia River at Kelley Point) to river mile 50.8 (the confluence of Chehalem Creek near Newberg, OR). The lower Willamette was listed as Category 5, impaired, on Oregon's Impaired Waters, or 303(d), list in 1998 and 2004 for exceeding the numeric migration corridor temperature criterion. The migration corridor was moved from Category 5 to Category 4 upon completion of the 2010 303(d) list following completion of the Willamette Basin temperature TMDL.

The U.S. EPA approved the Willamette Basin TMDL in September 2006. The TMDL indicated that attainment of the CWR narrative criteria was a key element needed for TMDL implementation. The TMDL indicated that thermal refuges likely occur throughout the Willamette basin but they had not yet been identified.

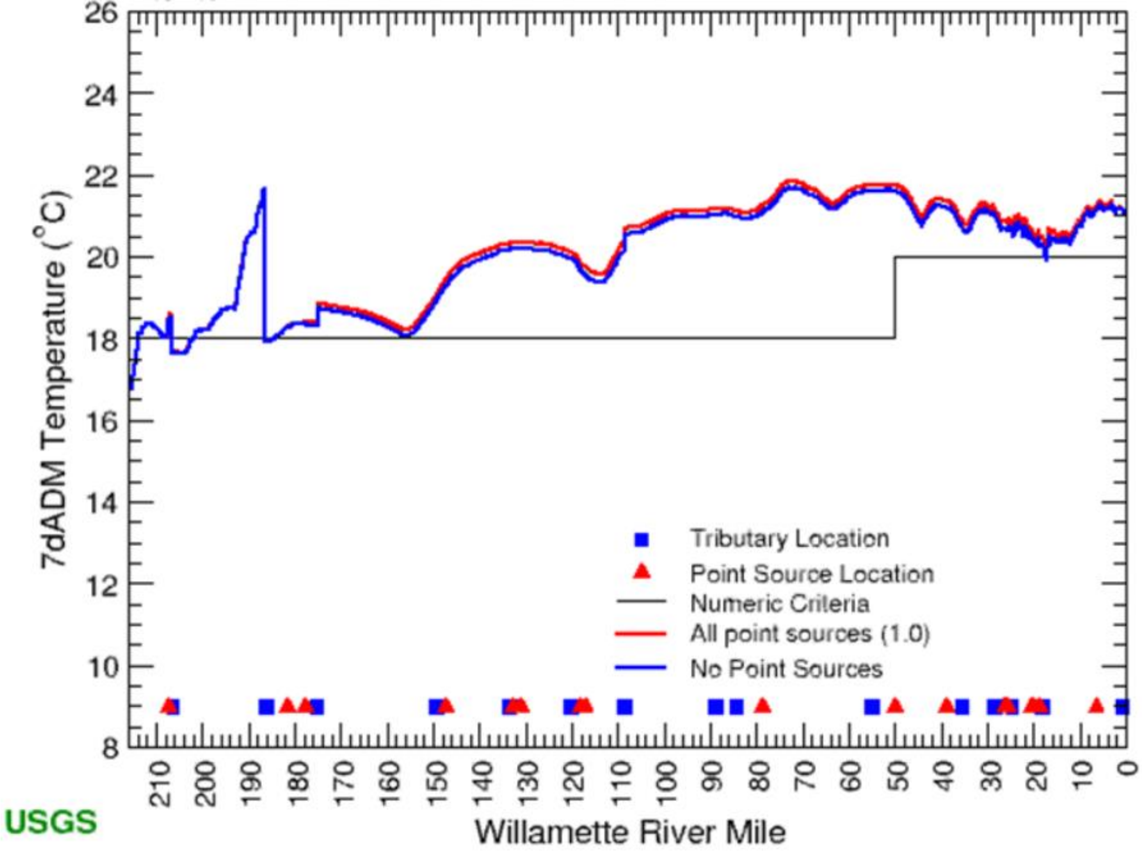
Specific implementation actions for identifying, protecting, and restoring cold-water refuge were not included in the TMDL. The TMDL specifically mentioned Tryon Creek and Stephens Creek (see map in Figure 3-10 and Figure 7-1) as sources of cooler water during the peak summer warm period. The TMDL also identified general measures that would maintain or restore thermal refuge– by entraining cool inflow from larger tributaries to enhance cold plumes and protection of riparian vegetation and floodplain connectivity along both tributaries and the main stem river.

2.2.4 National Marine Fisheries Service Endangered Species Act consultation and biological opinion of 2015

In November 2015, the National Marine Fisheries Service (NMFS) issued a biological opinion that found jeopardy for listed salmon and steelhead populations in the Lower Willamette with the EPA's action to approve Oregon's water temperature standards. NMFS based their jeopardy decision on the listed population's exposure to current river temperatures in excess of the 20°C migration corridor criterion in July and August. The biological opinion does not make clear whether attainment of the criterion would eliminate jeopardy for these populations in the Lower Willamette. Additionally, the NMFS conclusions (excerpted below) about run timing and exposure of UWR Chinook salmon and UWR steelhead under natural conditions were reported as possible but not confirmed. DEQ provides an in-depth analysis of these exposures using more current data in Chapter 4

NMFS acknowledged that modeling of natural thermal potential of the Lower Willamette migration corridor, even with thermal point sources removed and maximum vegetation restored, show that 7-day average daily maximum temperatures in August would still be above 20°C Therefore, the Reasonable and Prudent Alternatives (RPA) focused on the identification of cold-water refuge in the migration corridor in order to effectively interpret the refuge narrative.

Figure 2-1 Modeled natural thermal potential of Willamette River with riparian vegetation restored and either with point sources (red line) or without point sources (blue line) of thermal pollution. Natural thermal potential in the migration corridor is 20-22°C in August. Source: USGS at http://or.water.usgs.gov/proj/will_temp/wla_vs_ntp.html (accessed March 3, 2015) *referenced in* (NMFS 2015).



Excerpts from the Biological Opinion Section 2.7: Conclusion

After reviewing the current status of the listed species, the environmental baseline within the action area, the effects of the proposed action, and cumulative effects, it is our biological opinion that the proposed action is likely to jeopardize the continued existence of LCR Chinook salmon, UWR Chinook salmon, […] LCR steelhead, UWR steelhead […] and will destroy or adversely modify critical habitat that we have designated for these species.

- Adult UWR Chinook salmon are likely to be exposed during their upstream migration in the first half of July at non-peak abundance, and it is possible (but not confirmed) that larger numbers of fish would have migrated during July under more natural conditions.
- Overall, a small proportion of adult UWR Chinook salmon in all populations, and a substantial portion of juvenile UWR Chinook salmon in all populations, are likely to be exposed to the migration corridor criterion temperature.
- Adult UWR steelhead are unlikely to be exposed to this criterion, although it is possible (but not confirmed) that a portion of the run under more natural conditions that would continue to migrate in July has been truncated by the unnaturally warm temperatures now in the river. Adults of this species are unlikely to be exposed to this criterion because they migrate in the cooler months, although it is possible (although not confirmed) that some adults may have migrated into the summer under historical conditions.
- In the face of uncertain information about the proportion of juveniles that will be exposed, NMFS gives the benefit of the doubt to the listed species. On balance, out-migrating and rearing juvenile UWR steelhead are likely to be exposed to the migration corridor criterion and beneficial use designation throughout July and August, including during part of their peak migration period.
- The Clackamas population (of LCR Chinook) will receive additional exposure to the rearing and migration (20°C) criterion in the Willamette River, reducing growth and increasing disease risk of juveniles in a manner that likely will be severe enough to reduce abundance and productivity at the population scale.
- The Clackamas population (of LCR steelhead) will receive additional exposure to the rearing and migration (20°C) criterion in the Willamette River, reducing growth and increasing disease risk of juveniles in a manner that likely will be severe enough to reduce abundance and productivity at the population scale.

Excerpt from the biological opinion section 2.8: proposed RPA

In accordance with 50 CFR 402.14(g)(5), we have developed the following RPA in cooperation with, and using the expertise of, the action agency and applicant. In this case, the applicant is the State of Oregon, as represented by the Oregon Department of Environmental Quality (hereafter, “DEQ”). The DEQ has committed in writing to carry out certain elements of the RPA, as described below.[80] However, EPA is ultimately responsible for implementation of the RPA.

1. Cold-water Refugia

a. The EPA shall assist the DEQ in applying the cold-water refugia (hereafter, “CWR”) narrative criterion in the migration corridor reach of the Willamette River. To apply the criterion, DEQ, with technical assistance and oversight from EPA, will develop a CWR plan for this river segment as described below.

The purpose of the CWR plan is to adequately interpret the narrative criterion to allow for implementation of the criterion through DEQ’s Clean Water Act authorities.

i. With technical assistance from EPA, DEQ will gather and synthesize readily available data, information and professional expertise, and use the “Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes” (Torgersen et al. 2012) as guidance, to characterize:

1. the current spatial and temporal distribution of CWR,

2. the current use of CWR by LCR Chinook salmon, UWR Chinook salmon, LCR steelhead, and UWR steelhead in the migration corridor reach of the Willamette River, and

3. potential locations for the restoration or enhancement of CWR.

ii. Using the above information and professional expertise, DEQ will:

1. assess whether the spatial and temporal extent of CWR present meets the CWR narrative criterion (i.e., whether CWR are "sufficiently distributed to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the waterbody");

2. if DEQ concludes that the CWR criterion is not being met, characterize, to the maximum extent possible, the extent of additional CWR needed to attain the criterion; and

3. identify and prioritize potential actions by DEQ and others to protect, restore or enhance CWR.

iii. DEQ and EPA will identify any scientific uncertainties and data gaps regarding the above elements and identify additional studies needed to address the uncertainties and data gaps.

2.2.5 Listed populations affected

The National Maine Fisheries Service defines the evolutionarily significant units (ESUs) of the listed populations that migrate through the lower Willamette River migration corridor. These are identified in the RPA and defined by NMFS as follows[3]:

Upper Willamette River Chinook salmon

Listed as threatened on June 28, 2005 and updated on April 14, 2014. The ESU includes naturally spawned spring-run Chinook salmon (*Oncorhynchus tshawytscha*) originating from the Clackamas River and from the Willamette River and tributaries upstream of Willamette Falls (RM 26.7). Also included are spring-run Chinook salmon from six artificial propagation programs:

- McKenzie River Hatchery Program (Oregon Department of Fish and Wildlife (ODFW) Stock #23)
- Marion Forks Hatchery/North Fork Santiam River Program (ODFW Stock #21)
- South Santiam Hatchery Program (ODFW Stock #24) in the South Fork Santiam River
- South Santiam Hatchery Program (ODFW Stock #24) in the Molalla River
- Willamette Hatchery Program (ODFW Stock #22)
- Clackamas Hatchery Program (ODFW Stock #19)

Upper Willamette River steelhead trout

Listed as threatened on Jan. 5, 2006 and status updated on April 14, 2014. A distinct population segment including naturally spawned winter-run steelhead (*O. mykiss*) originating below natural and manmade impassable barriers from the Willamette River and its tributaries upstream of Willamette Falls to and including the Calapooia River.

---

[3] National Marine Fisheries Service. Salmon and steelhead listings. Accessed: 12/10/2018 https://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/salmon_and_steelhead_listings/salmon_and_steelhead_listings.html

Lower Columbia River Chinook salmon

Listed as threatened on June 28, 2005 and status updated on April 14, 2014. The ESU includes a distinct population segment of naturally spawned Chinook salmon originating from the Willamette River and its tributaries below Willamette Falls. Not included in this population segment are spring-run Chinook salmon originating from the Clackamas River.

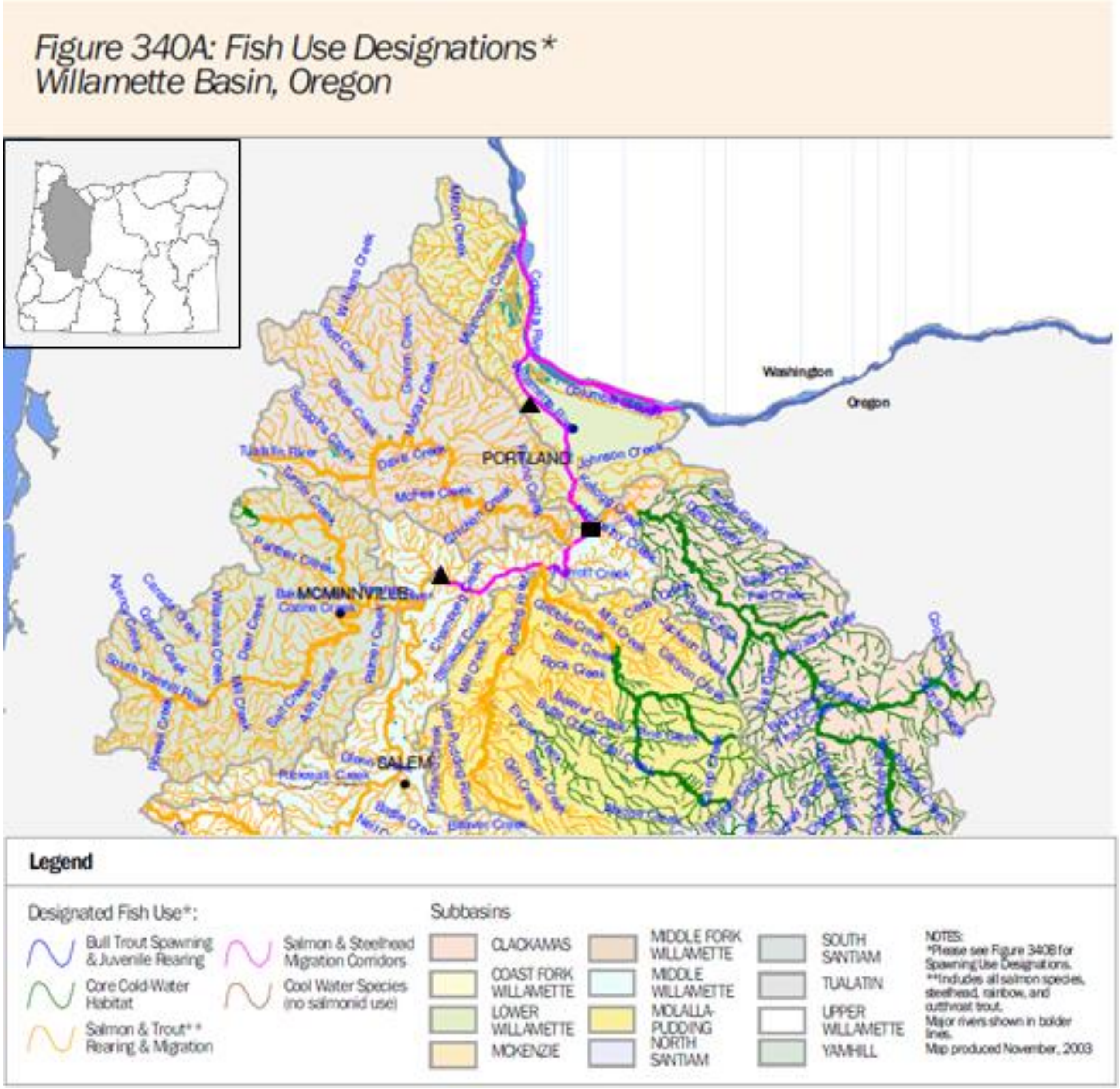
Lower Columbia River steelhead trout

Listed as threatened on Jan. 5, 2006 and status updated on April 14, 2014. This distinct population segment includes naturally spawned *O. mykiss* (steelhead) originating below natural and manmade impassable barriers in the lower Willamette River but excludes such fish originating from the upper Willamette River basin above Willamette Falls. This distinct population segment also includes steelhead from the artificial propagation program at the Clackamas Hatchery Late Winter-run Program (Oregon Department of Fish and Wildlife (ODFW) Stock #122).

2.2.6 Study area

The RPA and DEQ’s analysis are limited to the lower 50.8 miles of the Willamette River that is designated as a salmon and steelhead migration corridor. This corridor extends from the mouth of the Willamette at the confluence with the Columbia River just downriver from the City of Portland (RM 0), to approximately the confluence of Chehalem Creek and the Willamette River just upriver of the City of Newberg including the Newberg Pool (RM 50.8).

Figure 2-2 Location of the designated salmon and steelhead migration corridor (bold magenta line) within the northern Willamette Basin. Approximate locations shown for USGS stream temperature gages at Portland (RM 12.8, triangle, top) and Newberg (RM 50, triangle, bottom), and the Willamette Falls (RM 26.7, square, middle). Original map available at: https://www.oregon.gov/deq/Rulemaking%20Docs/figure340a.pdf Source: OR-DEQ.



2.3 Biology and ecology of CWR use

2.3.1 Thermal impacts on migrating salmon and steelhead

Migration is a time-sensitive activity as Chinook Salmon, Coho Salmon, and Sockeye Salmon do not eat during their migration period. They rely on metabolic reserves built up in the ocean in order to reach spawning grounds, build redds, and spawn. This leaves them vulnerable to conditions that prolong their migration time or increase energy consumption– risking exhaustion of energy reserves before they can spawn. Steelhead may feed during migration and can return to the ocean after spawning. High temperatures can interfere with migration by causing salmon and steelhead to cease progress toward spawning sites and seek cold-water refuge (Keefer et al. 2009, 2018) or cause mortality through metabolic exhaustion by depleting energy stores through increased metabolic rates (Naughton et al. 2005, Rand et al. 2006, Crossin et al. 2008). Migrating adults avoid critical stream temperatures first through adaptive seasonal timing of migration to avoid warm seasons (Waples et al. 2004), and second through delaying migration to seek and hold in CWR (Hodgson and Quinn 2002) .

The critical temperatures for migration delay varies by species and population. It also appears to have a strong genetic basis. Populations adapted to long migrations to interior spawning sites often have a higher critical temperature tolerance than coastal populations with short migrations. The critical temperature for delaying these long distance salmon runs can range from 19.0-24.0°C depending on the population and species (Farrell et al. 2008, Eliason et al. 2011). Coho in the Klamath River were observed to delay migration only after ambient temperatures exceeded 22.0°C (Strange 2010). Migration of Chinook, Coho, and steelhead delays to hold in CWR in the Lower Columbia, Lower Fraser, and Coastal Pacific Basins at temperatures of 18-21°C. With some variation, a particular critical temperature threshold appears to be crossed as temperatures exceed 20°C (Hyatt et al. 2003, Naughton et al. 2005, Goniea et al. 2006, Keefer et al. 2008a, Farrell et al. 2008). A critical temperature for migration delay has not been specifically determined for UWR or LCR Chinook salmon or steelhead trout migrating through the Lower Willamette River.

In addition to migration delay, high water temperature contributes to pre-spawn mortality and reduced spawning success. Prolonged exposure to temperatures greater than 20°C during migration were linked to greater pre-spawning mortality in salmon and steelhead populations (Cooke et al. 2004) through mechanisms of disease (Coutant 1999, Torgersen et al. 1999) and metabolic stress through either direct exposure or cumulative energy depletion (Naughton et al. 2005). Exposure to high temperatures during migration, holding, and spawning is also likely reducing the fitness and spawning success of salmon and steelhead in the Pacific Northwest (Keefer et al. 2010, NMFS 2015, Keefer and Caudill 2016, Bowerman et al. 2018). High temperatures that occur in spawning and holding tributaries of the greater Willamette Basin (outside of the migration corridor) are implicated in episodes of high pre-spawn mortality in adult Chinook salmon in the holding and spawning tributaries (Schreck et al. 1994, Keefer and Caudill 2010, Benda et al. 2015, NMFS 2015).

Table 2-1Constant temperature effects on migrating salmon and steelhead (McCullough 1999, EPA 2003, Richter and Kolmes 2005a).

Temperature Range	Exposure Timeframe	Effects
<18°C	Months	• Upper optimal range
18-20°C	Days to Weeks	• Chronic disease risk • Reproductive fitness reduction
19°C	Hours to Days	• Salmon and steelhead initiate refuge-seeking behaviors
20-21°C	Hours to Days	• Majority of steelhead populations seek refuge • Chinook begin to seek refuge
21-25°C	Hours to days	• Metabolic breakdown of respiration and circulation • High disease risk • High refuge-seeking behavior in steelhead and salmon • Migration delay
25°C	Hours	• Incipient lethal limit • Acute metabolic stress and mortality • Migration blockage
32°C	Instant	• Instantaneous lethal limit

2.3.2 CWR identification frameworks

Frameworks for the detection, quantification, and management of cold-water refuges have been developed (Torgersen et al. 2012, Ebersole et al. 2014). Identification of cold-water refuges is through temperature difference from the main stem temperature. Frameworks to identify CWR recognize that the ability of salmon and steelhead to access thermal refuges is dependent on the abundance and distribution of thermal refuge throughout river channels (Ebersole et al. 2003, Dugdale et al. 2013).

2.3.2.1 CWR definitions:

Operating cold-water refuge identification framework:

Thermal	- ≥2°C temperature reduction from main stem - High Quality: ≤18°C annual maximum
Spatial	Features within the floodplain at multi-scales: 1. tributary confluence plumes a. > 1 cfs for migrating adults b. < 1cfs for juveniles 2. riffle/pool channel units 3. microhabitat patches
Temporal	- Current conditions (10 years) - Available during June – September

Cold-water refuge will have at least a 2°C temperature reduction from the main stem.

High-quality cold-water refuge will have at least a 2°C temperature reduction from the main stem and a maximum temperature within the range of optimum temperatures for salmon and steelhead rearing and migration of 18°C or less.

2.3.2.2 Scale aspects of CWRs

There are multiple spatial and temporal scales over which cold-water refuges form and function (Torgersen et al. 2012). Maintaining thermal habitat heterogeneity across the spatial scales ensures that a variety of CWR suitable or different species and life stages will be available. Restoration or conservation of thermal habitat heterogeneity requires a landscape approach to identify and maintain the features that provide the habitat (Hester and Gooseff 2010). These features vary in scale from tributaries at the basin scale to off channels, gravel bars, and woody debris at the scale of individual channel units and microhabitats (Monk et al. 2013).

Basin scale: cold water tributaries

At the basin scale, protecting cool waters in headwaters and tributaries provides cold water habitat for spawning and rearing, while also providing refuge in the main stem from cold water plumes in the tributary confluence zone (Goniea et al. 2006). The volume of CWR provided by tributaries will vary with the relative discharge and local morphology of the confluence as the tributary water mixes with the main stem.

Reach Scale: Channel Units

Regionally, the interaction between hyporheic flows and stream water is more pronounced in alluvial river systems (Arrigoni et al. 2008) than in surface bedrock dominated systems (Hayashi and Rosenberry 2002). The Lower Willamette is a bedrock dominated system and so hyporheic and groundwater flows may be relatively limited. Hyporheic exchange is broadly dependent on the availability of gravels to induce local subsurface flow in the main channel. The availability of groundwater in the river channel is driven by surface geology and seasonal amounts of river discharge and precipitation (Dugdale et al. 2013, Ebersole et al. 2015).

At the channel unit scale, pool-riffle sequences (Torgersen et al. 1999, Baigún 2003, Ebersole et al. 2003a), canopy cover (Ebersole et al. 2003b, 2006), and channel sinuosity (Ebersole et al. 2003a) are the structural components associated with in-channel cold-water refuges. In reach scale pool-riffle sequences, stream water enters the hyporheic zone at the bottom of pools, and re-emerges downstream from riffle sediments (Figure 2-3) (Evans and Petts 1997, Poole and Berman 2001, Hannah et al. 2009, Gariglio et al. 2013). In meander-bend morphology, stream water or ground water enters the hyporheic zone at gravel bars or the bank of river bends. These flows re-emerge at cooler temperatures some times of the year in the alluvium of downstream meander bends in areas of preferred flow – such as abandoned channels, backwaters, spring brooks, alcoves, and lateral seeps (Figure 2-4) (Poole and Berman 2001, Fernald et al. 2006, Burkholder et al. 2008, Hester and Gooseff 2010). The occurrence of these channel unit features is more common in the mid-Willamette than in the migration corridor because of bedrock geology and channel morphology downstream of Newberg, OR (Mangano et al. 2018).

Figure 2-3 Hyporheic exchange (dotted lines) in lateral and vertical dimensions of channel morphology (Torgersen et al. 2012)

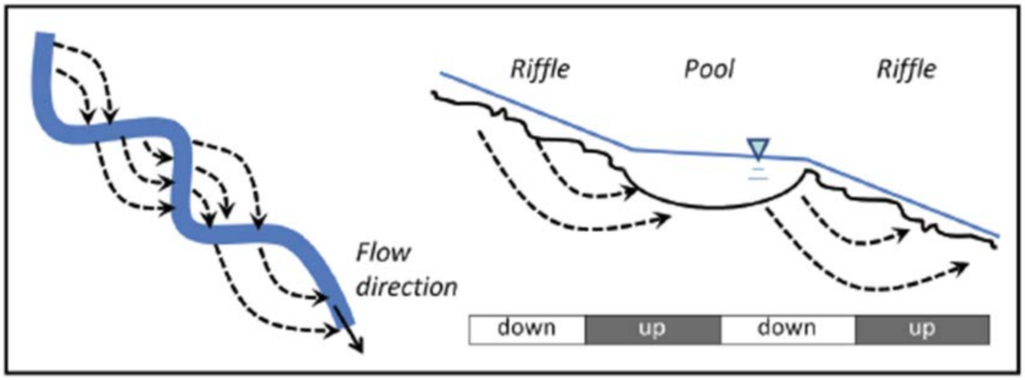


Figure 2-4 Examples of channel unit thermal habitat features in the mid-Willamette River. Main channel pools, side channels, bars, and alcoves near Eugene, OR. (Hulse et al. 2002, Lestelle et al. 2005)

At the microhabitat scale within reaches, woody debris (Malcolm et al. 2004, Loheide and Gorelick 2006, Sawyer et al. 2012, Sawyer and Cardenas 2012) and sediment bed forms (Fernald et al. 2006) can induce the fine-scale hyporheic exchange critical for developing fine-scaled thermal refuges. Induction of hyporheic exchange between stream water and groundwater occurs near in-stream geomorphic features including weirs, debris dams, and coarse woody debris. These features create localized hyporheic flow by forcing discharge through accumulated sediments (Hester et al. 2007, Sawyer et al. 2012). Cold-water refuge provided by microhabitat features are individually small in volume, but can be numerous along a river channel.

Channel-unit and microhabitat scale CWR are more common in reaches of the Willamette River upriver of Eugene, OR, where the channel is more dynamic. There is less occurrence of these features, and therefore less opportunity to create fine-scale CWR, in the lower Willamette migration corridor due to geologic and geographic constraints (Mangano et al. 2018) .

2.3.2.1 Temporal aspects of cold-water refuges

To be effective, cold-water refuge should be available during periods when the main stem temperature exceeds 18-20°C maximum for salmon and steelhead migration. In the Lower Willamette migration corridor, main stem temperatures can be expected to exceed 18-20° as a daily average during July – September under current conditions based on the most recent 10-years of water temperature data. To function as a refuge, patches of cold water should occur and be relatively persistent during this time period.

Persistence

Use of refuges is strongly dependent on ambient main stem temperatures (Brewitt and Danner 2014). Although thermal heterogeneity persists year-round, refuge use occurs during either migration or holding, concurrent with seasonal warm temperatures. Refuge use by salmon and steelhead generally persists until ambient temperatures return to a desirable range. Steelhead were shown to seek refuges as temperatures exceeded approximately 18°C (Ebersole et al. 2001, Baigún 2003), while Coho Salmon (Madej et al. 2006) , Chinook salmon (Goniea et al. 2006) and rainbow trout (Sutton et al. 2007),were shown to seek refuges as water temperatures approached 20-22°C. Salmon were able to persist despite average water temperatures above a 25.0°C threshold. In the Umpqua river, steelhead preferred cold pools 3°C lower than ambient as long as ambient temperatures exceeded 19.0°C (Baigun et al. 2000).

Diel and seasonal fluctuations in cool stratified pools are correlated to ambient air temperature (Tate et al. 2007). The occurrence of this refuge will vary with air temperatures. There is strong positive correlation between the number of lateral seeps and mean seasonal river discharge (Dugdale et al. 2013). In the Umatilla River, hyporheic exchange in pool riffle sequences exhibited diel cycles that were buffered to a shorter temperature range during the day, 2-6°C, and with maximum hyporheic temperatures lagged behind maximum surface water temperatures by 4-6 hours (Arrigoni et al. 2008).

Refuge Use

While the use of CWR by salmon and steelhead has been well documented in many major river systems in the Pacific Northwest, CWR use is not a universal phenomenon among salmon and trout populations. There are no comprehensive studies quantifying the density, size, or geographic distribution of cold-water refuges necessary to sustain salmon and trout populations.

The use of CWR has been documented in steelhead (Baigun et al. 2000, High et al. 2006), Chinook (Goniea et al. 2006, Keefer et al. 2018), Coho (Madej et al. 2006), and Rainbow trout (Sutton et al. 2007) in Oregon. Refuge use in the Columbia, John Day, and Snake River systems is especially prevalent when ambient temperatures exceed 20°-25°C during summer months. Chinook salmon in the John Day River were expected to exhibit clustering near cold water tributaries but instead clustered in fine-scale pool features in the main stem (Torgersen et al. 1999). Sockeye Salmon in the Fraser River, British Columbia, utilize lakes as cool holding areas during migration (Donaldson et al. 2009, Mathes et al. 2010).

However, a lack of CWR use has also been noted in some major migratory corridors in Oregon and British Columbia. Chinook salmon in the Willamette Basin (Keefer et al. 2015), Sockeye and Chinook salmon populations in the Frasier River, British Columbia (Donaldson et al. 2009, Hasler et al. 2012) and bull trout in the Lostine River of Oregon (Howell et al. 2010) have been observed not to use CWR in migration corridors. They continued migration even when exposed to potentially lethal temperatures up to 24°C. Researchers have not determined whether this lack of CWR use represents behavioral adaptation not to delay migration or a natural or man-made structural lack of cold-water refuge availability in these systems (Baigun et al. 2000).

Refuge Sufficiency Framework

To date, there are no comprehensive studies available that have determined the density, size, or geographic distribution of cold water refuges necessary to sustain populations. The existing frameworks for the detection, quantification, and management of CWR recognize that the ability of salmon and steelhead to access thermal refuges is dependent on the abundance and distribution of thermal refuges throughout river systems (Ebersole et al. 2003a, 2015, Torgersen et al. 2012, Dugdale et al. 2013). There is little data available on the required density and capacity of cold-water refuge at the scale of main stem rivers and for entire populations. There is especially no currently available data specific to the Willamette River or the migration corridor.

Density of refuges

Cold water patches are frequently concentrated in confluence zones between tributaries and main-stem rivers. These may result from the mixing of colder tributary water through surface flows from cool perennial streams, and as cold hyporheic discharge from below dry stream beds in intermittent and ephemeral streams (Ebersole et al. 2015). As the width-depth ratio of channels increases (creating wider, shallower channels), the distances of cold water patches from main channels also increased (Ebersole et al. 2003a).

Late run UWR Chinook salmon in the Willamette River have been observed migrating an average of 16-40 km/day in the period when river temperatures are expected to be > 20°C (Schreck et al. 1994, Keefer and Caudill 2010). This is consistent with Chinook salmon migration rates observed in the Columbia river (Keefer et al. 2004, Goniea et al. 2006). Columbia River steelhead are more likely than Columbia River Chinook salmon to reduce migration rates and delay for extended periods by holding in CWR when main stem temperatures are above 20°C (Keefer et al. 2009). UWR steelhead migration rates range from 10-60 km/day and tend to be fast near Willamette Falls and Newberg, then slow in successive upriver reaches (Jepson et al. 2015). These daily migration rates may establish upper limits for acceptable distances between CWR in order to be accessible and adequate for the needs of migrating adult salmon and steelhead.

Capacity of refuges

In general, the number of fish that cold-water refuge can support will be based on the number of refuges in a given area (refuge density), the volume of cold water in the patches (refuge volume), and the abundance and proportion of the fish population that requires CWR.

The EPA is currently developing an analysis to quantify the capacity of CWR in the Columbia River from Bonneville dam to the confluence with the Snake River. Their approach relies on quantification of the volume of cold water plumes and accessible portions of adjoining tributaries through hydrologic mixing modeling of temperature and empirical analysis of salmon and steelhead holding in the reach. Estimates of carrying capacity (density of supportable fish) in holding areas for salmon and steelhead are being derived from estimates of the total number of fish in refuge and the duration of refuge use within the reach. EPA is expected to publish the results of this analysis in 2019. DEQ may be able to adapt these methods to the lower Willamette for further analysis if sufficient data and resources are available.

3. Existing cold-water refuge for adult Chinook and steelhead in the lower Willamette River

3.1 Chapter outline

3.1.1 Objectives:

1. Characterize the current thermal regime of the lower Willamette River main stem and its major tributaries.
2. Identify currently existing cold-water refuges within the project area.
3. Characterize the spatial and temporal extent of existing cold-water refuges
4. Identify whether the source of existing CWR are:
    a. tributary rivers or streams, or
    b. main stem channel features, such as side channels, alcoves, gravel bars or pool/riffle complexes.

3.1.2 Definitions:

1. The **"Lower Willamette River"** means the lower 50 miles of the main stem of the Willamette River, from the confluence with the Columbia River upstream to the Newberg pool at the confluence of Chehalem Creek. This reach is designated in Oregon's water quality standards as "salmon and steelhead migration corridor" aquatic life use.

2. "**Cold-water refuge**" (CWR) means those portions of a water body where or times during the diel temperature cycle when the water temperature is at least 2 degrees Celsius colder than the temperature of the adjacent well-mixed flow of the main stem river.

3. "**High-Quality CWR"** – refuges that are cooler than 18°C will be qualified as "high-quality" CWR due to the additional benefits to fish of holding in waters less than 18°C.

4. "**Limited Use CWR"** - refuges that have limited availability due to a barrier or poor water quality conditions (i.e. low dissolved oxygen) will be qualified as "limited-use CWR."

5. **Temperature difference** – the difference in temperature from the main stem calculated as:

$$dTemp = T_m - T_x$$

Where: $dTemp$ = temperature difference

T_m = the main stem temperature

T_x = temperature of tributary or feature

A **temperature difference** greater than zero indicate tributaries or features are cooler than the main stem. A **temperature difference** less than zero indicates tributaries or features are warmer than the main stem.

3.1.3 Assumptions and limitations:

In the Columbia River CWR study, EPA assumes that tributaries with August mean flows of less than 10 cubic feet per second generate cold water plumes too small for upstream migrating adult salmon or steelhead to detect and therefore do not function as CWR. Flows on the Columbia River at The Dalles average approximately six times the flow of the Willamette at Portland. DEQ's assumption is that minimum flow rates for tributary refuges would need to be greater than 1 cfs to be detectable and to accommodate migrating adults. Refuges suitable for juveniles includes tributaries with flow less than 1 cfs and are listed separately in Chapter 5.

For Willamette tributaries, DEQ used modeled August mean temperature and discharge from the NorWeST spatial stream temperature model (Isaak et al. 2017) as a screening tool. Tributaries identified by NorWeST as having a modeled to main stem August mean temperature difference of >2°C and an estimated August mean flow rate >1 cfs were considered as candidates for cold-water refuge. DEQ sought additional temperature data sources according to this candidate list.

The USGS gaging station for the Willamette River at Portland was used as the reference temperature for the main stem unless a specific complimentary temperature measurement of the well-mixed main stem was available to compare to the temperature of a tributary or feature.

3.1.4 Data sources

Data Source	Data Type	Source	Accessed
NorWeST temperature model	Modeled August mean temperature for rivers and streams within the Willamette Basin	Peter Leinenbach, U.S.EPA. Memorandum: Evaluation of the potential cold water refugia (CWR) created by tributaries discharging into the Willamette River based on "NorWeST" temperature modeling.	October 12, 2017
USGS-NWIS	Continuous temperature data for main stem sites	https://waterdata.usgs.gov/nwis via the dataRetrieval R package.	Nov. 21, 2018
USGS Oregon Water Science Center	Continuous and synoptic data for offchannel sites and tributaries for summer 2016-2017	https://or.water.usgs.gov/grapher/ via the datRetrieval R package and USGS data release publications	Nov. 21, 2018
Johnson Creek Watershed Council	Continuous data for offchannel sites 2017-2018	Submitted to Oregon DEQ volunteer monitoring program	Nov. 14, 2018
City of Portland	Continuous data for offchannel sites	Portland Bureau of Environmental Services	July 30, 2018
City of Portland	FLIR thermal imagery, August 2011	Portland Bureau of Environmental Services	July 26, 2018
Oregon DEQ	Continuous temperature data	Oregon DEQ LASAR and AWQMS databases	Nov. 14, 2018
Oregon DEQ	FLIR thermal imagery	Oregon DEQ TMDL Program	Nov. 7, 2018

3.2 Temperature for the lower Willamette main stem and major tributaries

3.2.1 Temporal variation in Lower Willamette River main stem temperatures

Seasonal and diurnal temperature variability in the Willamette main stem

The 10-year average of mean daily temperatures in the Lower Willamette migration corridor are shown in Figure 3-1. Winter temperatures are similar at Newberg and Portland during November through May. Summer temperatures at Newberg are ~1°C cooler than in the lower end of the reach at Portland during July – October. On average, both daily mean and 7-day average of daily maximum (7-DADM) temperatures in the migration corridor are over 20°C for 69 days a year, from July 5 to Sept. 12 (Table 3-1).

Being a larger, main stem river, the lower Willamette River's large volume buffers against large diurnal (daily) swings in temperature from day to night. The average difference between daily maximum and daily minimum temperatures in the lower main stem is only 0.5°C (Rounds 2007, Mangano et al. 2018) and (USGS-NWIS). This limits the ability for the migration corridor to provide thermal relief at night.

Figure 3-1 Daily average temperatures in the Willamette main stem at Newberg and Portland 2007-2017. Source: USGS NWIS. Grey shading show standard error of the mean. The solid black line is the migration temperature criterion that applies to these sites. The dashed black line is the temperature criterion for salmon and trout rearing and migration that applies outside of the corridor.

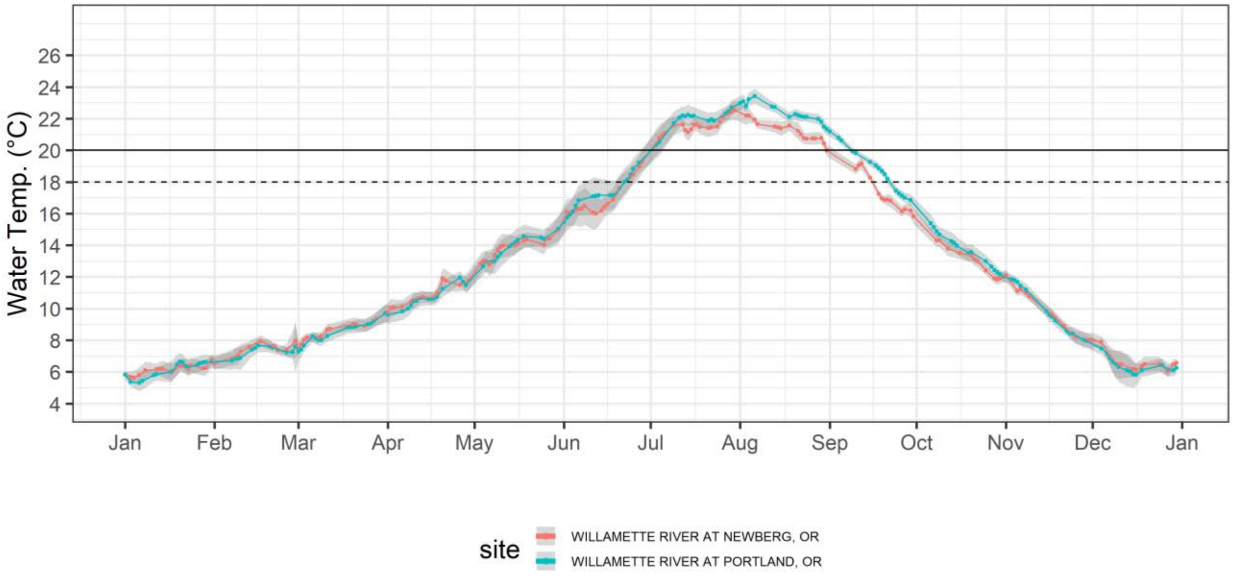


Table 3-1 Duration of migration corridor criterion exceedance in the Lower Willamette.

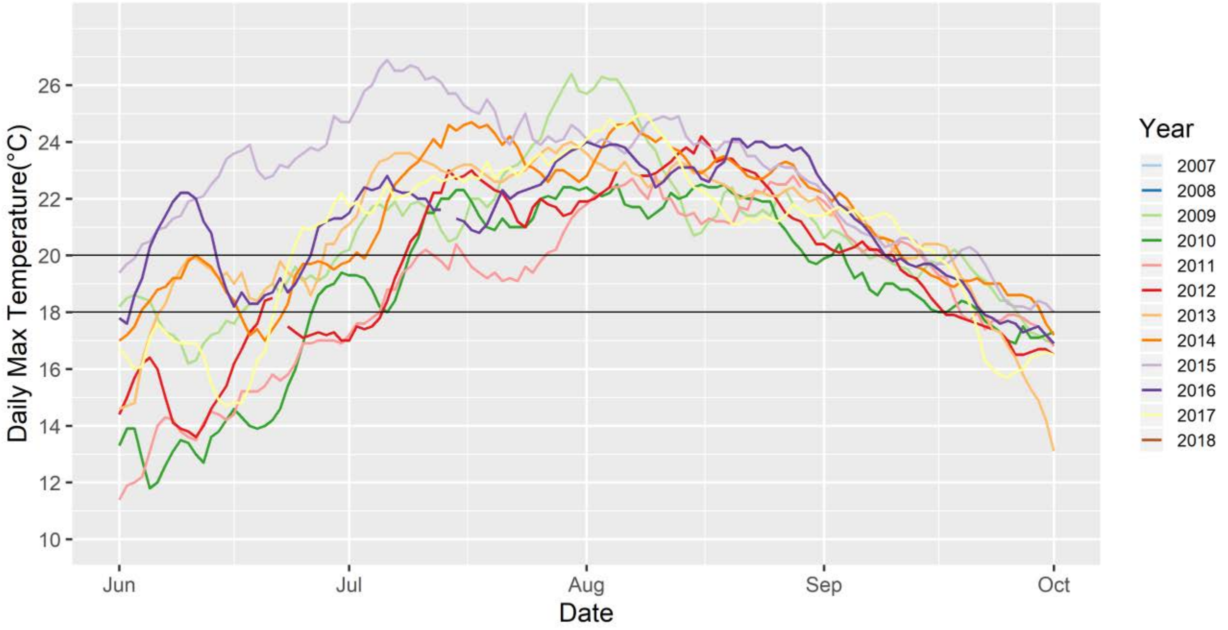
Willamette main stem (Portland) 2007-2017			
Temperature Metric	Days Exceeded 20°C	First Date Exceeded	Last Date Exceeded
Daily Average	69	July 2	September 8
Daily Maximum	74	June 29	September 10
7-DADM	69	July 5	September 11

Inter-Annual Temperature Variation in the Willamette main stem

Inter-annual variation in water temperature is a function of seasonal air temperatures, precipitation, and discharge. For the period 2007-2017, daily mean temperatures exceed 20°C starting in mid-July and persist until mid-September (Figure 3-2).

Variability is temperatures between years is higher in springtime than in the autumn. There is a large range in daily maximum temperatures for June and July among these years. The warmest spring in recent years occurred in 2015, when average temperatures exceeded 20°C for almost the entirety of June and 24°C the entirety of July. Early onset of warm water temperature conditions combined with low flows due to drought in 2015 resulted in fish kills of Chinook salmon in the Willamette Basin (ODFW 2015). Inter-annual variability in water temperatures is lower in all years as temperatures cool in early fall from September to October.

Figure 3-2 Interannual variability in main stem summer daily maximum temperatures June–October for years 2007-2017 for the Willamette River at Portland. Data source: USGS-NWIS



3.2.2 Spatial temperature variation in the Willamette main stem

The USGS measured temperature profiles of the Willamette main stem in summer 2015 and 2016. The main stem of the Lower Willamette in the migration corridor is characterized by confined channel geomorphology due to bedrock and anthropogenic bank stabilization, minimal off-channel features or channel complexity, and deep pool bathymetry (Mangano et al. 2018).

Vertical mixing of the main stem Willamette is pronounced downstream of Willamette Falls, with little variation in temperature profile with depth, even in sections of the channel up to 60 feet deep (Figure 3-3). Cross-sectional mixing along the channel profile was also limited, with some evidence of cooler water from the largest cool tributary plumes collecting along the channel bottom (Figure 3-4). Some stronger stratification occurs in the Newberg Pool (RM 26.7-50.8) but temperature differences are not usually greater than 1.1°C (Rounds 2007, Mangano et al. 2018).

In general, the main channel of the Lower Willamette River appears to be well mixed throughout its cross-section and depth profile.

Figure 3-3 Vertical temperature profile of the Willamette main stem upstream of Kellogg Creek, August 2016. Data source: (Mangano et al. 2016, 2017).

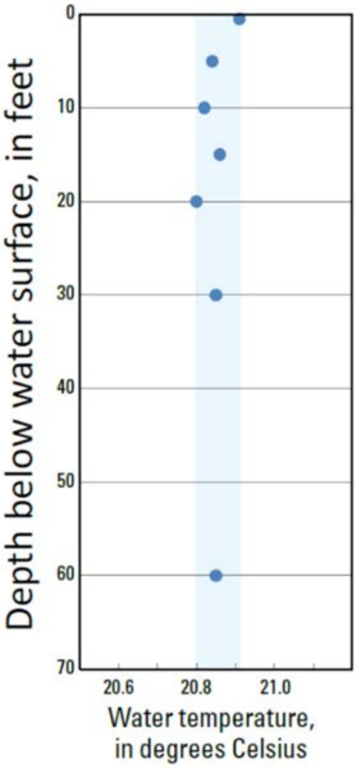
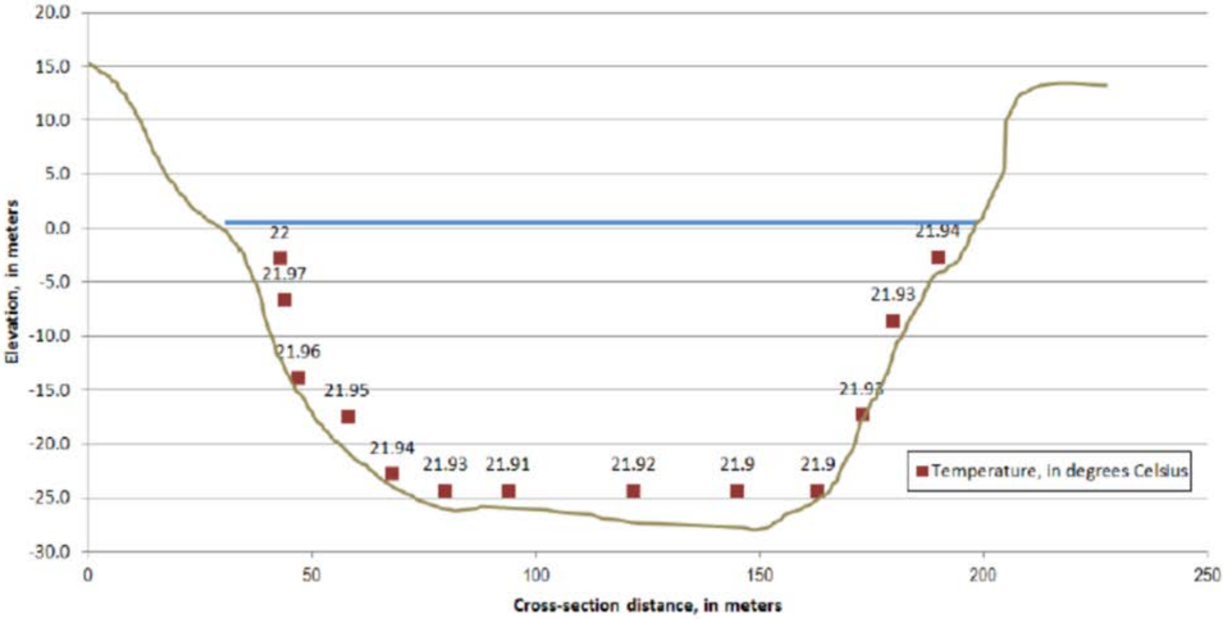


Figure 3-4 Willamette River main stem cross-channel bottom temperature profile near Oswego Creek outlet, August 2016. Data source: (Jones 2017, Mangano et al. 2018).



Historical temperature perspective

While water temperatures in the last decade have generally trended upward, the temperature regime of the lower Willamette main stem may not be far outside of historical ranges. The year 2015 had the hottest mean daily average water temperatures, the greatest number of days above 20°C, and highest annual maximum temperature in the current 10-year period. Historical water temperature records for Portland collected in years 1889 and 1941 show peak summer temperatures similar to 2015 (Figure 3-5). The years 2015, 1941, and 1889 were all years with a strong El Nino influence – that tends to produce unusually dry and warm weather in Oregon (Stephan Talke, Portland State University[4], personal communication).

Direct measurement of the truly natural temperature baseline for the lower Willamette is not possible. In addition, urbanization, deforestation, dredging, and agricultural land conversion were already impacting the structure and function of the lower Willamette main stem by the late 1850's, before any known temperature records are thought to be available (Sedell and Froggatt 1984, Hulse et al. 2002, Oetter et al. 2004). Even if full restoration of riparian vegetation were possible– dam operations, dredging, levee construction and other bank stabilization structures have permanently altered the morphological character of the main stem.

Present day Willamette Valley Project dam water releases are known to have a moderating effect on summer water temperatures and increase summertime flows which contribute to reduction in extreme temperature variability versus the historic periods (Rounds 2010). Occurrence of extreme high and low temperature anomaly (difference from the long-term mean of water temperature) decreased for the period 2000-2015 relative to the pre-dam period 1889-1891 (Figure 3-6). Only ~0.5% of extreme daily maximum temperatures are +/-4 °C different from the absolute climatological average of daily maximum temperature from 2000-2015. The historic deviation was greater, ~2% +/- 4°C for the period 1880-1891.

---

[4] Stefan Talke, Assistant Professor of Civil and Environmental Engineering, Portland State University.

Figure 3-5 Contemporary and historical daily mean water temperatures for select years in the Lower Willamette measured at Portland for years 1889, 1941, and 2015. Day of year 140 = May 20 and day of year 280 = October 7. Data source: (Jay and Talke 2015)

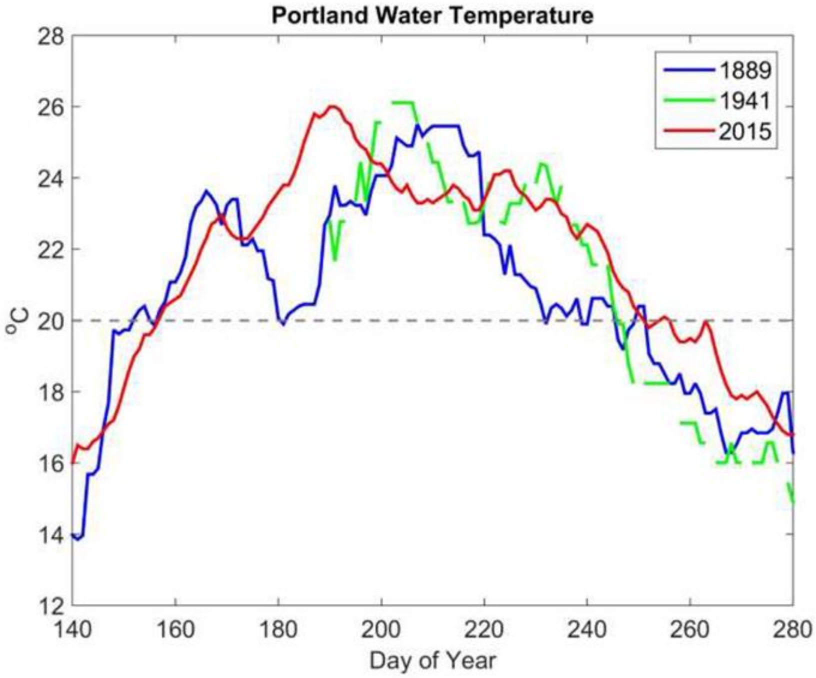
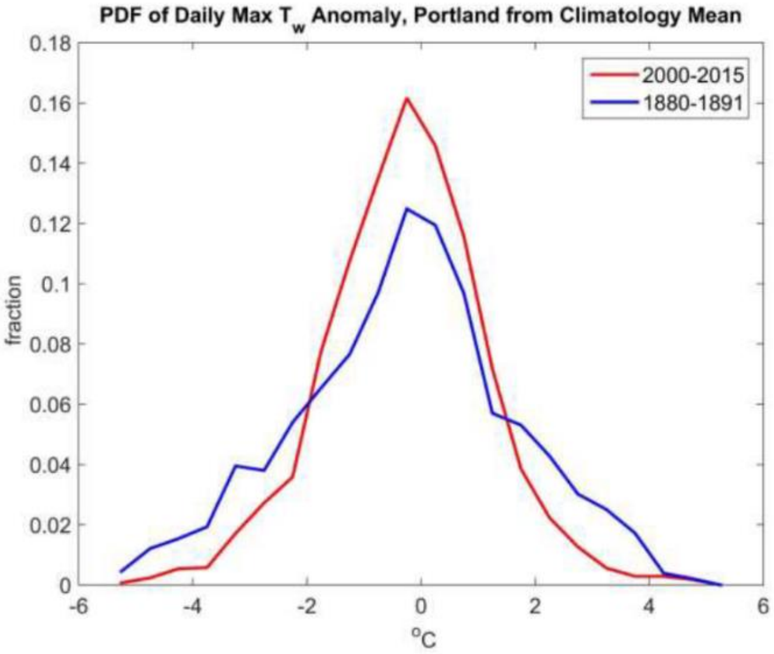


Figure 3-6 Distribution of temperature anomalies as deviations in degrees from the climatological mean (deviation = 0°C) of daily maximum temperatures. Y-axis shows percent (fraction) of daily max temperatures in deviation from the mean (x-axis). Data source: (Jay and Talke 2015)



Even with the warming caused by anthropogenic changes, the best available information on natural thermal regimes for the lower Willamette main stem indicate the river may still have naturally exceeded the migration corridor criterion in late summer. Modeling of natural thermal potential by DEQ for the 2006 Willamette TMDL and by the USGS supports this assertion. Even with complete restoration of historical shade, flow, and channel width conditions, the lower Willamette main stem would not meet the 20°C migration corridor criterion year-round (see Figure 2-1). The behavioral strategies of migrating Chinook and steelhead would have originally evolved to adapt to these natural conditions.

3.3 Tributary scale CWR

3.3.1 Candidate refuge screening using the NorWeST model

Tributary mouths and cold water plumes are expected to be the main features where cooler water is found along the lower Willamette River. Mean August water temperature of tributaries to the migration corridor were obtained from the NorWeST model to act as a screening tool to identify candidate sites of potential tributary CWRs. The modeled average stream temperatures are a historical composite of 19 years of monthly mean stream temperature for August from 1993 – 2011. NorWeST also estimates mean monthly flows for August using an extended Unit Runoff Method (EROM) model in NHDPlusV2[5]. The U.S. EPA provided DEQ with a memorandum summarizing the NorWeST results for the Willamette Basin (Leinenbach 2017). The full text of the memorandum is included as an appendix to this report.

There are 38 tributaries along the Lower Willamette migration corridor captured by the NorWeST model on 1:100K hydrography (Figure 3-7, Figure 3-8). Thirty-four of the tributaries had mean August temperatures differences of at least 2°C from the main stem temperature. Twelve tributaries fit our refuge identification framework for temperature and flow to qualify as potential tributary CWR within the Lower Willamette reach (Table 3-2).

DEQ focused subsequent data analysis at the tributary scale on characterizing annual temperature patterns and corroborating the NorWeST results with field temperature data for current conditions (2007-2017) in these candidate tributaries.

---

[5] http://www.horizon-systems.com/NHDPlus/NHDPlusV2_17.php

Figure 3-7 NorWeST predicted average August stream temperatures for current conditions (1993-2011) the Willamette River basin and the locations of tributary confluences into the Willamette River

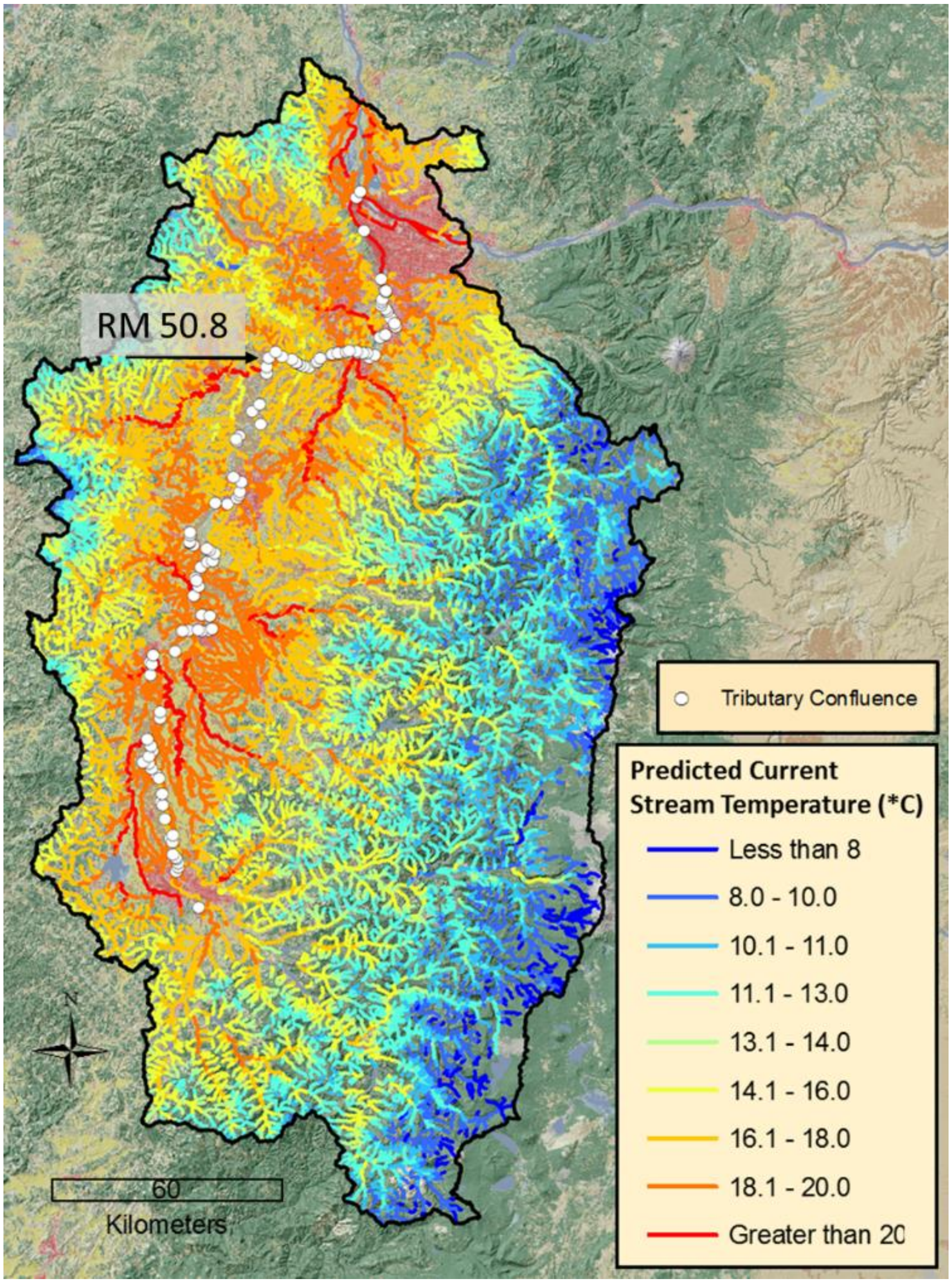


Figure 3-8 NorWeST predictions of average August temperature and flow for current conditions (1993-2011). Circle size is proportional to average August flow in cfs. Dashed line indicates upriver extent of the study area. Data source: (NorWeST, (Leinenbach 2017))

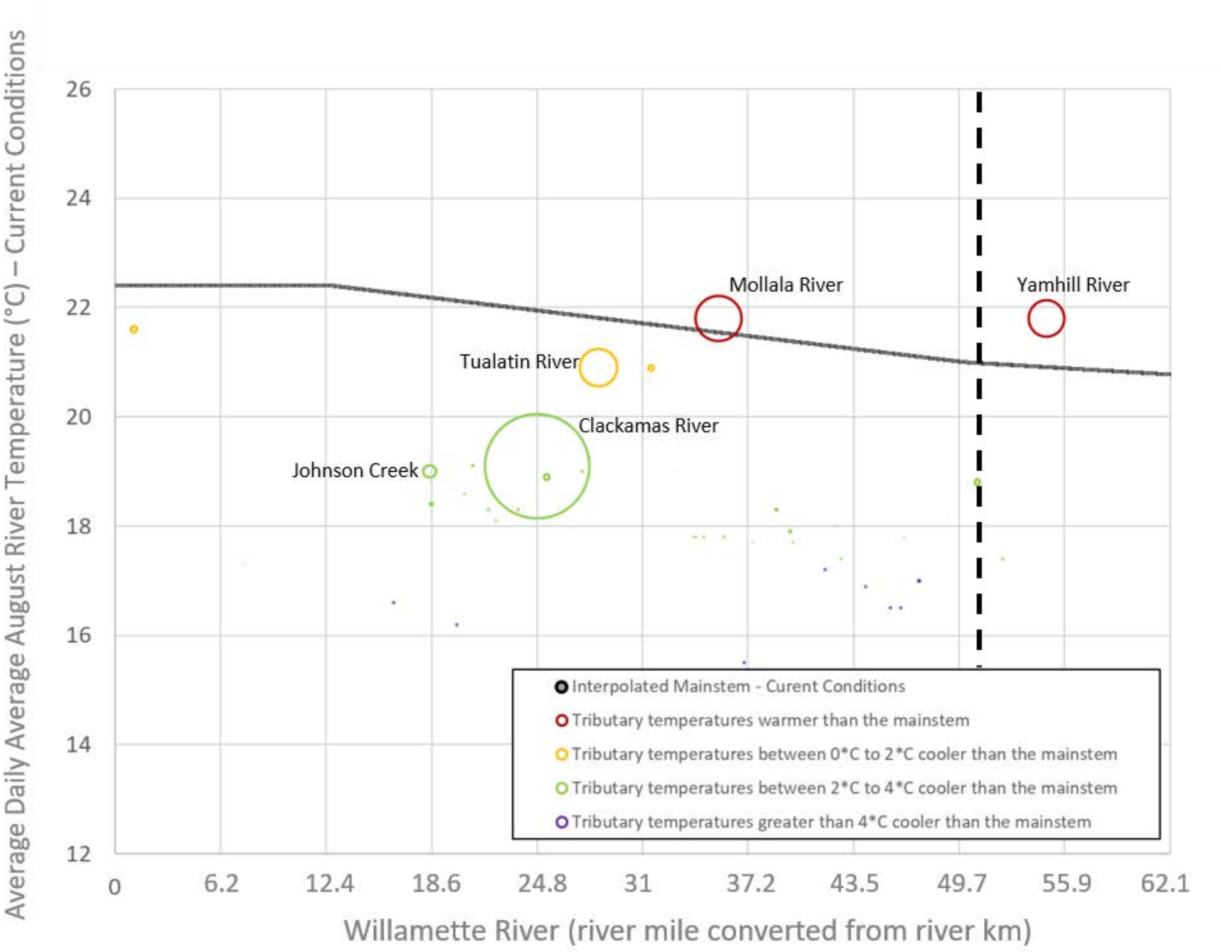


Figure 3-9 Flow distribution of Lower Willamette tributaries <20°C (Data: NorWeST)

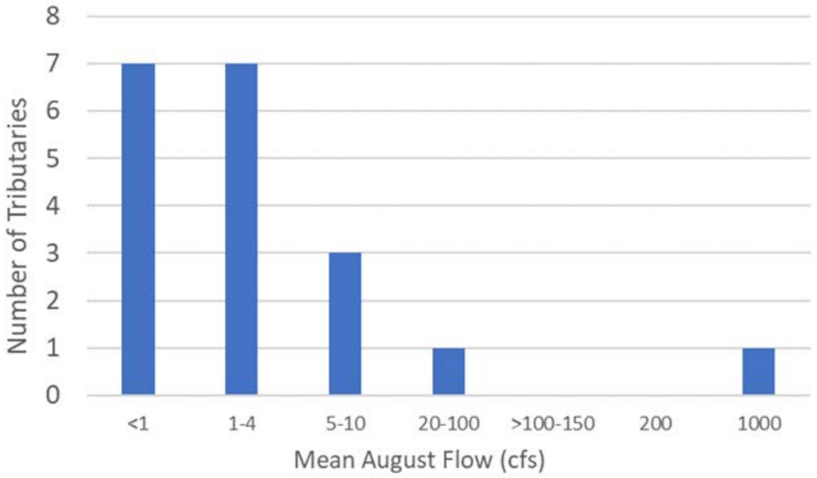
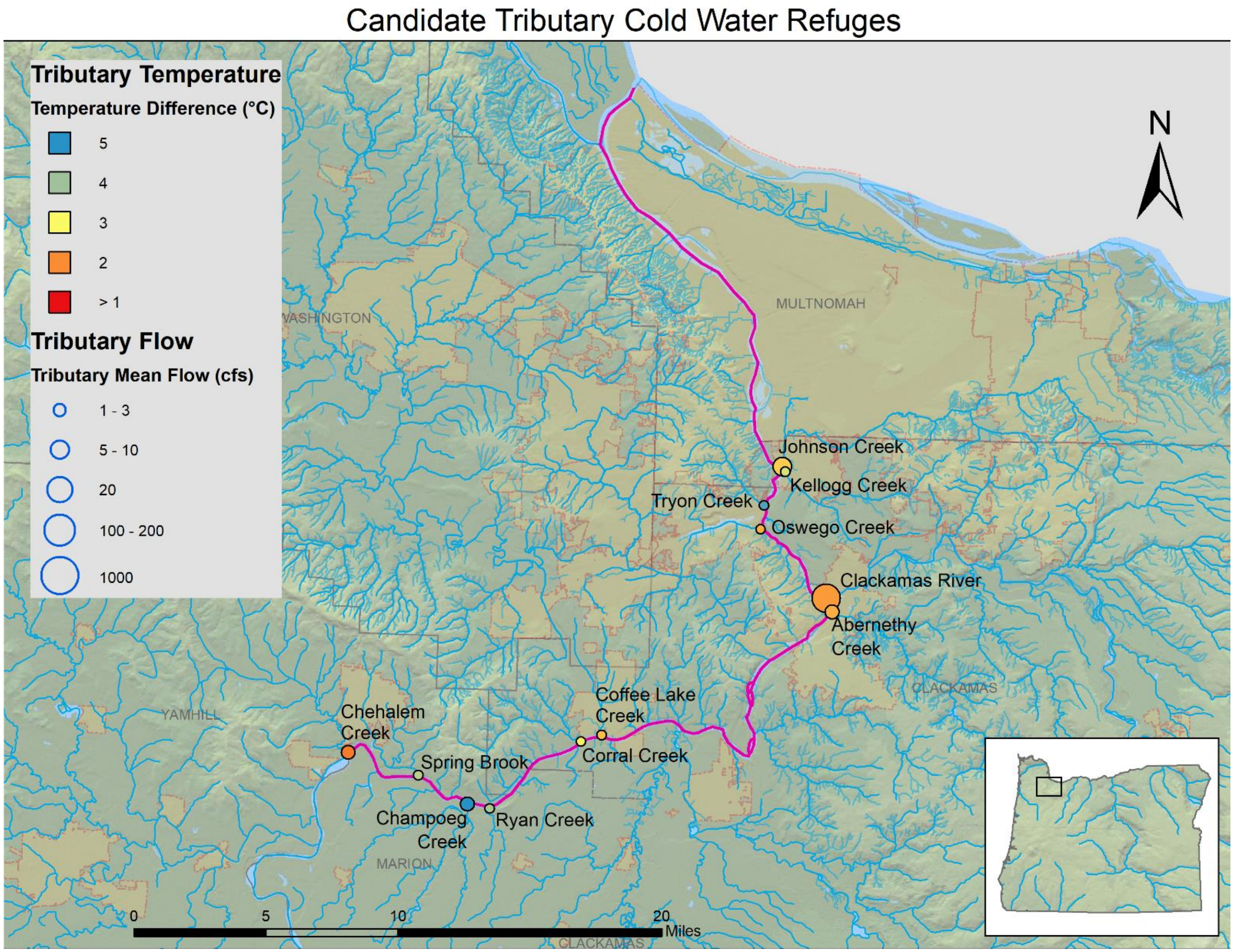


Table 3-2 Candidate cold-water refuge from tributaries identified by the NorWeST model. Candidates have at least a 2°C August mean temperature difference from the mainstem and modeled mean flow of at least 1 cfs. Data source: NorWeST (Leinenbach 2017).

NorWeST Tributary Name	river km	river mi	Modeled main stem mean Temp (°C)	Modeled tributary max Temp (°C)	ΔT from main stem (°C)	Modeled tributary mean Flow (cfs)
Johnson Creek	29.8	18.5	22.2	19	3.2	21
Kellogg Creek	30	18.6	22.2	18.4	3.8	2.7
Tryon Creek	32.4	20.1	22.1	16.2	5.9	1.1
Oswego Creek	33.9	21.1	22.1	19.1	3	1.2
Clackamas River	40	24.9	21.9	19.1	2.8	1008.7
Abernethy Creek	40.9	25.4	21.9	18.9	3	6.1
Coffee Lake Creek	62.7	39.0	21.4	18.3	3.1	1.4
Corral Creek	64	39.8	21.4	17.9	3.5	1.8
Ryan Creek	71.1	44.2	21.2	16.9	4.3	1
Champoeg Creek	72.5	45.0	21.2	14.9	6.3	5.2
Spring Brook	76.2	47.3	21.1	17	4.1	1.9
Chehalem Creek	81.7	50.8	21	18.8	2.2	5.7

Figure 3-10 Location of candidate cold-water tributaries identified by the NorWeST model. Candidates have at least a 2°C August mean temperature difference from the mainstem and modeled mean flow of at least 1 cfs. The reach designated for salmon and steelhead migration is shown in pink. Data source: NorWeST (Leinenbach 2017).



3.3.2 Temperature patterns in potential tributary Refuge sites

3.3.2.1 Major Tributary Temperatures in the Lower Willamette Basin

Summer Temperatures in Major Willamette Tributaries

The USGS maintains gages on four major tributaries of the Lower Willamette reach. Continuous temperature monitoring data is available near the mouth of Johnson Creek, the Tualatin River, and the Clackamas River (Figure 3-11). These are the largest tributaries by discharge and drainage area to the Lower Willamette. The Molalla River is gaged for discharge but not currently for temperature, and drains a largely agricultural and rural watershed. Johnson Creek and the Tualatin drain relatively large urbanized areas. The Clackamas has headwaters on the front range of the Cascade Range, and supports a population of native Chinook salmon as well as hatchery stocks (NMFS 2015).

The Tualatin River temperature mirrors the temperature in the Willamette main stem from July to August. Temperatures in the Tualatin heat up faster than the main stem through the month of June. Johnson Creek and the Clackamas River are several degrees cooler than the main stem throughout the summer months. Daily average temperatures at the mouth of the Clackamas River and Johnson Creek typically exceed 18°C but not 20°C in July and August. (Figure 3-11). Both the Clackamas River and Johnson Creek maintain a temperature difference of at least 2°C from the main stem throughout the summer months (Figure 3-12).

Figure 3-11 Ten-year average of summertime temperatures for major tributaries in the Lower Willamette, 2007-2017. Gray bars show the standard error of the mean. (Source USGS-NWIS).

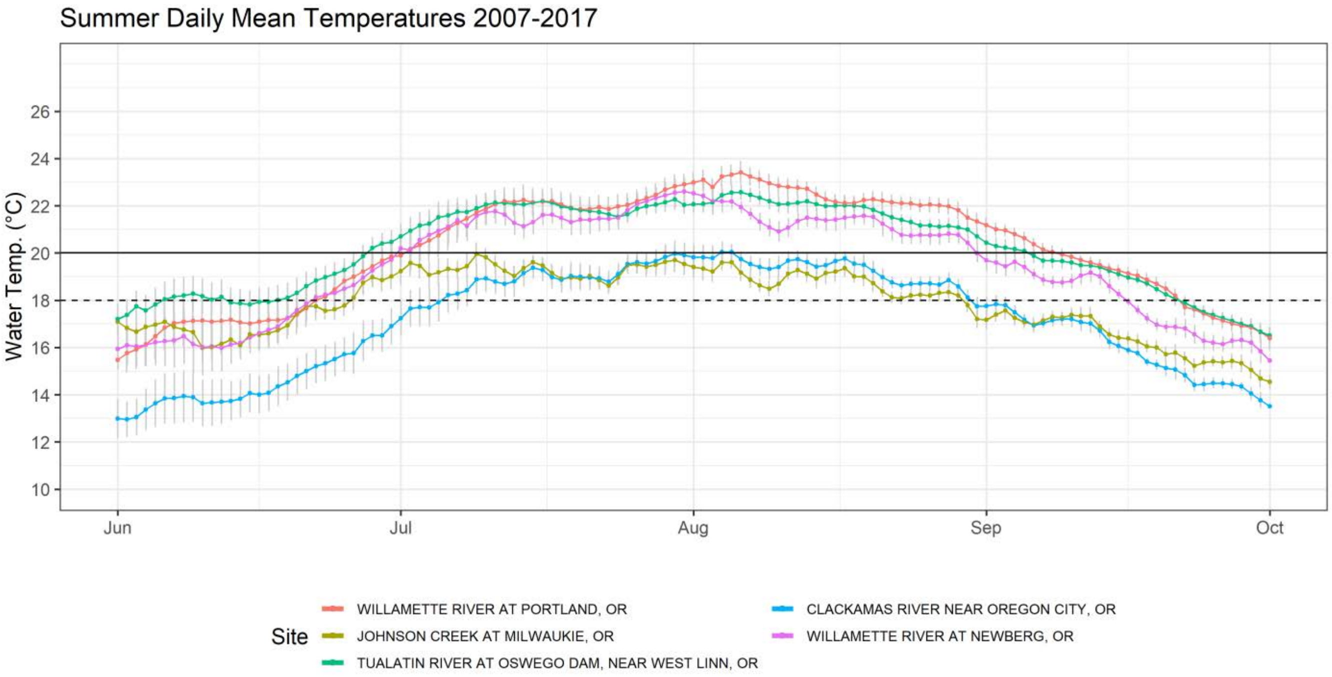
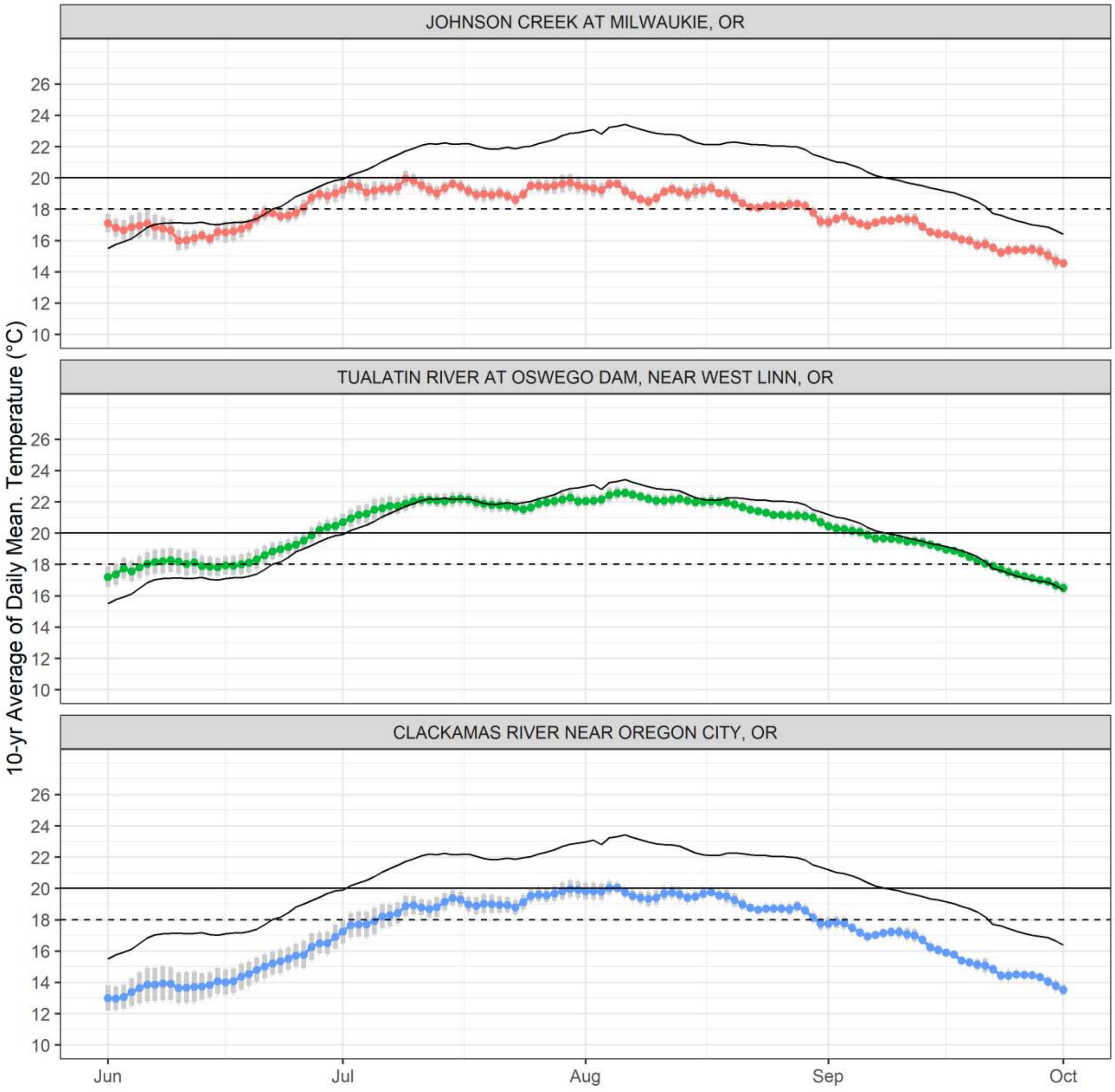


Figure 3-12 10-year daily average temperature difference at major tributaries, 2007:2017. Main stem temperature at Portland is shown as a black line. Grey error bars show standard error of the mean. Solid black horizontal line shows the temperature criteria for migration corridors. The dashed horizontal black line shows the temperature criterion for salmon and trout rearing and migration outside of the migration corridor (data: USGS-NWIS)



3.3.3 Minor tributary and off-channel temperatures in the lower Willamette Basin

3.3.3.1 Summer Temperature Surveys in Minor Willamette Tributaries

Portland Bureau of Environmental Services

In August and September 2011, The City of Portland Bureau of Environmental Services (BES) conducted temperature surveys of tributary inflows of the Lower Willamette from RM 0 – 28 through direct temperature measurements (Figure 3-13). The BES survey data corroborates the NorWeST model results in finding a 2–3°C temperature difference for the confluence of Johnson Creek, Kellogg Creek, the Clackamas River and Abernethy Creek. The BES survey also identified a number of very small unnamed inflows that were at least 2°C cooler than the main stem temperature (Table 3-3).

Figure 3-13 Median channel temperatures plotted versus river mile for the Rm 0 – RM 28 of the Willamette River in August and September 2011. The locations of detected surface inflows are illustrated on the profile (red squares). Data source: (Portland BES 2011)

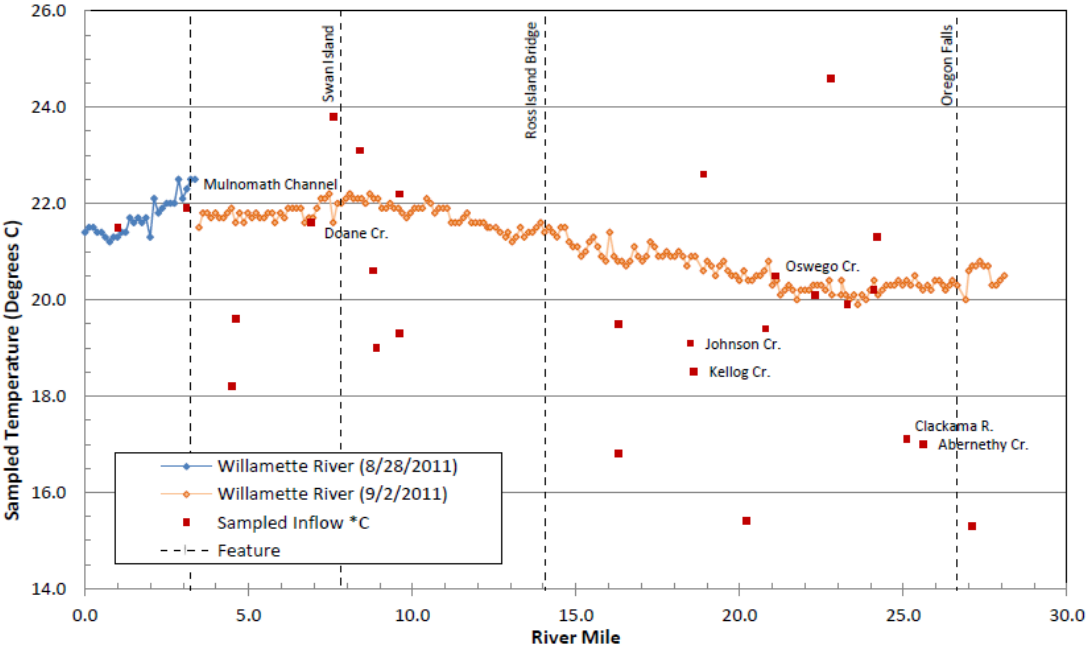


Table 3-3 Willamette River and tributaries temperature survey, August and September 2011. Data source: Portland Bureau of Environmental Services Willamette Thermal Report (Portland BES 2011).

Sampled Inflow	Main stem river mile	Main stem Temp (°C)	Tributary Temp (°C)	Temperature Difference (°C)
Unnamed Inflow (Right bank)	4.5	22.8	18.2	4.6
Unnamed Inflow (Right bank)	4.6	22.3	19.6	2.7
Unnamed Creek (Left bank)	8.8	23.6	20.6	3
Very Small Inflow (Right bank)	8.9	24.2	19	5.2
Unnamed Inflow (Left bank)	9.6	23.8	19.3	4.5
Unnamed Inflow (Left bank)	16.3	23.6	16.8	6.8
Johnson Creek (Right bank)	18.5	21.1	19.1	2
Kellogg Creek (Right bank)	18.6	21.4	18.5	2.9
Tryon Creek (Left bank)	20.2	21.3	15.4	5.9
Clackamas River (Right bank)	25.1	20.5	17.1	3.4
Abernethy Creek (Right bank)	25.6	20.3	17	3.3
Unknown Inflow (Left bank)	27.1	21	15.3	5.7

U.S. Geological Survey

In summer 2016 and 2017, the USGS deployed temperature loggers to small tributaries and off-channel features in the entire Lower Willamette reach– although areas near Wilsonville (RM 38) had less coverage (Jones 2017, Mangano et al. 2017, 2018, Piatt et al. 2018). A number of small tributaries have temperatures that are much colder than the Willamette main stem at Portland during July, August, and September (Figure 3-14).

Of the potential refuge sites identified by the NorWeST model, Coffee Lake Creek, Corral Creek, and Tryon Creek maintain a temperature difference of at least 2°C consistently from June-September (Figure 3-16). At times, the temperature difference in these tributaries is >4°C from the main stem temperature. Abernethy Creek, Johnson Creek, and Kellogg Creek maintain a 2°C temperature difference in August, but are not cooler than the Willamette main stem in July and September.

Figure 3-14 Daily average temperatures in off-channel and minor tributaries, 2016 or 2017. Dark-grey solid line is concurrent temperature of the Willamette main stem at Portland. Horizontal reference lines show 18°C (dashed) and 20°C (solid). (Data: USGS-NWIS and DEQ Volunteer Monitoring)

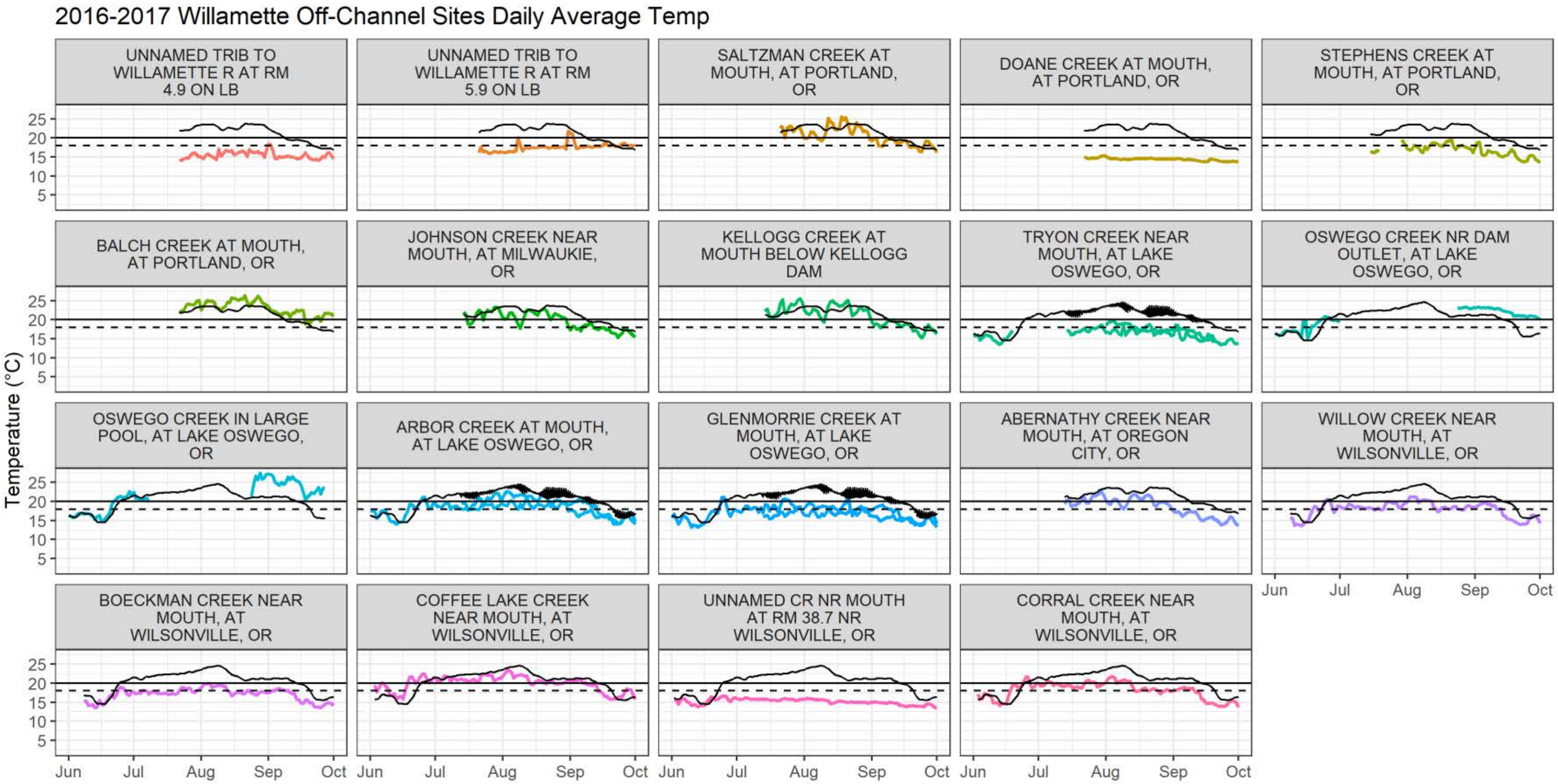


Figure 3-15 Temperature differences in off-channel sites and minor tributaries, 2016 or 2017. The solid black line shows where temperature difference is zero. Values above the line are cooler than the main stem and values below the solid line are warmer than the main stem. The dashed black line shows where temperature difference is at least 2°C. Main stem temperature is from USGS gage at Portland. (Data: USGS-NWIS and DEQ Volunteer Monitoring)

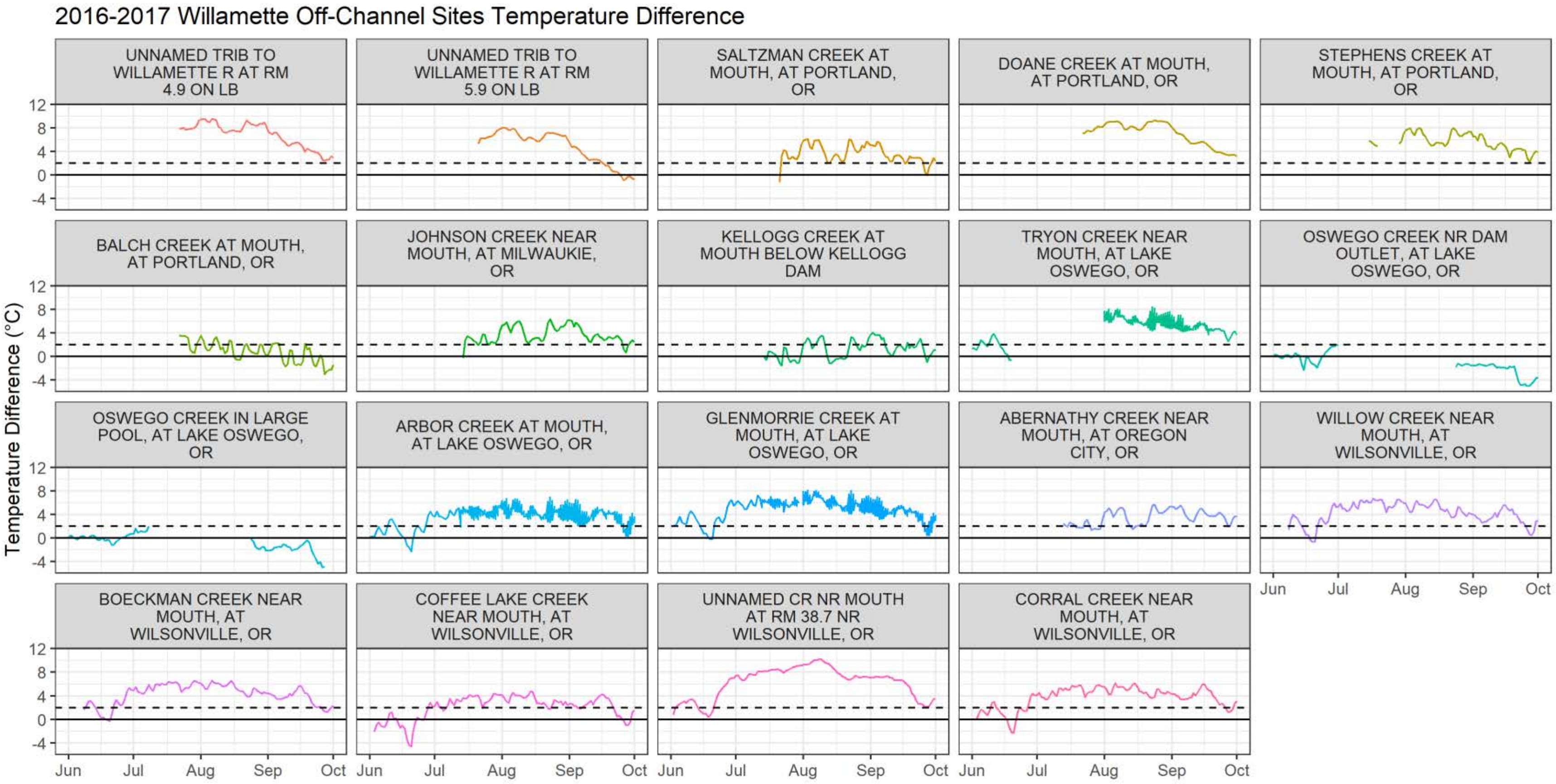
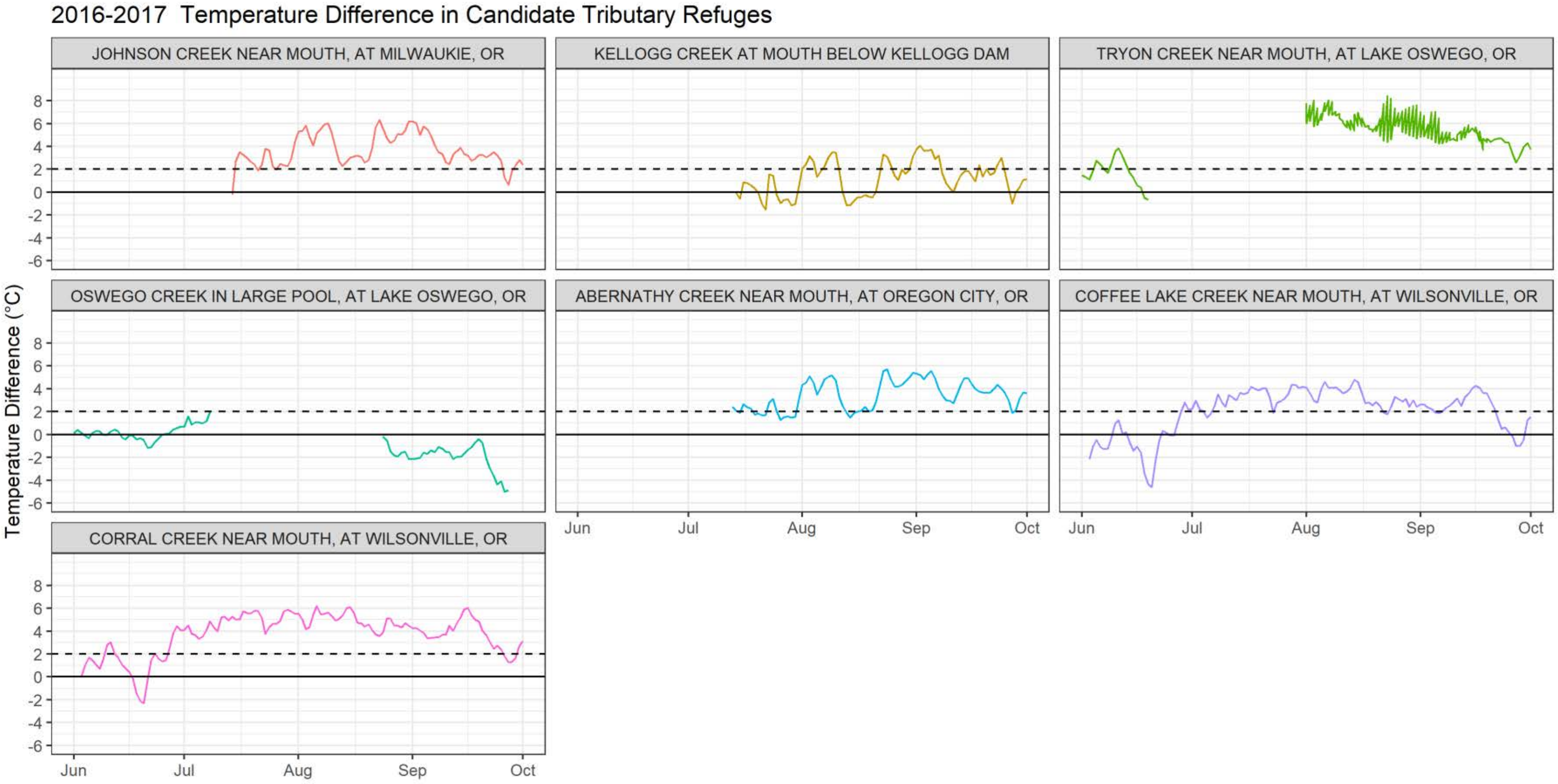


Figure 3-16 Summer temperature differences for minor tributary candidate refuges identified by NorWeST, 2016 and 2017 (Data: USGS-NWIS and DEQ Volunteer Monitoring).



3.3.4 Potential refuge – thermal plume evidence

3.3.4.1 FLIR by Site

The existence of cold water tributaries does not necessarily mean that cold-water refuge is provided to migrating salmon and steelhead. The cold water must be detectable and accessible to the fish without requiring a significant detour from the migration route. DEQ examined aerial imagery and infrared imagery of candidate tributaries to identify:

1) The existence and size of discernible cold water plumes
2) Physical barriers that could block access to cold water

High-resolution aerial imagery is readily available for the Lower Willamette region. Additionally, the City of Portland Bureau of Environmental Services and Oregon DEQ have contracted aerial surveys using forward-looking infrared (FLIR) sensors to measure surface temperatures in the study area. Portland BES contracted flights for the lower 30 miles of the migration corridor in August 2011 (Portland BES 2011). The DEQ TMDL program also contracted flights for the Willamette Falls area and Johnson creek in July 2001.

An important limitation of the FLIR imagery is that it only shows surface temperatures. The vertical area of plumes is not shown. Plumes that appear limited on the surface may have greater volume near the channel bottom. Plumes that form are likely to be of limited size because mixing with the much higher flow of the main channel occurs rapidly (Mangano et al. 2018).

Temperature differences greater than 2°C during September occur for Johnson Creek, Kellogg Creek, Tryon Creek, the Clackamas River, and Abernethy Creek. Oswego Creek, which had a data gap in the USGS tributary study, appeared warmer than the main stem at the time of FLIR imagery capture.

The Willamette main stem remains well mixed throughout the confluences with these cold-water tributaries. Temperatures near the middle of the channel are usually cooler than near the shoreline. Tributary plume formation within the main stem is minimal for most tributaries due to mixing and the large differences in flow volume with the main stem. Only the largest tributary by flow volume, the Clackamas River, shows clearly detectable plume development along the shore of the main channel.

Johnson Creek

Stream temperatures at the mouth of Johnson Creek are lower than the rest of the waterbody as a whole due to the influence of cold water from nearby Crystal Springs Creek. Temperatures in the mouth of Johnson Creek were only ~1-2°C cooler than the main stem temperature at the time the FLIR image was taken (Figure 3-17). However, the temperature in Johnson Creek was less than 20°C. The plume created by Johnson Creek is minimal and quickly dissipated within the main channel. Access to the creek is open and somewhat shaded for the first 150 meters until a culvert at SE 17th Ave.

Figure 3-17 Surface temperatures at the mouth of Johnson Creek, Sept. 2, 2011. Data source: Portland BES

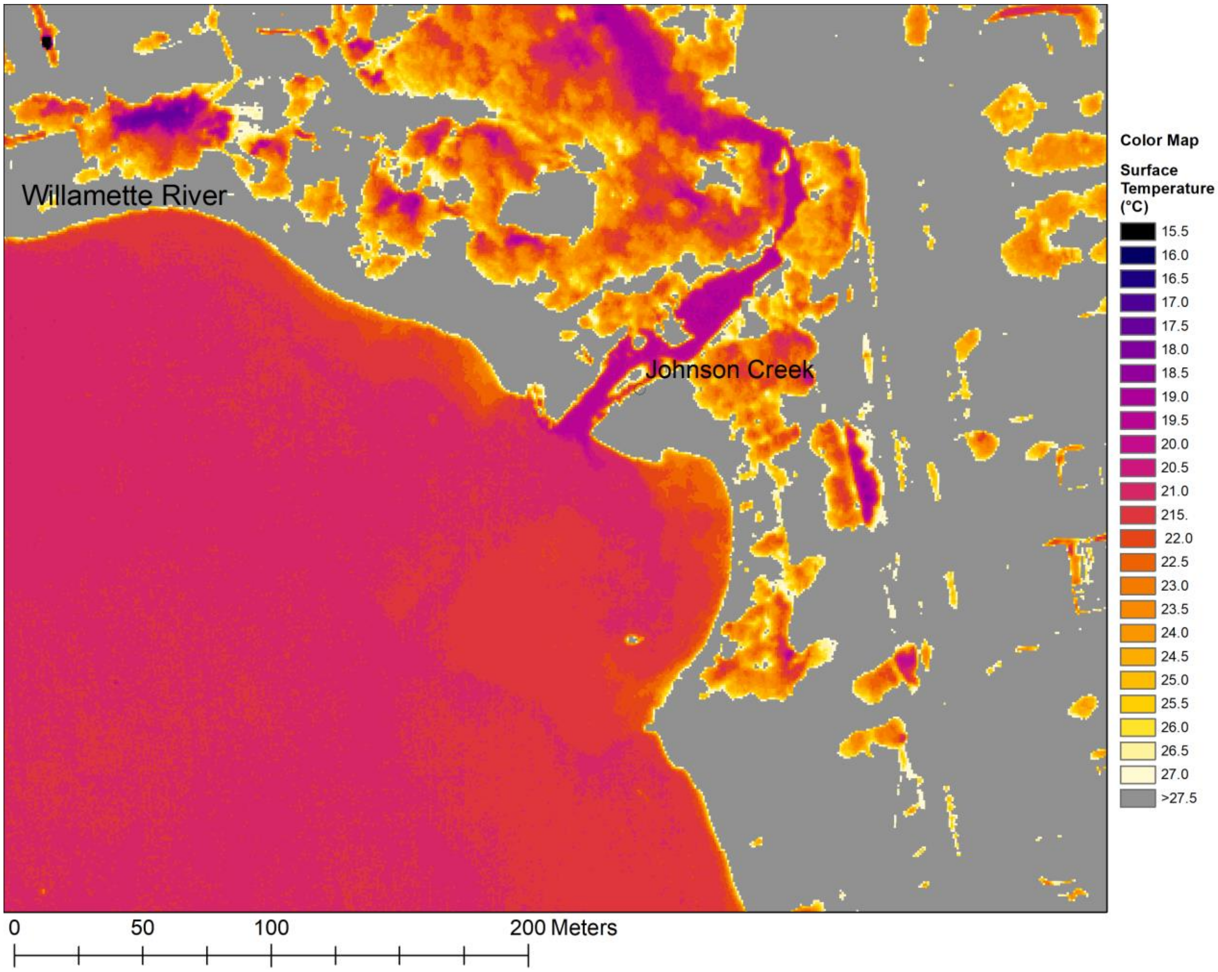


Figure 3-18 Aerial orthophoto of the mouth of Johnson Creek.

Kellogg Creek

Plume formation at the mouth of Kellogg Creek is minimal. Surface temperatures are cooler within a limited zone protected by the banks at the mouth of the creek. Cooler flow from the creek mixes quickly with the main stem flow and plume formation in the main stem channel is minimal. A dam and culvert at highway 99E limit access further up the creek. A fish ladder permits passage of the dam during high mainstem river stage, but the ladder is inaccessible at low river stage during the summer.

Figure 3-19 Surface temperatures at the mouth of Kellogg Creek, Sept. 2, 2011. Data source: Portland BES

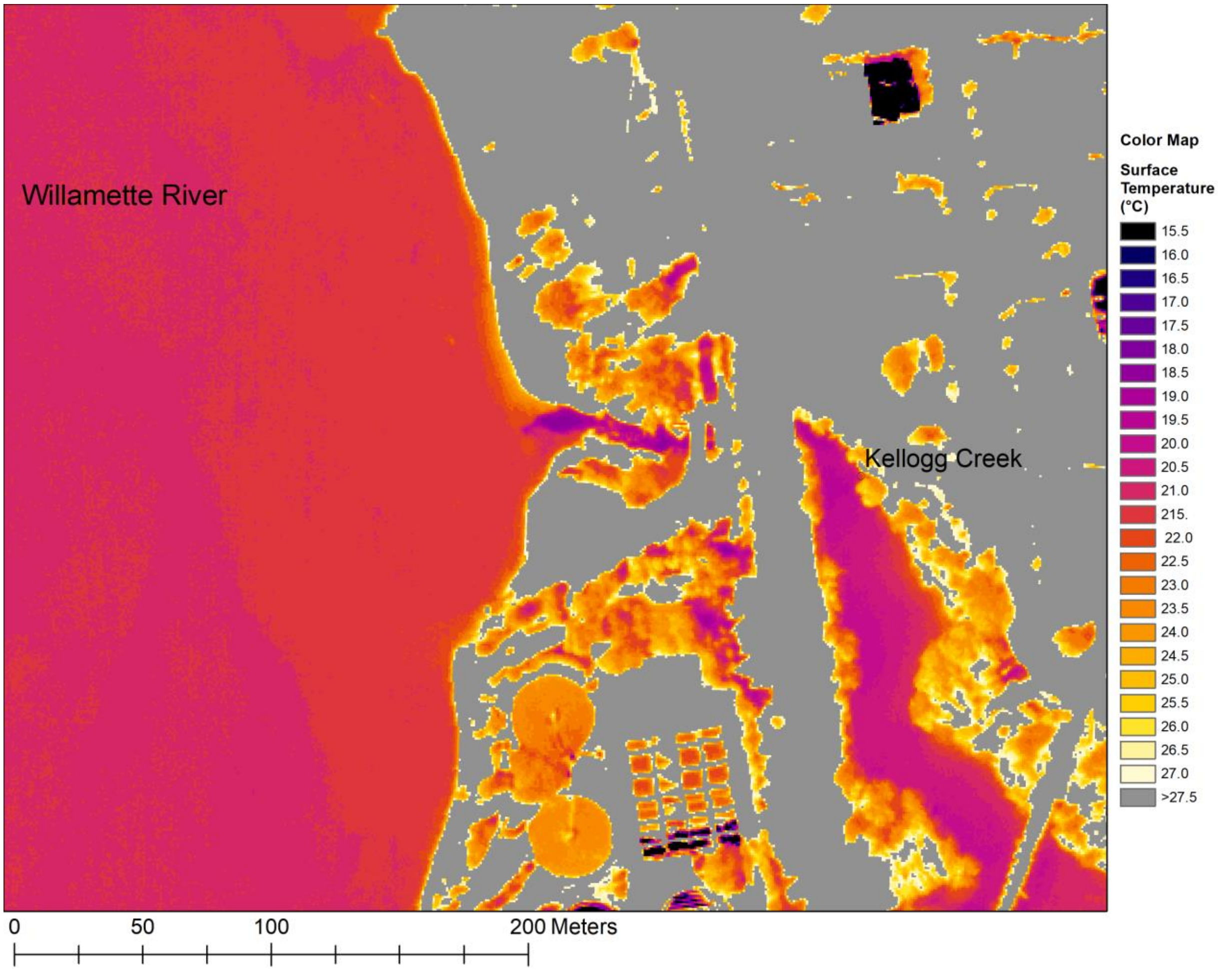


Figure 3-20 Aerial orthophoto of the mouth of Kellogg Creek.

Tryon Creek

Tyron Creek is an extremely cool tributary that originates in the Tryon Creek State Natural Area near Portland. Because of the low relative flow and narrow channel of this tributary, the cold-water plume is minimal and extends only a few meters past the banks into the main channel. The nearshore area of the main channel is shallow near the Tryon creek mouth, so water temperatures are warmer there than in the deeper part near the middle of the main channel. Fish access to the creek is open and well shaded, but the width of the Tryon Creek channel at the mouth is narrow.

The U.S. Fish and Wildlife Service and the City of Portland have been working to restore access to Tryon Creek (Silver et al. 2017a). Fish passage to the upper portion of the tributary is currently limited by a culvert on Highway 43. Tryon Creek is a tributary site identified as having cold-water refuge in our inventory. It is unique in draining a relatively undisturbed watershed in the lower Willamette migration corridor in the reach downstream of Willamette Falls near the city of Portland. The watershed was historically thought to support resident trout and both adult and juvenile migrating salmon and steelhead.

Figure 3-21 Surface temperatures at the mouth of Tryon Creek, Sept. 2, 2011. Data source: Portland BES

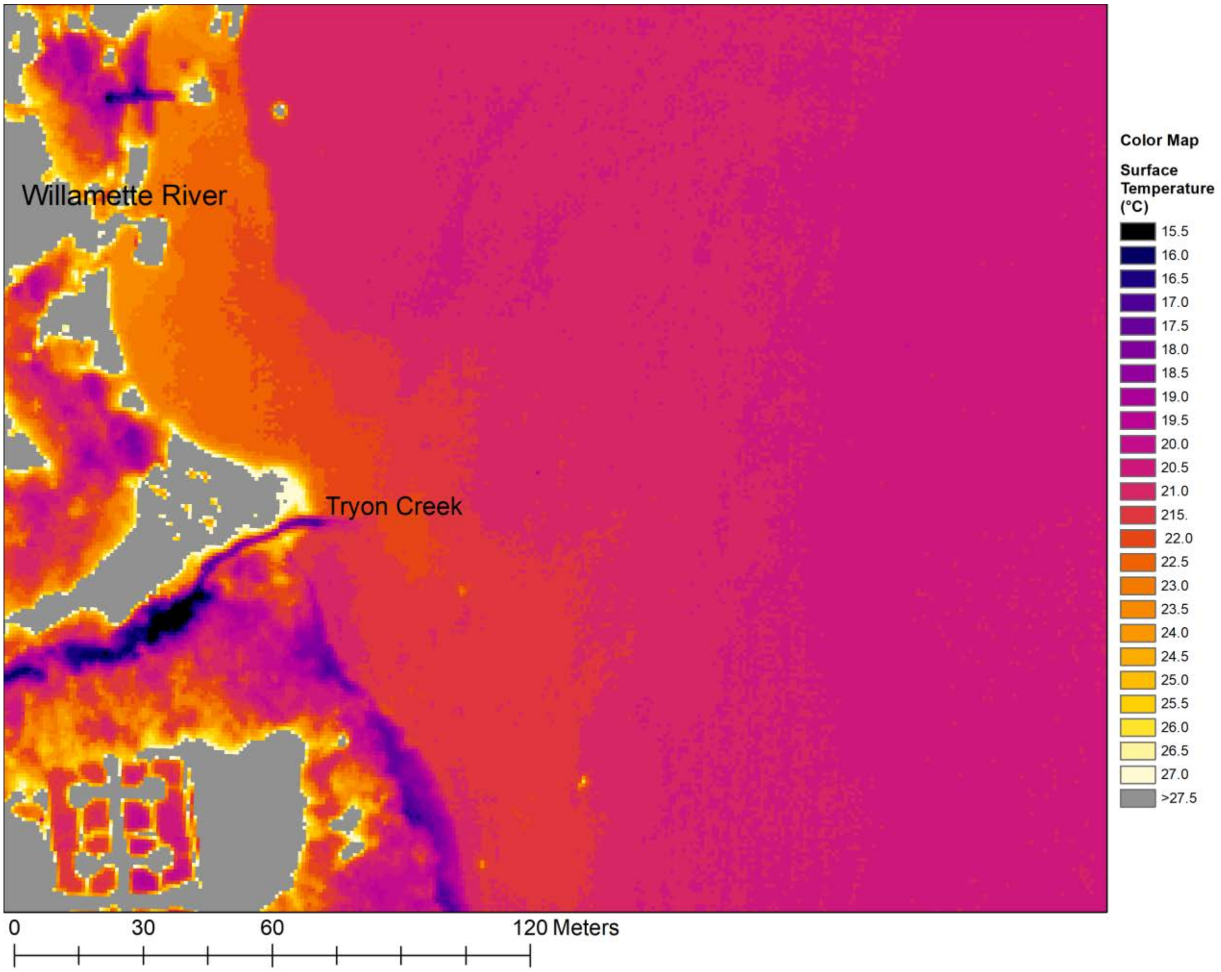


Figure 3-22 Aerial orthophoto of the mouth of Tryon Creek.

Clackamas River

The Clackamas is the largest tributary by volume in the Lower Willamette reach. Mean August discharge of ~1000 cfs can make up to 10% of the main stem Willamette River flow at this point. The tributary mouth is wide with no obstructions from the main stem. The Clackamas River drains high-altitude streams on the western slope of the Cascade Range and has a high proportion of vegetation cover in the headwater areas. The Clackamas basin supports the Lower Columbia River populations of Chinook salmon and steelhead.

Unlike most Lower Willamette tributaries, a large discernable surface plume of cold water is evident at the Clackamas River confluence. At the time the FLIR image was taken below (Figure 3-23), a surface plume of >2°C cooler water extended at least a quarter mile along the east bank of the Willamette main stem. Water within the tributary mouth was 4-6°C cooler than the main stem.

Figure 3-23 Surface temperatures at the mouth of the Clackamas River, Sept. 2, 2011. Data source: Portland BES

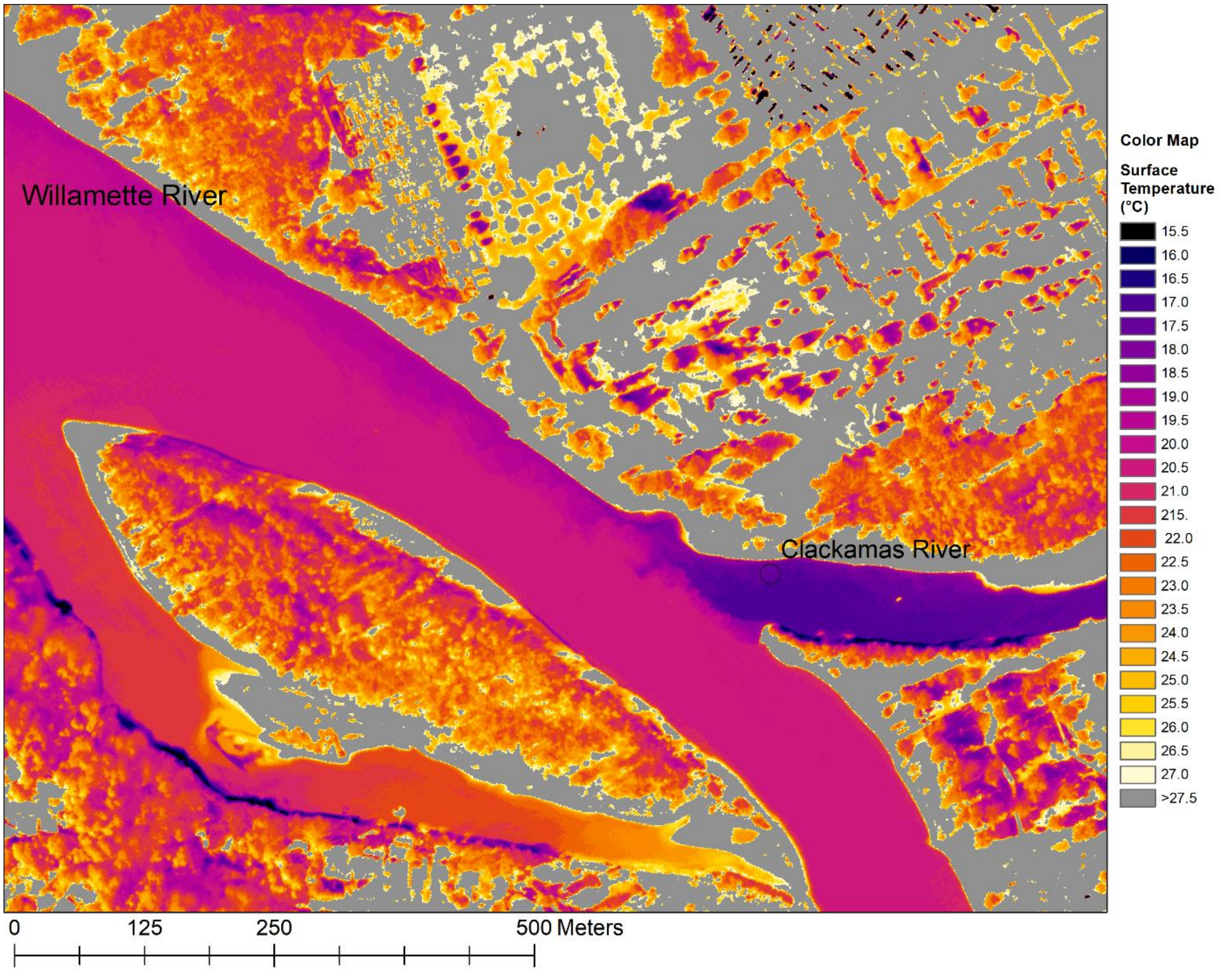
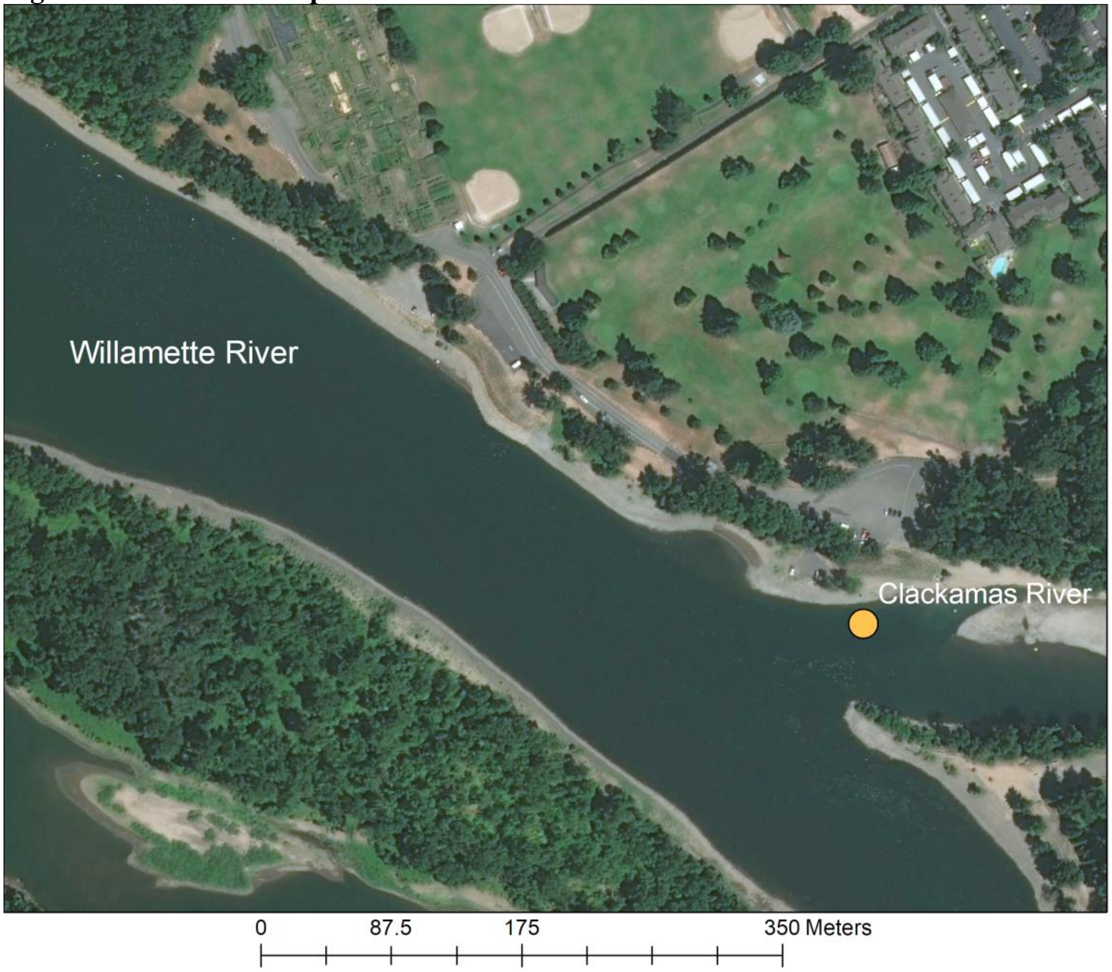


Figure 3-24 Aerial orthophoto of the mouth of the Clackamas River.



Abernethy Creek

In this image taken Sept.2, 2011 Abernethy Creek was 3°C cooler than the main stem and less than 18°C at its mouth. A small surface plume ~25m in length was evident on the eastern shore of the Willamette River. Access is limited to the creek upstream of the mouth by pilings for the Interstate 5 Abernethy Bridge and a pair of culverts beneath Clackamas Drive. The creek drains largely agricultural and residential land near Oregon City.

Figure 3-25 Surface temperatures at the mouth of Abernethy Creek, Sept. 2, 2011. Data source: Portland BES

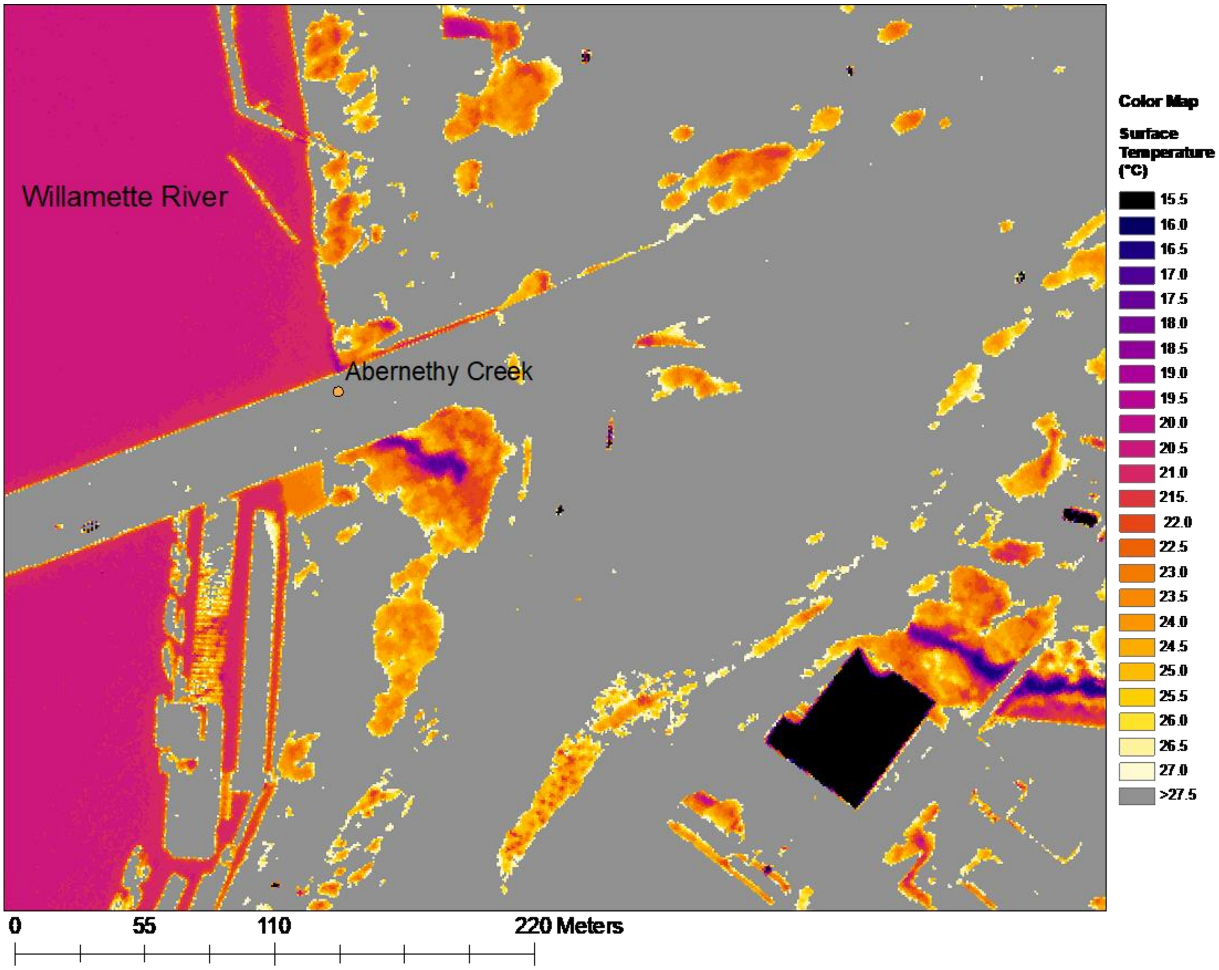


Figure 3-26 Aerial orthophoto of the mouth of Abernethy Creek.

Coffee Lake Creek

No FLIR imagery identified. The mouth of coffee lake creek is partially obstructed by a floating dock and pilings. The mouth is narrow, but the lower reaches are well shaded.

Figure 3-27 Aerial orthophoto of the mouth of Coffee Lake Creek.

Corral Creek

No FLIR imagery was identified for Corral Creek. The mouth of corral creek is narrow, but access is open. The lower reach of Corral Creek are heavily shaded and free from obstructions.

Figure 3-28 Aerial orthophoto of the mouth of Corral Creek.

3.4 CWR associated with in-channel geomorphologic features

1. Identify geomorphological channel features (islands, springs, hyporheic flows, gravel bars, tributary seeps, etc.) that may serve as potential CWR.
2. Characterize the areal extent and volume of identified refuges to the extent possible.

The Lower Willamette area has simpler, less dynamic, and more constrained channel geomorphology and fewer off-channel habitats than the main stem reaches farther upriver (Hulse et al. 2002, Gregory 2008). Below the Willamette Falls (RM 26.7) in Oregon City the main channel is constrained by bedrock that may limit hyporheic flow potential. Many of the existing off-channel alcoves, secondary channels, and backwaters have been eliminated from the area around Portland and replaced with revetment (Friesen 2005). Coldwater features in the Lower Willamette River are expected to be mainly limited to the tributary junctions and seeps along bars (Mangano et al. 2016). Many of the islands in the river are volcanic or bedrock outcrops, rather than gravel bars or historic meander remnants(Lestelle et al. 2005).

3.4.1 Cold water patch surveys

A small number of habitat and cold-water patch surveys have been conducted in the Lower Willamette migration corridor. These surveys used temporary continuous temperature logger stations or trawling/wading point-surveys of features and focused on small-scale in-channel and off-channel hydrogeomorphology and cold water patches. (Hulse et al. 2010, Portland BES 2011, Mangano et al. 2018) or habitat surveys of features that may produce cold water patches (Friesen 2005).

3.4.1.1 Chinook salmon and steelhead rearing habitat surveys

In 2004, Friesen conducted a salmon rearing habitat survey of the lower Willamette that catalogued river features that could serve as cold-water refuge. Alcove sites associated with channel bars and man-made shelter habitats were identified. There was no accompanying temperature data with these habitat surveys. The Doane Point, Cedar Oak Boat ramp (Cedar Island), and Meldrum Bar alcoves were recently surveyed by the USGS and fit the framework for CWR.

Table 3-4 Description of alcove habitat sites in the reach from Portland Harbor to Willamette Falls from (Friesen 2005).

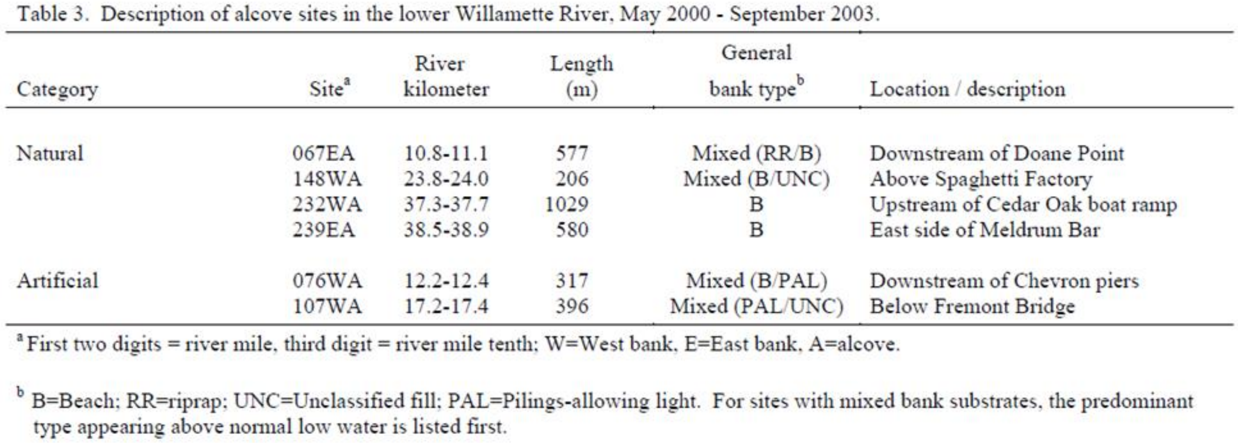


Table 3. Description of alcove sites in the lower Willamette River, May 2000 - September 2003.

Category	Site[a]	River kilometer	Length (m)	General bank type[b]	Location / description
Natural	067EA	10.8-11.1	577	Mixed (RR/B)	Downstream of Doane Point
	148WA	23.8-24.0	206	Mixed (B/UNC)	Above Spaghetti Factory
	232WA	37.3-37.7	1029	B	Upstream of Cedar Oak boat ramp
	239EA	38.5-38.9	580	B	East side of Meldrum Bar
Artificial	076WA	12.2-12.4	317	Mixed (B/PAL)	Downstream of Chevron piers
	107WA	17.2-17.4	396	Mixed (PAL/UNC)	Below Fremont Bridge

[a] First two digits = river mile, third digit = river mile tenth; W=West bank, E=East bank, A=alcove.

[b] B=Beach; RR=riprap; UNC=Unclassified fill; PAL=Pilings-allowing light. For sites with mixed bank substrates, the predominant type appearing above normal low water is listed first.

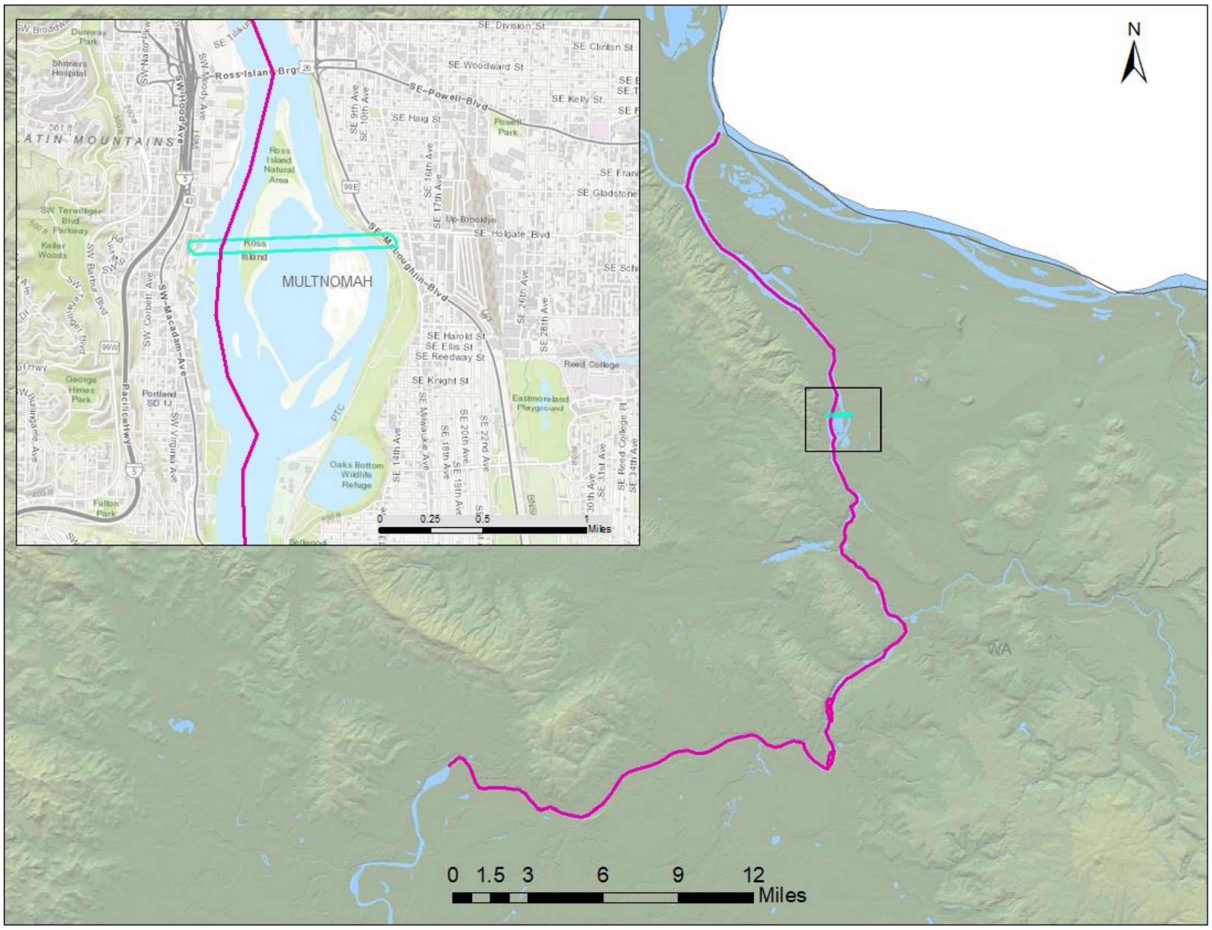
3.4.1.2 SLICES and Stepping Stones

In 2010, an Oregon State University Institute for a Sustainable Environment completed a basin-wide analysis of main stem Willamette floodplain characteristics; implementing a high-resolution spatial information framework for classifying river-channel and floodplain habitats. The framework includes habitat features related to channel complexity, floodplain forest, number of cold-water refuges, observed native and non-native fish species richness and non-structural flood storage. Habitat features were classified within 100m transect "slices" across the width of the floodplain and perpendicular to the channel (Hulse et al. 2010).

The OSU researchers conducted temperature surveys of cold-water features from 2011-2016 in transects throughout the Willamette River main stem. They used temperature data for the months of July and August acquired from USGS gaging stations in 2014 – 2015 and a longitudinal array of temporary data loggers from 2011-2016. The framework for CWR identification used by the researchers was a 2°C temperature difference from the main stem and dissolved oxygen concentration >4 mg/L. They assigned CWR status to a slice if at least one location monitored within the slice fit this framework.

Figure 3-29 Example of 100-meter wide floodplain survey "slices" within a 1mi long reach in the Willamette Falls area (RM 26.7). Data source: http://ise.uoregon.edu/slices/data.html

Figure 3-30 Cold-water refuge "slices" identified in the Lower Willamette main stem. One cold-water refuge was identified along the migration corridor, at Ross Island. Data source: http://ise.uoregon.edu/slices/data.html (Hulse et al. 2010)

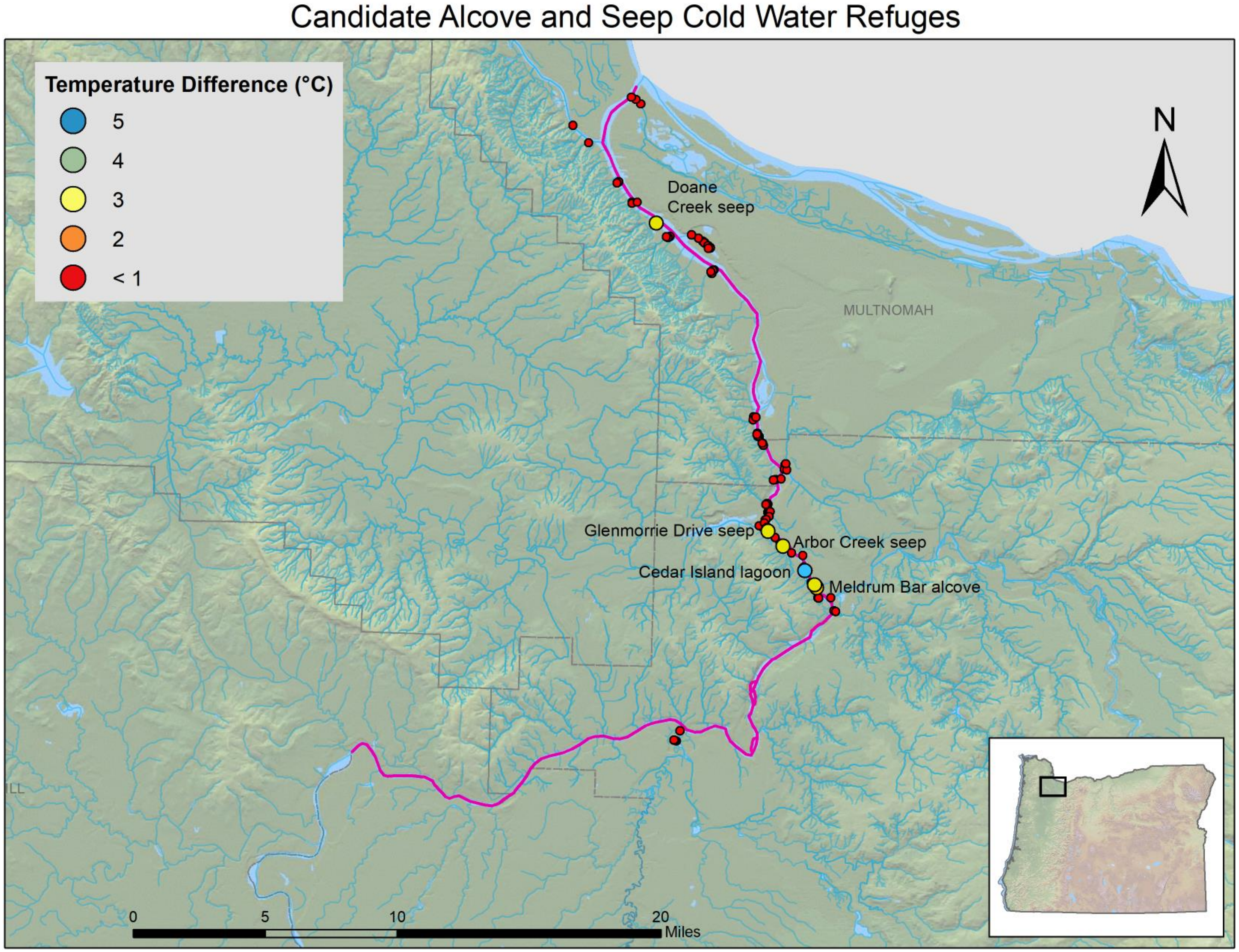


3.4.1.3 USGS Surveys 2016-2017

In summer 2015, 2016, and 2017, the USGS conducted synoptic point and transect surveys of morphological features with potential to create CWR within the main channel of the Willamette River. They made point measurements in alcoves, gravel bars, side channels, seeps, main channel pools and other features of the main channel for temperature, dissolved oxygen, pH, and specific conductance (Mangano et al. 2017, 2018, Piatt et al. 2018).

The USGS survey comprised 245 temperature measurements in 45 separate locations from the mouth of the Willamette at the Columbia River confluence to the Molalla River confluence. Nine locations had a temperature difference ≥2°C from the main stem.

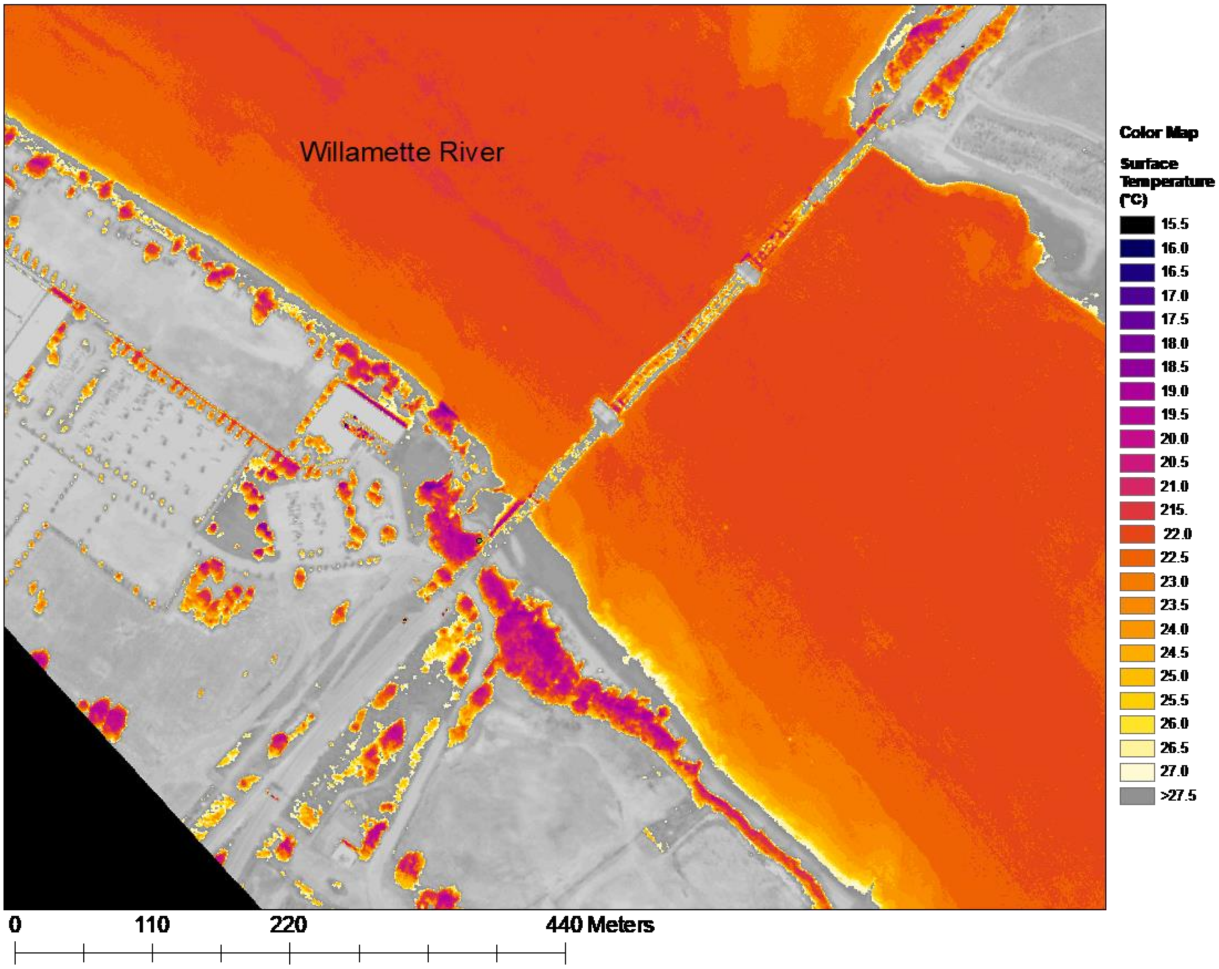
Figure 3-31 Temperature difference from main stem of off-channel cold-water refuge locations. Size of candidate refuge symbols exaggerated for emphasis. Data source: USGS Data Releases (Mangano et al. 2017, Piatt et al. 2018)



Doane Creek Seep

A small but cold plume of water >3°C cooler than the main stem is evident near the western abutment of the Burlington Northern Railroad Bridge. The seep is cooler than the mouth of Doane Creek 16 meters to the north. The FLIR imagery may be confounded by edge effects caused by near-shore shadows cast by vegetation and the bridge. The plume does not extend to any length within the Willamette main stem.

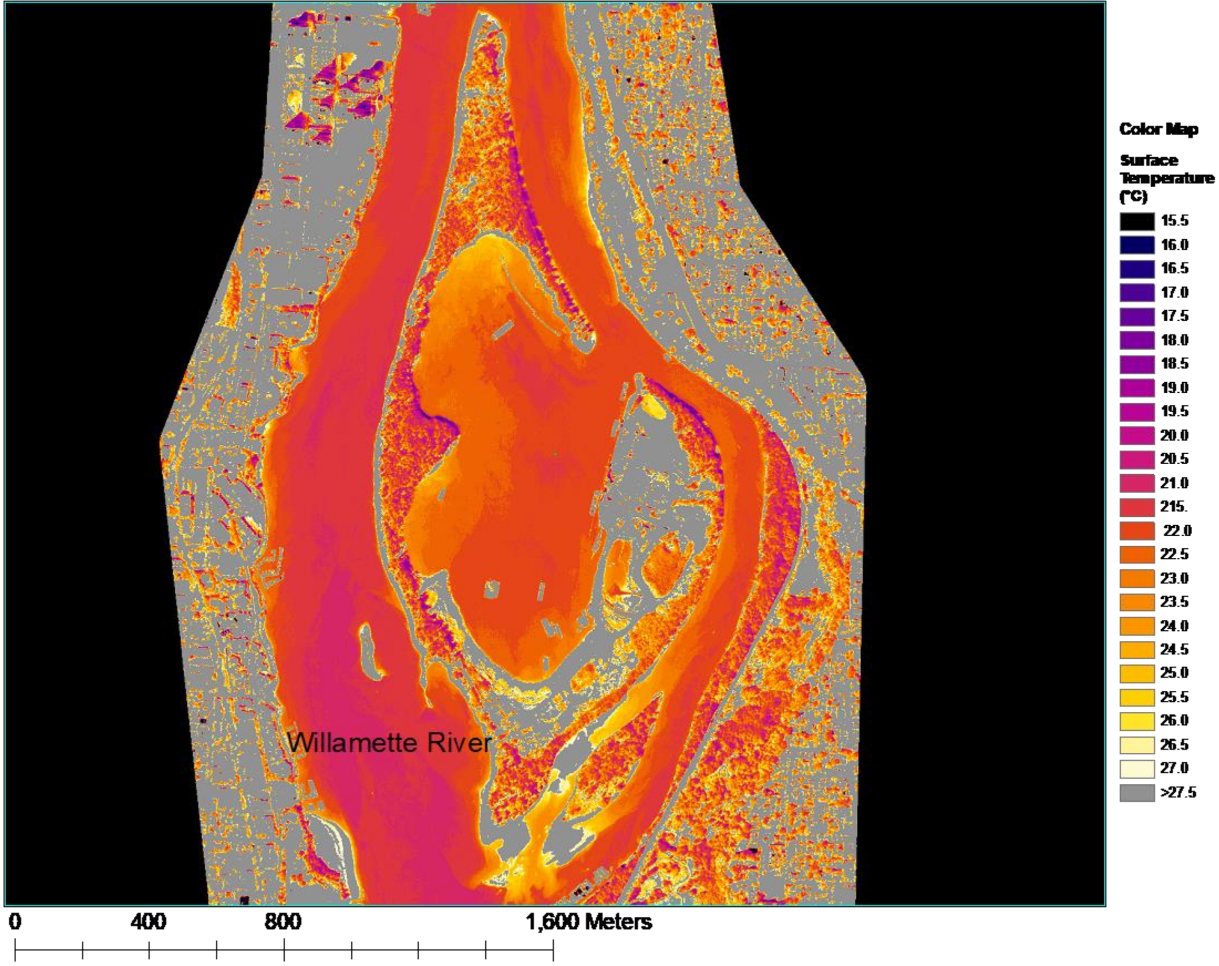
Figure 3-32 Surface temperatures at seep near Doane Creek, Sept. 2, 2011. Data source: Portland BES



Ross Island

The 2010 SLICES survey (Hulse et al. 2010) detected a cold water patch at Ross Island (Figure 3-30). The USGS did not survey the lagoon area during its synoptic temperature sampling. The 2011 FLIR imagery shows extremely limited ribbons of cold water at the downstream edge of the gravel bars that enclose the Ross Island Lagoon. These cold areas could also be artifacts caused by edge effects from tree shadows along the shoreline in the imagery.

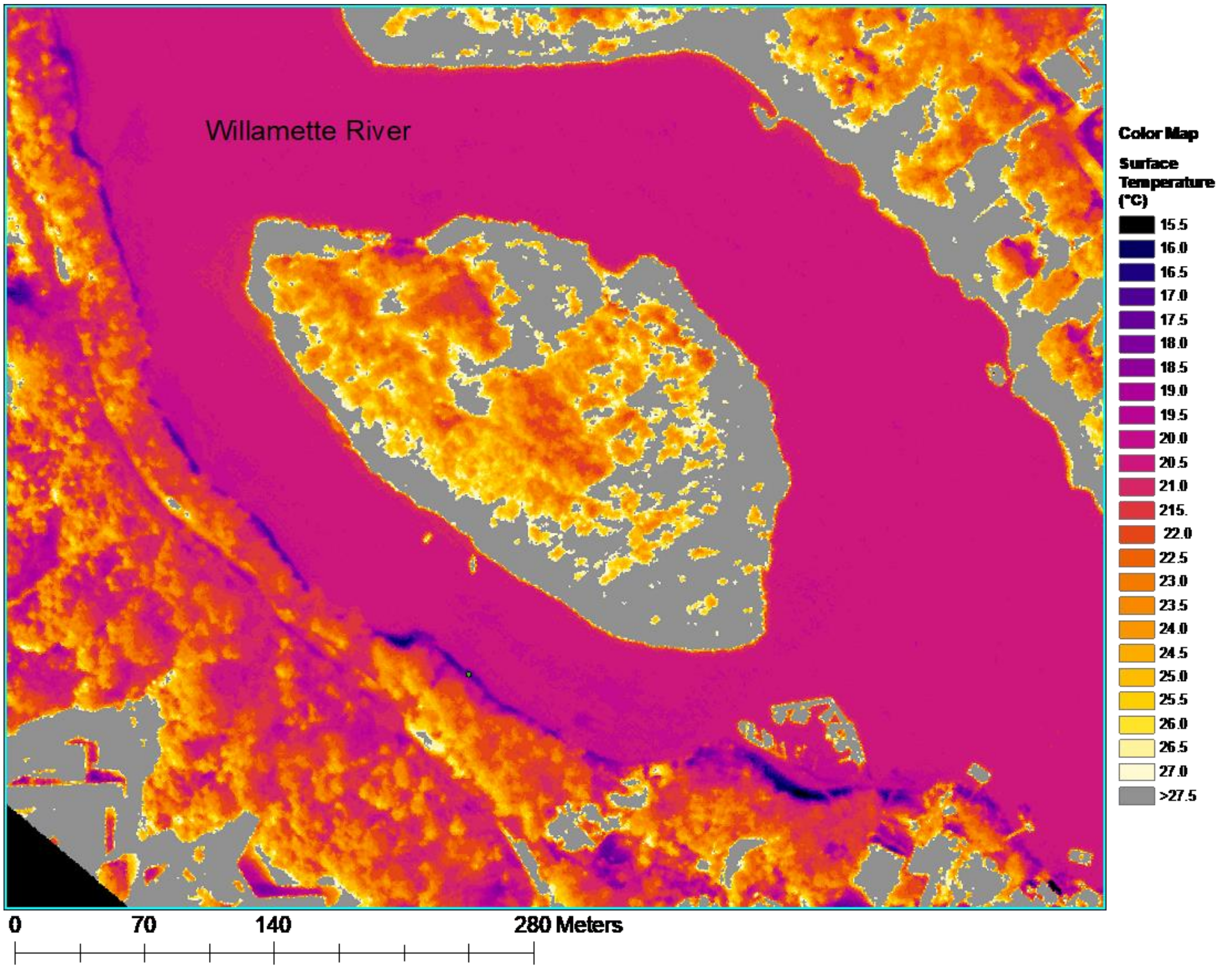
Figure 3-33 Surface temperatures at Ross Island Lagoon, Sept. 2, 2011. Data source: Portland BES



Arbor Creek Seep

The USGS survey detected cold water at a depth of 0.2 meters near Arbor Creek. An apparent ribbon of cool water is evident at the surface near the shore (western bank) in the 2011 FLIR imagery. Nearshore vegetation creating shadows on the water surface can cause artifacts in the FLIR imagery that appear as colder temperatures. Some turbulent patches of slightly cooler water 17-18°C are evident in the main stem between the shoreline seeps and Hog Island. In general the cold patches were <2°C different from the rest of the main stem at the time this image was captured.

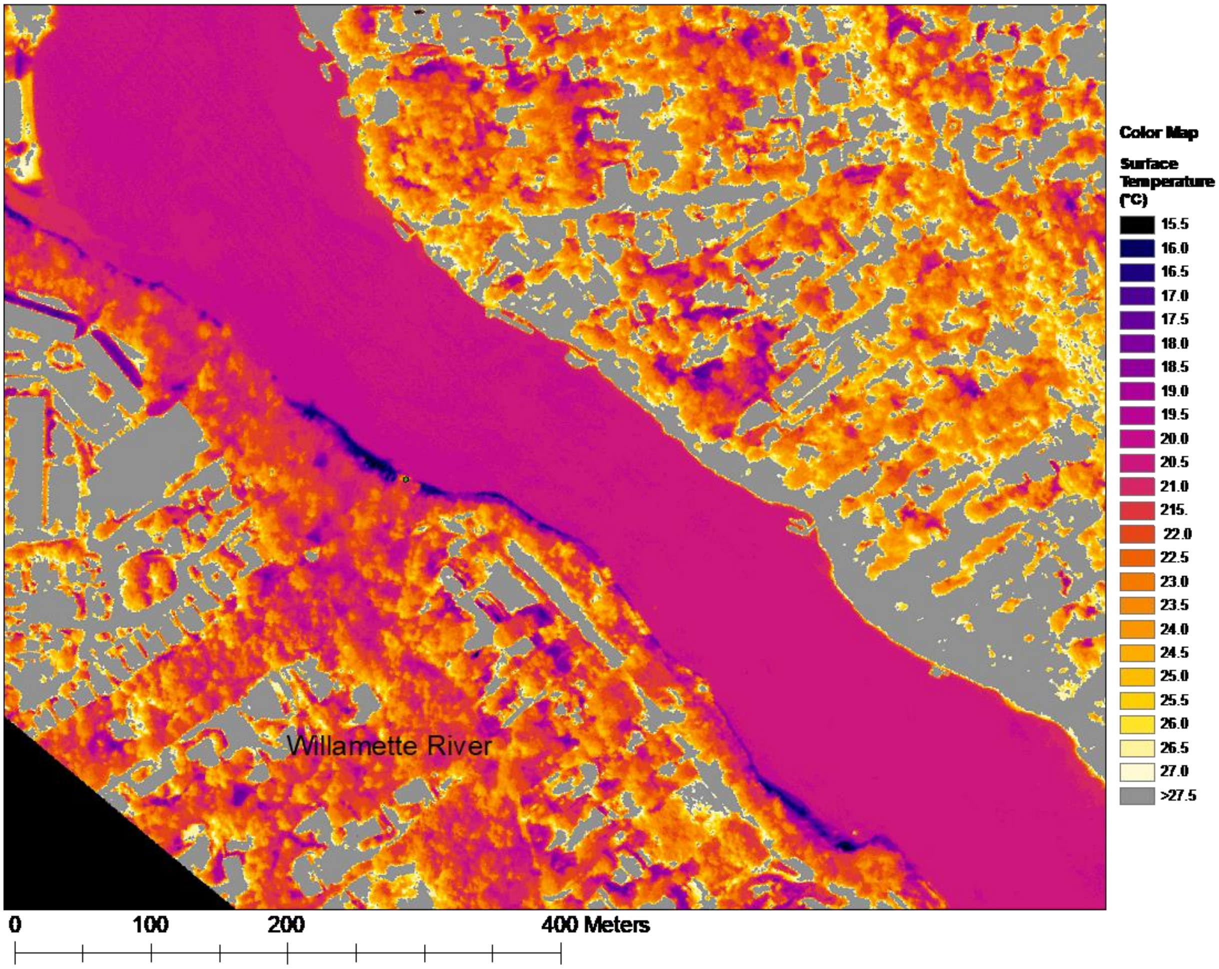
Figure 3-34 Surface temperatures at seep near Arbor Creek, Sept. 2, 2011. Data source: Portland BES



Glenmorrie Drive Seep

An apparent ribbon of cool water is evident near the shore in the 2011 FLIR imagery near Glenmorrie Creek. Nearshore vegetation creating shadows can cause artifacts in the FLIR imagery that appear as cold surface temperatures. Areas of cooler main stem temperatures are evident downstream of the seeps, but are not >2°C cooler than the rest of the main stem at the time this image was taken.

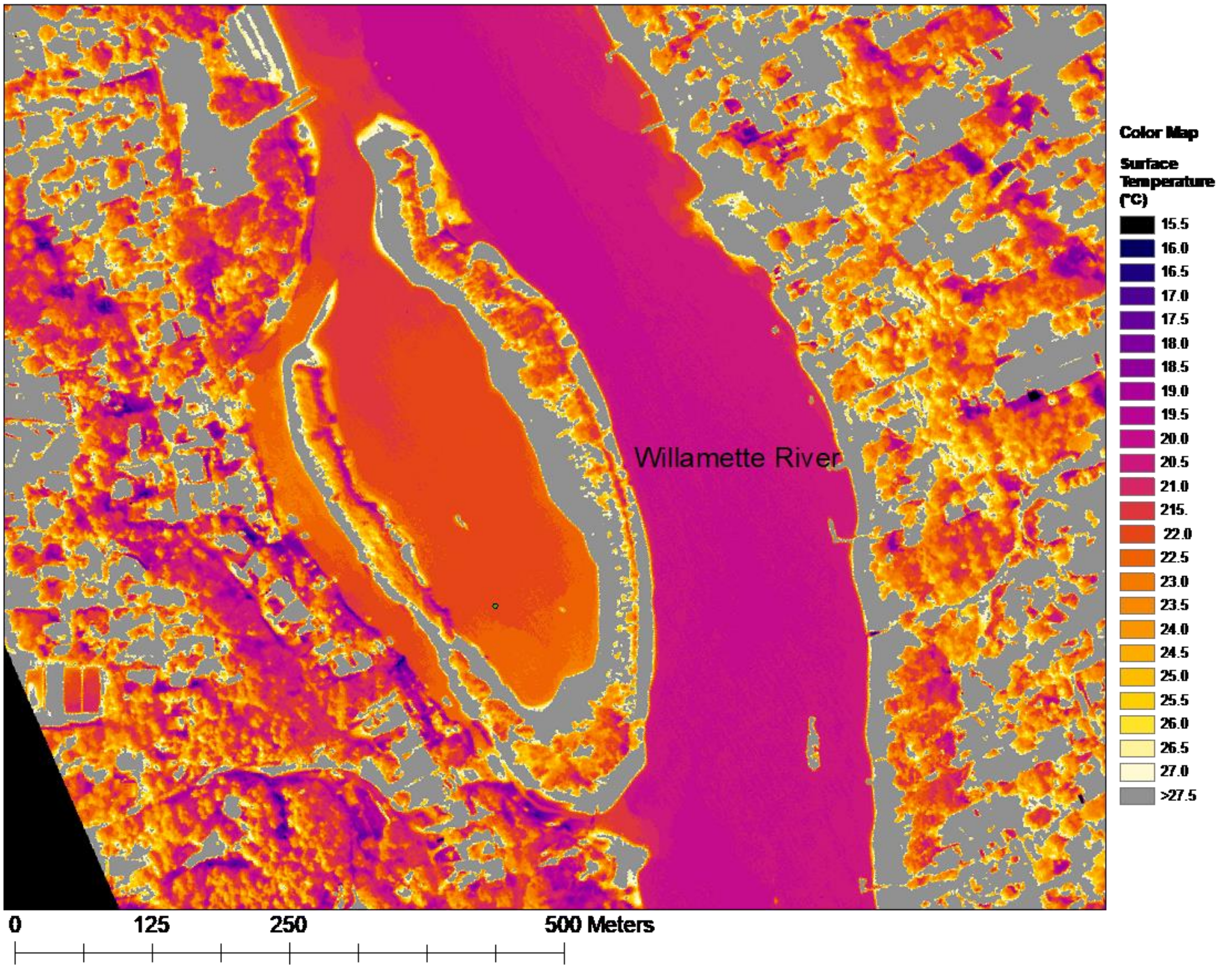
Figure 3-35 Surface temperatures at seep near Glenmorrie Drive, Sept. 2, 2011. Data source: Portland BES



Cedar Island Lagoon

The USGS surveyed cold water at Cedar Island at depths of 3.4-4.7 meters. The cold water detected by the USGS in 2016 is not evident in the 2011 FLIR imagery. The main surface area of the lagoon is warmer than the Willamette main stem. Several narrow bands of cool water are evident on the downstream side of the western arm of the gravel bar that forms the lagoon but do not extend into the lagoon. These bands could be an artifact of shadows from nearshore vegetation rather than cool surface water. There is also a cooler band of main stem temperatures along the eastern shore of the island.

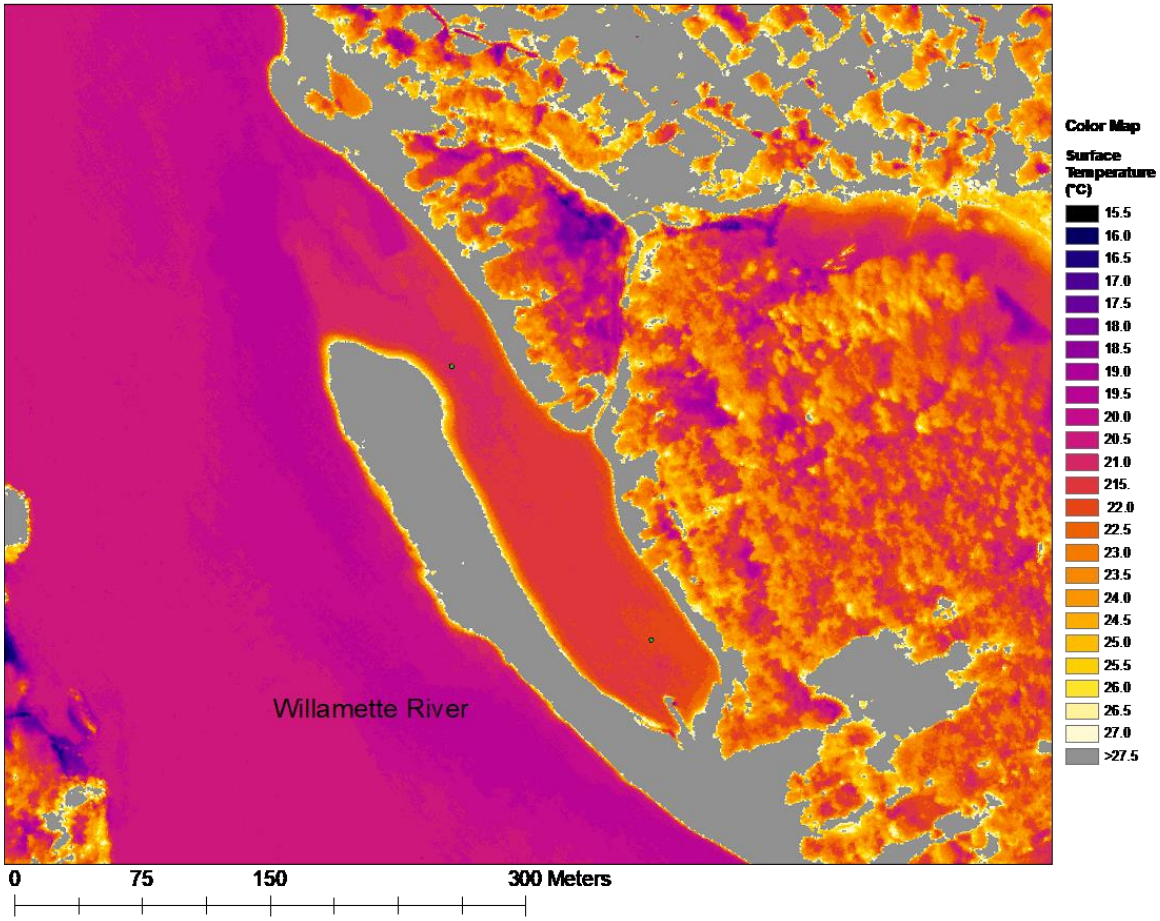
Figure 3-36 Surface temperatures at Cedar Island lagoon, Sept. 2, 2011. Data source: Portland BES



Meldrum Bar

The USGS surveyed cold water at depths from 0.2-3.7 meters for this site in 2016. Cold water at depth behind the gravel bar may not be detectable in the FLIR imagery. The cold water surveyed by the USGS is not evident in the surface temperatures recorded by Portland FLIR imagery from 2011. The cold water plume that extends along the gravel bar in the main channel at left originates from the mouth of the Clackamas River. The water between the gravel bar and the shore in the FLIR image was several degrees warmer than the main stem. Meldrum bar is periodically inundated or exposed by the Willamette main stem depending on water depth.

Figure 3-37 Surface temperatures at Meldrum Bar, Sept. 2, 2011. Data source: Portland BES



3.5 Summary of results identifying geomorphic cold water features

Geology and urban development interact to limit the availability of cold-water refuge created by hydrogeomorphological features within the main stem of the Lower Willamette migration reach (Hulse et al. 2002, Gregory 2008, Jones 2017, Mangano et al. 2018). Main stem channel heterogeneity that would create cold-water refuge appears more complex in the middle and upper reaches of the Willamette main stem (Fernald et al. 2006, Gombert 2018).

The USGS temperature surveys in 2016 and 2017 detected cold water associated with seeps, gravel islands, and bars. Portland BES's FLIR imagery corroborates the existence of cool water at many of these CWR sites for the main stem reach below the falls. However, these features are spatially limited in size and in most cases are in shallow water adjacent to the shoreline.

3.5.1 Inventory of existing lower Willamette CWR suitable for adult salmon and steelhead

Inter-annual variability may mask the long-term suitability of tributaries to serve as cold-water refuge in a given year. For example, the Johnson Creek synoptic sampling in summer 2016 indicates that it did not provide conditions for CWR for the entire summer (Figure 3-16). However, long-term daily average temperatures show Johnson Creek is consistent enough to qualify the tributary as CWR in most summers under current conditions (Figure 3-11). Synoptic temperature sampling at the in-channel morphological features collected in 2010, 2016, and 2017 by the USGS and City of Portland did not always corroborate with surface temperatures observed in the FLIR imagery captured in 2011.

A table of the final tally of cold-water refuges suitable refuges for adult salmon and steelhead identified in each of our data sources is provided at the end of this chapter (see Figure 3-38).

In some cases, data from multiple sources was available to cross-reference the existence of cold-water refuge that fit our identification framework. To date, a greater number of temperature surveys have been conducted in the area below Willamette Falls (RM 0 – 26.7) than in the area from the falls to Newberg (RM 28 – 50.8). In particular, there was not additional data to corroborate the occurrence and size of cold-water refuge at Ryan Creek, and Chehalem Creek with the NorWeST predictions. These creeks have potential to provide areas of tributary refuge in the upper half of the migration corridor.

With the exception of the Clackamas River, the refuge locations identified are of small volume with very limited influence on water temperatures within the main stem of the Willamette River. Their utility as refuge to support migrating populations is likely limited because they are not likely to be easy to detect and may not be able to support large numbers of fish at any given time.

3.5.2 Refuge density and distribution

Cold-water refuges suitable for adult salmon and steelhead are distributed throughout the migration corridor. About a third of currently identified refuge is between the mouth of the Willamette River and Willamette Falls (Figure 3-38). Refuge density is slightly higher and average and maximum distances between refuges are lower in this reach than from Willamette Falls to Newberg. The maximum distance between refuges is 7.9 RM in the downtown Portland area of the mouth-to-Falls reach, and 13.5 RM near the Molalla River in the falls-to-Newberg reach (RM 26.7-50.8).

Table 3-5 Density and distribution of CWR suitable for migrating adult salmon and steelhead in the lower Willamette migration corridor.

	Refuges (n=)	Refuge density (km^{-1}) / (mi^{-1})	Ave distance (km) / (mi)	Max distance (km) / (mi)
Entire Corridor (RM 0 – 50.8)	20	0.23 / 0.39	4.4 / 2.7	21.8 / 13.5
Mouth to Falls (RM 0 – 26.7)	14	0.34 / 0.52	3.2 / 1.9	12.7 / 7.9
Falls to Newberg (RM 26.7-50.8)	6	0.13 / 0.24	5.6 / 3.5	21.8 / 13.5

3.6 CWR identification conclusions

1. NorWeST identifies multiple cold tributaries distributed throughout the Lower Willamette migration corridor.
2. Most cold tributaries identified by NorWeST corroborate with temperature data from synoptic surveys and short-term monitoring projects conducted in summers of 2010, 2011, 2015, 2016, and 2017.
3. Inter-annual variation may result in changes in availability of CWR at these locations in any given year. Sites were not always identified as CWR across each data source or for each year.
4. Available CWR locations are of small volume with the exception of the Clackamas River confluence.
5. Bedrock geology in the lower Willamette between Portland and Oregon City constrains both natural formation and artificial restoration of in-channel CWR features.
6. Main stem Willamette River water temperature is well-mixed and mostly homogeneous.

An inventory of all identified existing cold-water refuges in the lower Willamette migration corridor of sufficient size for adult salmon and steelhead is below in Table 3-6.

Table 3-6 List of identified cold-water refuges suitable for migrating adult salmon and steelhead and sources of supporting data.

X = refuge observed	Supporting Data Sources
O = refuge not indicated	
— = not sampled	

Tributary Name	Type[6]	Class	Main stem River Mile	NorWeST	PDX	USGS	FLIR	Other data
Columbia Slough[7]	CWR	Tributary	1.1	—	X	X	O	X
Miller Creek[7]	CWR	Tributary	2.1	—	—	—	O	X
Doane Seep	CWR	Morphologic	7	—	X	X	X	
Ross Island	CWR	Morphologic	14.9	—	—	—	O	X
Johnson Creek	High Quality CWR	Tributary	18.5	X	X	X	X	O
Kellogg Creek	CWR	Tributary	18.6	X	X	X	X	
Tryon Creek	High Quality CWR	Tributary	20.1	X	X	X	X	
Oswego Creek	CWR	Tributary	21.1	X	O	—	O	
Glenmorrie Seep	CWR	Morphologic	21.2	—	—	X	X	
Arbor Creek	CWR	Morphologic	22	—	—	X	X	X
Cedar Island Lagoon	CWR	Morphologic	23.4	—	—	X	O	
Meldrum Bar	High Quality CWR	Morphologic	24.1	—	—	X	O	
Clackamas River	High Quality CWR	Tributary	24.9	X	X	X	X	
Abernethy Creek	CWR	Tributary	25.4	X	X	X	X	
Coffee Lake Creek	CWR	Tributary	39	X	—	X	—	
Corral Creek	CWR	Tributary	39.8	X	—	X	—	

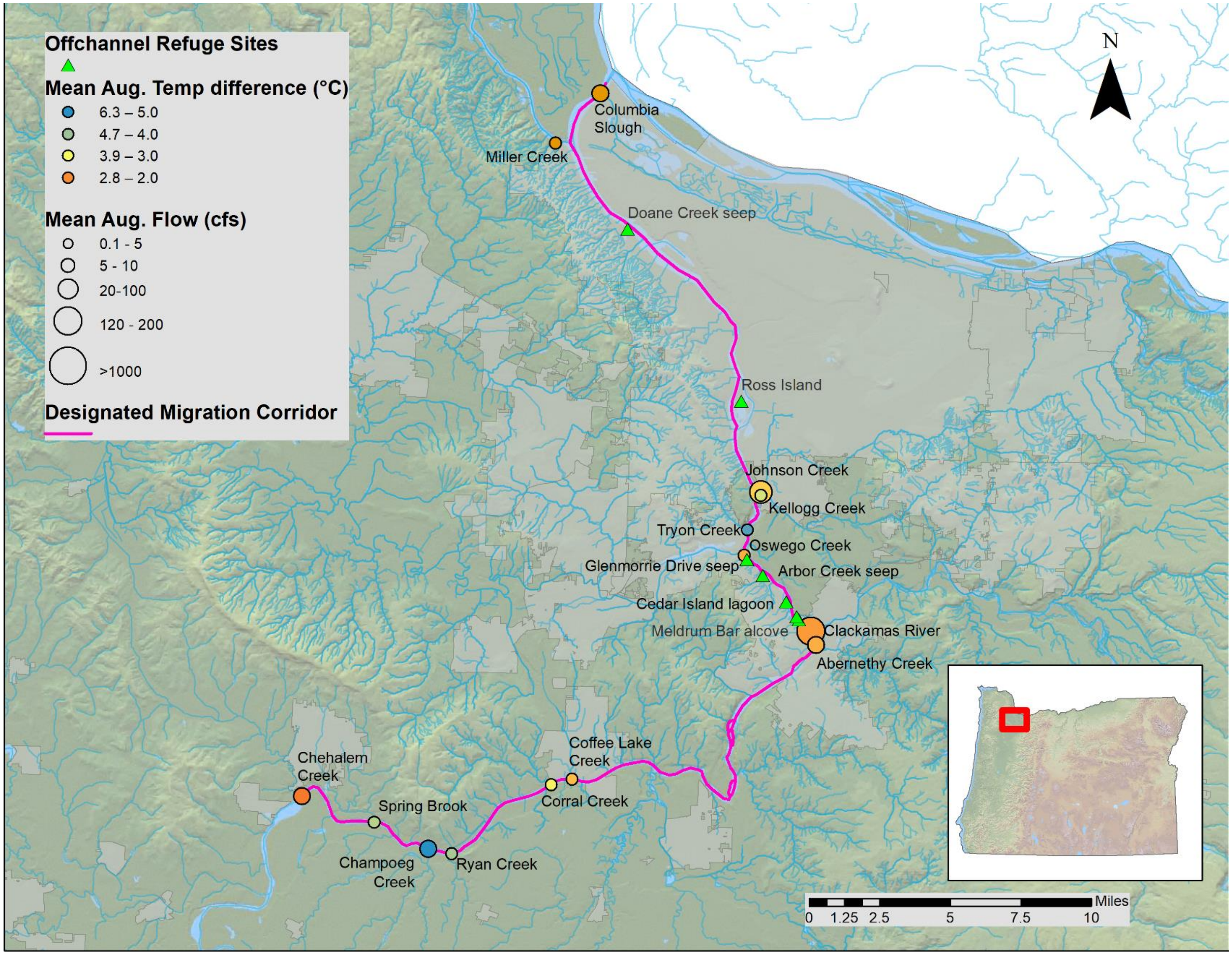
---

[6] See definitions in Section 3.1.2

[7] Added by opinion of expert scientific panel. Corroborating data not cited in this report.

Tributary Name	Type[6]	Class	Main stem River Mile	NorWeST	PDX	USGS	FLIR	Other data
Ryan Creek	High Quality CWR	Tributary	44.2	X	—	—	—	
Champoeg Creek	High Quality CWR	Tributary	45	X	—	—	—	
Spring Brook	High Quality CWR	Tributary		—	—	X	—	
Chehalem Creek	CWR	Tributary	50.8	X	—	—	—	

Figure 3-38Map of cold-water refuge locations suitable for migrating adult salmon and steelhead.



4. Adult salmon and steelhead migration patterns and CWR use

4.1 Chapter outline

4.1.1 Objectives:

1. Characterize the current pattern of Cold-water refuge use by Upper Willamette River Chinook salmon, Lower Columbia River Chinook salmon (Clackamas population), Upper Willamette River steelhead and lower Columbia River steelhead that migrate through the Lower Willamette River between June and September.
2. Identify the Willamette River temperatures that trigger use of CWR.
3. Assemble and synthesize existing studies, reports and data to document thermal exposure and refuge use to the extent possible.
4. Obtain review and input from fish biologists with expertise on these species and the Willamette River populations.

4.1.2 Assumptions and limitations:

1. Analysis limited to existing research, reports, and publicly available data sources.
2. Limited data and observation of Chinook salmon and steelhead use of cold-water refuge in the Lower Willamette migration corridor.
3. Obtain review and input from regional fish biology experts on the sufficiency of refuge for target species and the Willamette River.

4.1.3 Tasks

1. Characterize the migration patterns of the UWR and LCR Chinook salmon and UWR and LCR steelhead populations that migrate through the lower Willamette River (at Willamette Falls Dam RM 20.6) between June and September including:
   A. run timing, and
   B. run size.
2. Compare the migration patterns of each population to Willamette main stem temperature and flow patterns.
3. For each species, quantify overall thermal exposure to temperatures above biological thresholds under different temperature conditions (e.g., hot, cold, median summers), if possible.
4. Evaluate how CWR use is affected by the river temperature, the difference between the main stem temperature and that of the CWR, water depth of the refuge, and depending on availability of data, distance from migration route and/or destination.
5. Describe the evidence of CWR use for each population. Correlate CWR use and migration rate through the Willamette River with main stem temperatures.
6. Identify, by species, what data would help fill knowledge gaps and describe those in Chapter 7.

4.1.4 Definitions

ODFW began reporting daily totals of “clipped” (fish with adipose fins clipped to indicate hatchery bred fish) and “unclipped” (wild-bred) Chinook salmons and steelhead in data from the Willamette Falls fish ladder in 2012. We adopt a combination of fin clip status and run timing following the definition of ODFW and others (Jepson et al. 2015) to differentiate between fish counts that include hatchery, natural spawners of hatchery origin, or native wild upper Willamette River (UWR) populations of Chinook salmon and steelhead for this analysis.

4. "**Unclipped Chinook**" and “**Unclipped steelhead**” means all adult individuals without a clipped adipose fin passing Willamette Falls Dam, (RM 26.7), regardless of migration timing. These represent natural production of both native and introduced genetic stock, or unmarked hatchery origin fish.
5. “**UWR spring Chinook**” means all clipped and unclipped adult individuals passing Willamette Falls dam or North Fork dam between 1 March and 15 August. Corresponds to the naturally spawned spring-run Chinook salmon originating from the Clackamas River, the Willamette River, and its tributaries above Willamette Falls, and hatchery stock bred from native genetic stock. This definition corresponds to the evolutionarily significant unit (ESU) identified in the 2015 biological opinion.
6. “**UWR winter steelhead**” means all unclipped adult steelhead that pass Willamette Falls dam between November 15 and May 15. This represents the naturally propagating winter steelhead population. This definition corresponds to the distinct population segment identified in the 2015 biological opinion.
7. **“LCR fall Chinook”** includes the fall run of Chinook spawning in the Clackamas Basin. This means all clipped and unclipped adult fall Chinook salmon that pass North Fork Dam on the Clackamas River (Clackamas River mile 29.9) regardless of date. Corresponds to the Clackamas River-based distinct population segments of LCR Chinook salmon included in the jeopardy decision in the 2015 biological opinion.
8. **”LCR winter steelhead”** includes all clipped and unclipped adults in the listed population of winter steelhead passing North Fork Dam on the Clackamas River (Clackamas River mile 29.9) between November 15 and May 31 and spawning above North Fork Dam. This includes naturally propagating individuals derived from reintroduced hatchery genetic stock. This definition corresponds to the distinct population segment identified in the 2015 biological opinion.
9. A**TU (accumulated thermal unit) =** A measure of temperature accumulation per unit time. One ATU is equal to the average temperature in °C for 1 day. For example, an average water temperature of 4°C experienced over 24 hours would mean an accumulation of 4 ATU.

4.1.5 Data sources

Data Source	Data Type	Source	Accessed
USGS-NWIS	Continuous temperature data for main stem sites	https://waterdata.usgs.gov/nwis via the dataRetrieval R package.	Nov. 21, 2018
Fish Passage Center	Daily fish passage counts, Willamette Falls Dam	http://www.fpc.org/web/apps/adultsalmon/Q_adultcounts_dataquery.php	May 2, 2018
Oregon Department of Fish and Wildlife	Lower Willamette Fisheries and	https://www.dfw.state.or.us/fish/fish_counts/willamette%20falls.asp	May 4, 2018

Data Source	Data Type	Source	Accessed
	Willamette Falls Fish Counts		
Portland General Electric	North Fork Dam (Clackamas River) daily fish passage counts	https://www.portlandgeneral.com/corporate-responsibility/environmental-stewardship/water-quality-habitat-protection/fish-counts-fish-runs/clackamas-fish-runs	Dec. 6, 2018
Columbia Basin PIT Tag Information System (PTAGIS)	Passive Integrated transponder (PIT) tag data	https://www.ptagis.org/home	Oct. 10, 2018
Published Literature	Historical and contemporary run timing and migration behavior. Fish tag studies, counts, and surveys.	Various journals and reports (see bibliography)	2017-2018
Unpublished data	Fish tag and thermal logger data	Unpublished data sourced directly from primary researchers, as cited.	2017-2018

4.2 Migration patterns of Willamette River Chinook salmon and steelhead

4.2.1 Review of historical runs and run timing

4.2.1.1 Native Chinook salmon

There are no data from direct observation of the migration timing, life-history characteristics, or abundance of historical Willamette River Chinook salmon populations prior to 1940. It is likely that early fishery exploitation (mid-1880s), habitat conversion due to land cover change, channelization in rivers and streams of the lower Willamette Valley (starting in early 1800s), and urban pollution in the lower Willamette River (by early 1900s), altered life-history diversity of native Chinook salmon. Reliable data collection efforts only began in the mid-20th century (Dimick and Merryfield 1945, McElhany et al. 2007a).

Spring Chinook

The current population of native Upper Willamette Chinook salmon is a spring run. This run was historically the largest Chinook salmon run on the Willamette River. Based on observations of spring Chinook salmon runs in the 1940's, the peak migration period for Willamette Falls was April 1 – May 30 (Mattson 1948). Migration could be delayed as late as June 20 in years when spring flows were extremely high (Dimick and Merryfield 1945). In the period before the Willamette Valley Project dams were built spawning occurred in upper basin tributaries from late August through early October, with peak spawning in September (Myers et al. 2006).

Summer Chinook

There are historical accounts of a smaller-sized run of native summer Chinook that passed Willamette Falls in June. Passage in June would have been challenging because of low flows creating a barrier at the falls. Only large fish capable of strong leaps could ascend the falls in summer – similar to the phenomenon of "June hogs" at Celilo Falls in the pre-dam era of the Columbia River (Myers et al. 2006).

The late Willamette River run was apparently wiped out in the 1920s and 1930s due to sudden declines in water quality associated with the period of heaviest dredging activity (Dimick and Merryfield 1945). Dredge fill used to reclaim Swan Island and Guild's Lake reduced the amount of available floodplain habitat downstream of Willamette Falls.

Fall Chinook

The current LCR fall Chinook run spawning in the Clackamas Basin is a native fall run migrating from August – November. A smaller native run of UWR fall Chinook also historically occurred in the lower Willamette Basin in September and October. The fall run did not pass the Willamette Falls and spawned only in the tributaries downstream of Willamette Falls and in the Clackamas basin (Fulton 1968). By the 1930s this run was considered essentially extinct due to pollution and low summertime dissolved oxygen levels from discharges around Portland (Dimick and Merryfield 1945, Myers et al. 2006). A hatchery program to reintroduce fall Chinook using non-native genetic stock ran from 1950 – 1981. A small remnant of late-running Chinook from this hatchery program established reproduction in the upper Willamette River. Reintroduced fall Chinook are able to migrate above Willamette Falls via the fish ladder, where they were not present historically. They are counted at Willamette Falls dam from mid-August to November (Taylor 1999, McElhany et al. 2007b, Keefer and Caudill 2010).

4.2.1.2 Native steelhead

The only historically occurring native run of Upper Willamette River steelhead is the winter run. Before the construction of the first fish ladder at Willamette Falls in the early 1900s, there was not believed to be adequate flow for steelhead to ascend Willamette Falls until winter rains raised the river level in late winter and early spring – roughly October through March (Myers et al. 2006, ODFW and NMFS 2011). This prevented establishment of a native summer steelhead population upstream of Willamette Falls. The winter steelhead run prior to 1940 reportedly passed the falls starting in October. Peak migration over the falls occurred in January and February. Late winter steelhead would not enter the Willamette River until January or February, and wait to ascend to their spawning areas as late as March or April (Dimick and Merryfield 1945, Keefer and Caudill 2010). Construction of a fish ladder at the falls, especially since it was improved in 1971, and increased summer flows from the Willamette Valley Project dams allows winter steelhead migration to extend through to May.

4.2.2 Ecological factors affecting run timing

4.2.2.1 Willamette Falls as a natural migration barrier

One of the most important biogeographic features for the evolution of migration timing and behavior in the native UWR Chinook and UWR steelhead populations was the seasonal migration barrier created by Willamette Falls. Historically, low flows over the falls during the summer months prevented establishment of Coho salmon, summer-run steelhead, or a reliable fall-run Chinook salmon population in the Upper Willamette Basin (Dimick and Merryfield 1945, Schroeder et al. 2007, ODFW and NMFS 2011). The seasonal migration barrier physically and reproductively isolated UWR Chinook and UWR steelhead populations. This isolation produced local behavioral and genetic adaptations resulting in earlier migration timing relative to the Columbia River populations of these species (Myers et al. 2006, Keefer and Caudill 2010, NMFS 2018). Few fish would have been able to migrate past the falls in June because of diminished flows, and only extremely large fish would have been powerful enough to ascend (NMFS 2018).

4.2.2.2 Willamette Falls fish ladder

Fish ladders were installed at Willamette Falls as early as 1872 but were expanded and modernized in 1971. As a result, Chinook salmon and steelhead migration is not currently blocked by low flow levels at the falls. A majority of both hatchery and naturally propagating populations of Chinook salmon and steelhead ascend the falls via the fish ladder throughout the year. The spring/summer migration of these species now extends into June and July. It is not clear if the availability of fish passage via the fish ladder during low flow conditions is reducing localized adaptation in migration behavior in UWR fish populations by removing the historical block to passage in the summer months (NMFS 2018). Downstream of the dams, the Willamette Valley Project has moderated flows, decreasing the frequency and intensity of both very high and very low flow events (Hughes and Gammon 1987). Summer flows in the main stem of the Willamette River are generally cooler and higher than before the Willamette Valley Project dams were constructed (Rounds 2007).

4.2.2.3 Temperature cues and behavioral strategies

Salmon and steelhead respond to both high and low water temperatures during migration. The start of migration for UWR Chinook appears to cue off of the annual rise in water temperatures above 10°C (Mattson 1948, Howell et al. 1985, Nicholas 1995 as cited in NMFS et al. 2018). Changes to timing in the warming of water temperatures may result in delayed start of migration, slower upstream adult migration rate, and delayed onset of spawning in the tributaries. These changes can result from annual weather variability or releases from Willamette Valley Project dams that are cooler than the main stem in spring and summer (Rounds 2007, Keefer and Caudill 2010). Changes to timing in cooling of water temperatures from weather variability or anthropogenic warming may increase pre-spawn mortality in holding tributaries when they affect temperatures in autumn, or lead to earlier emergence and out migration of juveniles when they affect temperatures in the spring. Climate change, anthropogenic warming, or releases from Willamette Valley Project dams in autumn or winter can result in unusual timing of warm water temperatures in the main stem (Rounds 2007) and (Myers et al. 2006, Schroeder et al. 2007) *cited in* (Keefer and Caudill 2010).

Slowed migration rate (delay) in response to rising water temperatures is a behavioral indicator of cold-water refuge use. Maintained or increased migration rates as water temperatures warm is a behavioral indicator that holding in refuge does not occur. Studies for the Upper Willamette basin observed that tracked Chinook salmon maintain their migration rate (i.e., speed) in the main stem even when exposed to temperatures up to 24°C (Keefer et al. 2014). This matches observations of Fraser River Sockeye and Chinook salmon in British Columbia (Donaldson et al. 2009, Hasler et al. 2012), and Bull trout in the Lostine River of Oregon (Howell et al. 2010) that were also observed to increase migration rates in response to higher water temperatures. Meanwhile, slowed migration rate and delay in CWR during high temperatures is well documented in fall Chinook and all steelhead populations in the Columbia River, indicating these populations hold in CWR to one degree or another (Goniea et al. 2006, USACE 2013, Keefer et al. 2018).

These studies suggest alternate migration strategies among populations in response to high water temperatures. The strategy to move and not delay by holding in CWR, even in the presence of stressfully high water temperatures, with the goal of reaching relief in cooler waters upstream. This strategy is effective when unfavorable thermal conditions will worsen in the near term, such as in spring turning to summer. The strategy to delay and hold in CWR, has the goal of waiting for main stem conditions to improve. This strategy is effective when unfavorable conditions are likely to improve in the near term, such as cooling temperatures from summer to fall. Specific data is needed to determine whether lack of observed CWR use indicates a behavioral adaptation in the specific population not to use CWR or rather a structural lack of CWR that would be used if available (Baigún 2003).

4.2.2.4 Genetics

There is a strong genetic component to migration run timing in UWR Chinook salmon and UWR steelhead. UWR Chinook salmon are genetically distinct from other Chinook salmon populations in the

Pacific Northwest. It is generally recognized that UWR Chinook from native genetic stocks return to spawn earlier in the year than interior Columbia River populations or hatchery-bred salmon derived from Columbia River genetic stocks (e.g., Cramer et al. 1996; NMFS 2008 *cited in* Keefer and Caudill 2010). Genetic differentiation caused by geographic and migration behavioral isolation in UWR Chinook salmon is thought to have emerged due to selective pressure against late-running individuals caused by the seasonal migration blockage at Willamette Falls (Waples et al. 2004). Only late winter and early spring passage during higher, but not flood-level, flows allowed passage over the falls before the installation of the fish ladder (Myers et al. 2006, McElhany et al. 2007a, Keefer and Caudill 2010).

The unique winter migration behavior of UWR winter steelhead is also thought to be the result of a genetic isolating mechanism of selection due to the seasonal migration barrier at Willamette Falls (Myers et al. 2006). Like UWR spring Chinook, UWR winter steelhead are also genetically and phenotypically distinct from other lower Columbia River, interior or coastal steelhead populations (e.g. Resienbichler et al. 1992 and NMFS 1996, *cited in* Keefer and Caudill 2010). Compared to other Lower Columbia River populations of steelhead, the native run of UWR steelhead occurs later in the winter season. This population passes Willamette Falls from February through May, with the peak of migration in February or March. This contrasts with steelhead introduced to the Willamette from Columbia River genetic stocks through hatchery programs. Introduced winter steelhead pass the Willamette Falls earlier than the natives, starting in November, and continuing at low levels until late January. This unique late winter migration behavior of UWR steelhead is thought to reflect selective pressure to delay passage over Willamette Falls until flows increased from winter rains (Korn 1961, Howell et al. 1985, Firman et al. 2004 and 2005, *cited in* Keefer and Caudill 2010).

4.3 Fish passage counts

4.3.1 Notes and assumptions on fish passage data

The Oregon Dept. of Fish and Wildlife and the Fish Passage Center maintain publicly available databases of fish counts at the Willamette Falls fish ladder (RM 26.7). These data quantifies salmon and steelhead migration timing and abundance in the Lower Willamette migration corridor. This data assumes that salmon and steelhead counted passing Willamette Falls represent individuals migrating to spawning habitat farther upstream in the Willamette basin. These counts include both hatchery and naturally propagating populations of Chinook salmon and steelhead. Lower Columbia River populations of Chinook and steelhead that spawn in tributaries below The Falls should not be included in these counts, although counting of some strays is possible.

4.3.1.1 Oregon Department of Fish and Wildlife data

ODFW maintains annual passage totals for adult, jack, and minijack Chinook, adult steelhead, and Coho salmon divided into seasonal run groups counted at Willamette Falls since 1946. Daily passage counts of adult, jack, and minijack Chinook, adult steelhead, and adult Coho salmon are available from 2004-present. ODFW did not begin differentiating “clipped” hatchery-origin Chinook salmon (fish with adipose fin-clips) from “unclipped” wild spawning Chinook salmon in their data products for Willamette Falls until 2007.

ODFW divides the fish counts into winter, spring, fall, and summer seasonal run groups as applicable according to date ranges based on long-term averages of run timing. Where ODFW separates counts into fin-clipped or unclipped individuals, it is possible to infer estimates of hatchery-derived versus wild propagating or native populations. ODFW has also produced run timing tables for each run group that provides the range of dates when these populations use habitat in main stem and tributary locations throughout the Willamette Basin (see Figure 4-5).

4.3.1.2 Fish Passage Center Data

Daily counts of adult, jack, and minijack Chinook, adult steelhead, and Coho salmon are available from 2000-2017 for the Willamette Falls fish ladder. The fish passage center provides data as daily counts of adult, jack, and mini Chinook, adult steelhead, and Coho salmon by run. Their data reports do not differentiate between counts of hatchery (clipped) and wild or native (unclipped) salmon and steelhead.

4.3.1.3 Portland General Electric Data

Portland General Electric operates a fish trap and fish ladder as part of wildlife and habitat conservation activity at the North Fork Dam hydroelectric project (Clackamas River RM 29.9). Annual passage count totals are available from 1985-2017. Daily fish count data is only available from 2014-2017. The counts track clipped (hatchery) and unclipped (wild) spring and fall Chinook salmon, Coho salmon, summer steelhead, and both un-clipped and clipped winter steelhead. North Fork Dam is approximately 30 river miles from the main stem Willamette. Therefore, UWR spring Chinook, LCR fall Chinook, and LCR steelhead passage counts at the North Fork Dam are time lagged. Temperatures recorded in the Willamette River at Portland at the time passage occurs at North Fork do not reflect the timing, abundance, and thermal exposure of these populations while they were in lower Willamette River migration corridor.

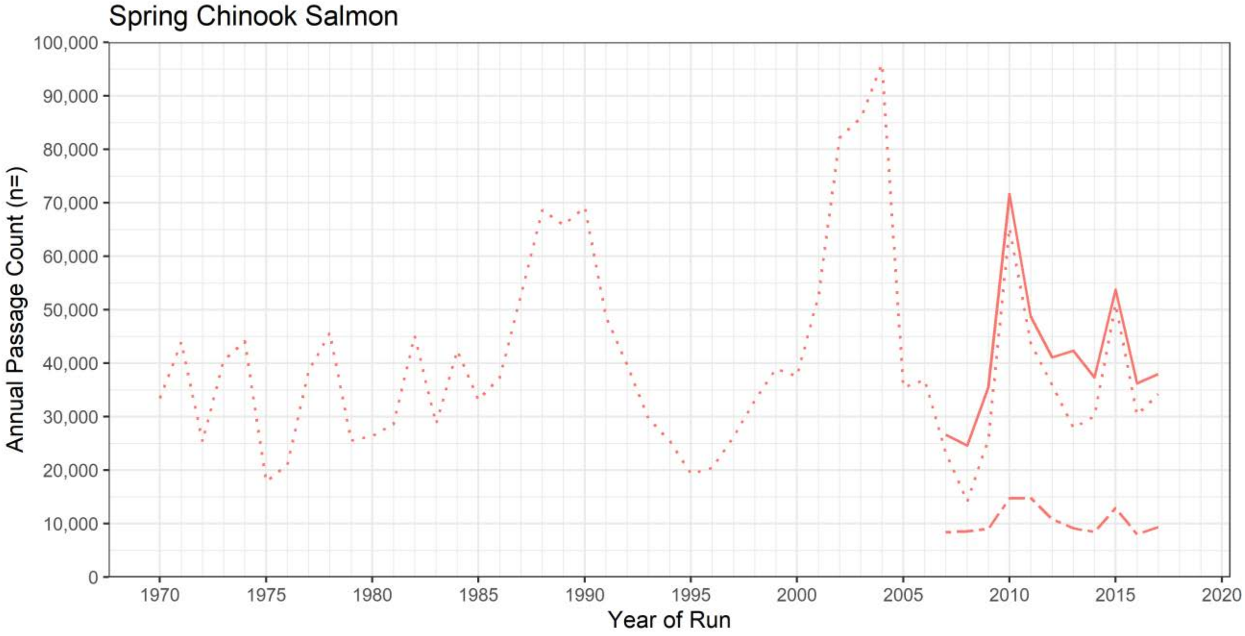
4.3.2 Returns and run sizes

Environmental factors in the ocean that affect productivity, including ocean temperatures and upwelling, demographic factors such as survival of the natal population of returning adults, and the abundance and spawning success of the parent generation, affect the number of returns in a given year (Keefer et al. 2008b, Anderson and Beer 2009). Poor ocean conditions have been especially implicated in contributing to recent declines in winter steelhead returns for 2014-2017 (Peterson et al. 2017). Multiple factors interact to determine the size of runs and it is difficult to attribute specific causes to changes in run size in a given year.

4.3.2.1 Upper Willamette River Spring Chinook

Annual run size of spring Chinook has been measured at Willamette Falls since 1946. ODFW has parsed the runs by origin using fin-clip status since 2007. In recent years, hatchery-bred (‘clipped’) Chinook salmon have made up the majority of individuals in the spring Chinook run at Willamette Falls (Figure 4-1).

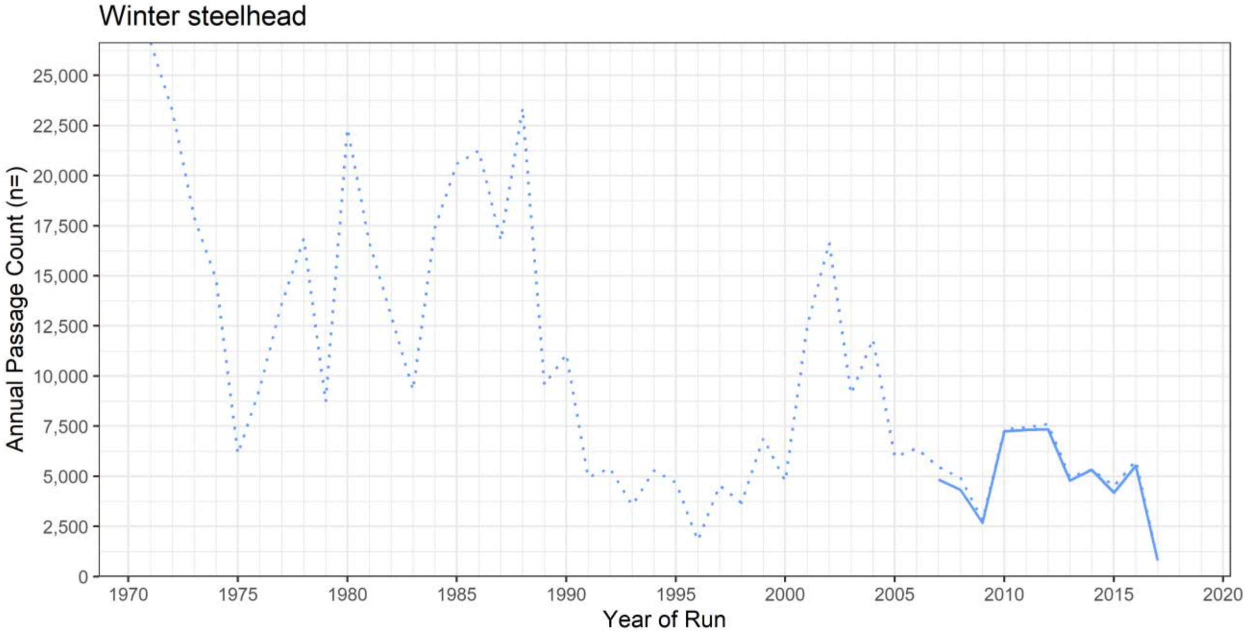
Figure 4-1 Annual run totals for spring Chinook salmon at Willamette Falls Dam (RM 6.7). Dotted line shows total of clipped + unclipped spring Chinook. The solid and dashed lines show clipped and unclipped spring Chinook, respectively, since 2007. Data source: ODFW.



4.3.2.2 Upper Willamette River Winter steelhead

ODFW began counting annual run size of winter steelhead at Willamette Falls in 1971. Parsing of the run counts by origin using fin-clip status began in 2007 (Figure 4-2). The stocking program of hatchery winter steelhead ceased in 1999. Winter steelhead returns have declined in the last 20 years. However, returns are now almost entirely ‘unclipped’ wild fish from natural production.

Figure 4-2 Historic annual run size of winter steelhead at Willamette Falls dam (RM 26.7) line shows all clipped + unclipped migrating steelhead, solid line shows only unclipped UWR winter steelhead since 2007. Data source: ODFW



4.3.2.3 Lower Columbia River Winter steelhead

Annual counts of winter steelhead passage at North Fork Dam on the Clackamas River began in 1984. PGE began parsing the data according to origin using fin-clip status for winter steelhead starting in 1997 (Figure 4-3).

Two principle populations of winter steelhead make up the run in the Clackamas River. The early portion of the run primarily represents ‘clipped’ hatchery-bred steelhead from the U.S. Fish and Wildlife Service’s Eagle Creek Fish Hatchery. Early run fish are present in the Willamette River. The later portion of the run primarily represents ‘unclipped’ steelhead from natural propagation. Late run individuals tend to be slightly larger than the early run fish. Late-run fish begin to enter the Willamette River in January, with peak use of the Willamette River expected by ODFW in March (Figure 4-5). Data on migration timing and abundance are not available for this run until they reach North Fork Dam. Peak passage at North Fork Dam is primarily in April and May, after they leave the Willamette (Figure 4-8). LCR steelhead spawn upriver of North Fork Dam from late March to mid-June. PGE supports a wild brood stock program for LCR steelhead.

Figure 4-3 Historic totals of annual LCR steelhead counts at North Fork Dam (Clackamas River mile 29.9). Blue bars shows total numbers of unmarked (naturally propagating) steelhead. Green bars show total numbers of hatchery steelhead. Numbers at top show totals for both unmarked and hatchery steelhead. Data source: PGE.

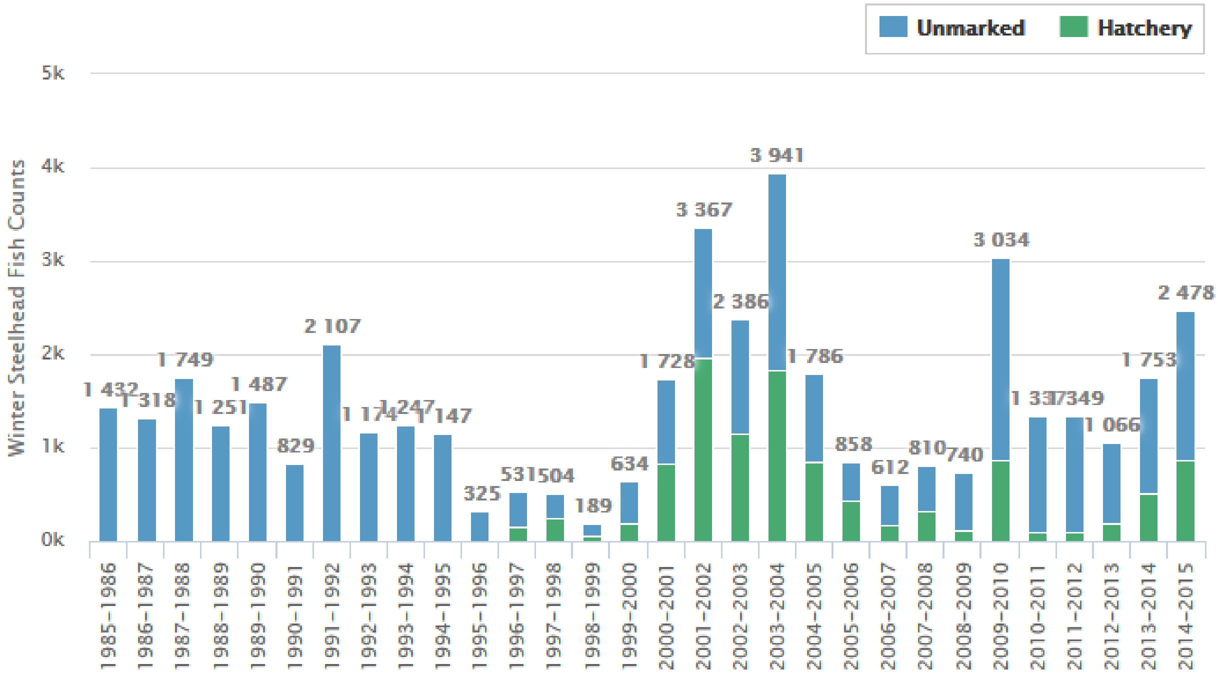
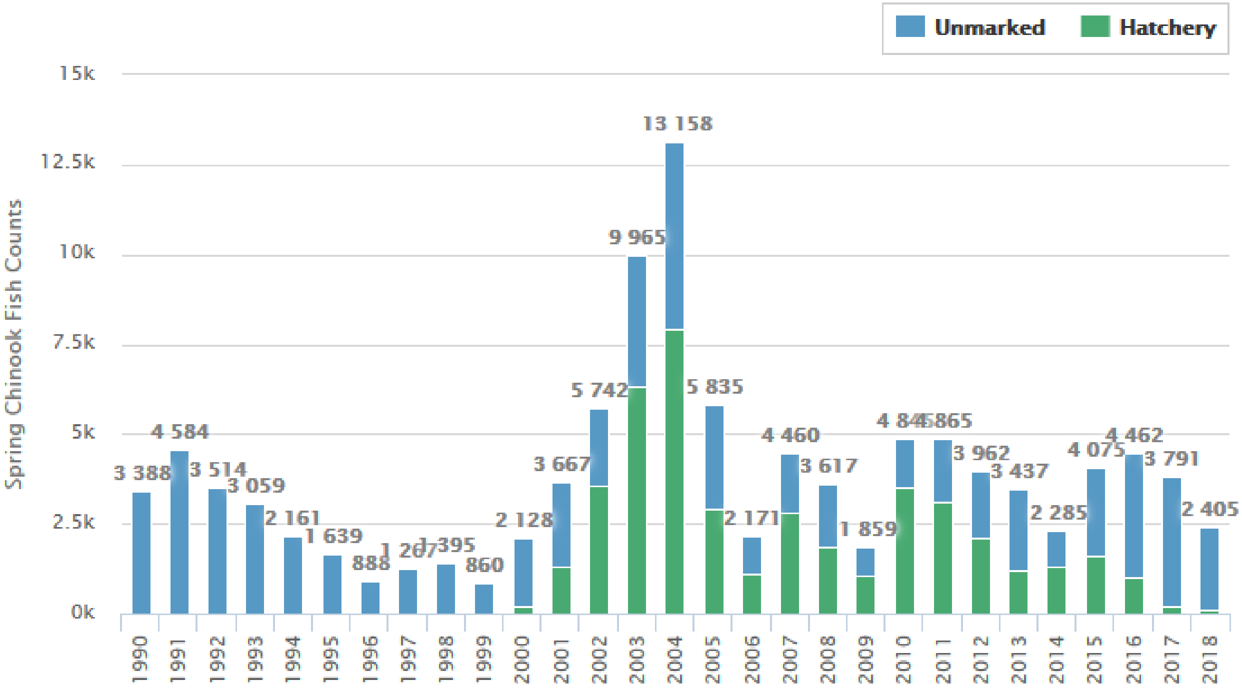


Figure 4-4 Historic totals of annual UWR spring and LCR fall Chinook counts at North Fork Dam (Clackamas river mile 29.9). Blue bars shows total numbers of unmarked (naturally propagating) steelhead. Green bars show total numbers of hatchery steelhead. Numbers at top show totals for both unmarked and hatchery steelhead. Data source: PGE.



4.3.3 Recent migration timing, 2007-2017

DEQ compiled a ten-year average of daily fish passage counts for unclipped adult Chinook salmon and steelhead passing through the Willamette Falls fish ladder from data provided by ODFW. The fish counts show the relative size and timing of the spring, summer, and fall Chinook salmon runs, and the winter steelhead run. Only small numbers of straying individuals of the Lower Columbia River populations would count in the fish passage totals at the Willamette Falls dam. Most LCR steelhead should migrate as far as the mouth of the Clackamas River on their way to spawning grounds in that basin. ODFW does not have counts or run timing information to account for any LCR Chinook salmon that migrate to tributaries downstream of Willamette Falls and the Clackamas River.

Figure 4-5 Migration timing for native adult Upper Willamette River and Lower Columbia River Chinook salmon and steelhead in the lower Willamette migration corridor. Data source: ODFW. Accessed Oct. 16, 2018.

Life Stage/Activity/Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upstream Adult Migration- Mouth to Falls (RM 0 – 26.7)												
UWR winter steelhead	▨■	■	■	■	▨	▨					▨	▨
UWR spring Chinook salmon	▨	▨	▨■	■	■	▨						
LCR winter steelhead (Clackamas R.)	▨■	■	■	■	▨	▨					▨	▨
LCR fall Chinook (Clackamas R.)	░	░	░	░	░	░	░	▨	▨	■	■▨	
Upstream Adult Migration- Falls to Newberg (RM 27 – 50.8)												
UWR winter steelhead	■	■	■	■	▨						▨	■
UWR spring Chinook salmon	▨	▨	▨■	■	■	■	▨	▨				
Upstream Adult Migration - Newberg to Yamhill (RM 50.8 - 55)												
UWR winter steelhead	■	■	■	■	▨						▨	■
UWR spring Chinook salmon	▨	▨	▨■	■	■	■	▨	▨				

■ Represents periods of peak use (>90%) based on professional opinion.

▨ Represents lesser level of use (<10%) based on professional opinion.

░ Represents periods of presence, either with no level of use OR uniformly distributed level of use indicated.

Based on professional opinion, 90% of the life-stage activity occurs during the time frame shown as the peak use period.

Based on professional opinion, 10% of the life-stage activity occurs during the time frame shown as the lesser use period.

4.3.3.1 Upper Willamette River Spring Chinook

Upper Willamette River Chinook salmon are currently present in the Lower Willamette migration corridor from mid-January to the end of August (Figure 4-5). The peak of the spring run passes Willamette Falls from mid-March or April through May (ODFW 2013). The late portion of the spring run overlaps with the beginning of the fall run of introduced Chinook salmon populations (Myers et al. 2006, Schroeder et al. 2007). The proportion of unclipped Chinook salmon that represent native UWR genetic stock in a given year's run can be as low as 10% and as high as 90% and varies partially according to the spawning basin of origin (Schroeder et al. 2007). Present-day spring runs mainly pass The Falls via the fish ladder.

There are naturally propagating runs of fall Chinook salmon and summer steelhead that use the Lower

Willamette migration corridor. These runs are not federally listed and were either derived from introduced Columbia river stock, reintroduced Willamette basin hatchery stock, or native stocks that were historically limited to tributaries downstream of Willamette Falls (Fulton 1968, NMFS 2008) *cited in* (Keefer and Caudill 2010). These runs will not be included in our analysis to the extent that they do not overlap with the native UWR Chinook salmon and steelhead runs.

Fish passage data for adult UWR spring Chinook salmon show that, on average, passage at the Willamette Falls dam starts as early as March, though often in very small numbers. The majority of passage for the spring run occurs from April to June (Figure 4-6). There is a nadir in fish passage marking the transition from the spring run to the summer and fall runs in mid-June. A gradual decline in daily counts follows until mid-July where small numbers and sole individuals continue to pass the falls before a smaller fall run upticks counts in late September and ends by November. Fish passage counts decline during or before times of year when the main stem river temperature exceeds the 20°C criterion (Figure 4-6, grey box). Multiple populations and runs of Chinook salmon overlap, but the number of individuals passing the falls is low during the summer months (Figure 4-7).

4.3.3.2 Upper Willamette River steelhead

Columbia Basin winter steelhead return from the ocean to freshwater from October through April. The Willamette winter steelhead run is expected to occur from January to mid-May (ODFW 2013). Steelhead spawning occurs from March through June with peak spawning in late April and early May. (ODFW and NMFS 2011). While both summer- and winter-runs of UWR steelhead currently exist, only the winter run represents native steelhead (Myers et al. 2006).

UWR steelhead passage past Willamette Falls occurs in two groups. The first group derived from reintroduced stock from the Big Creek hatchery is now naturally propagating and begins passage in November and continues at low levels until late January. The native UWR steelhead run passes the falls from February through May, with a peak in February or March (Myers et al. 2006).

Upper Willamette River winter steelhead are present in the Lower Willamette migration corridor from mid-November to the end of June, with 90% of the run (peak use) occurring from mid-January to the end of April (Figure 4-5). The winter run count begins with small numbers of individuals passing the falls from November through January. Peak counts occur in February to March (Figure 4-6 and Figure 4-7). Sixty to eighty adult steelhead per day pass through the fish ladder in February. May is the cutoff date for counting the winter run.

Steelhead are counted passing the falls singly or in small numbers almost year-round. Any summer steelhead counted after May are thought to represents an introduced population of hatchery steelhead derived from Columbia River genetic stock that now propagate naturally. Summer steelhead in the Willamette River are not considered a native stock that could persist without the presence of the fish ladder (Myers et al. 2006). Summer steelhead run passes through the lower Willamette from March through late October, with the bulk of the run passing from mid-April to mid-July (ODFW fish counts and (Keefer and Caudill 2010)).

The reduction in daily passage counts of UWR Chinook salmon and UWR steelhead during time periods when maximum temperatures in the Lower Willamette migration corridor exceeds 20°C could be due to two different processes:

1) run timing is adapted to avoid the warm period- spring migrants have already moved upstream and/or fall migrants have not yet entered the lower Willamette migration corridor.
2) fish cease migrating during the warm period and delay by holding in CWR within the corridor.

Figure 4-6 10-year average of daily average fish counts of UWR Chinook salmon and UWR steelhead at Willamette Falls dam. Grey bars show standard error of the average. The grey rectangle with dashed border shows the date range when the 7-day average of daily mean temperatures exceed 20°C at the USGS gage at Portland. Data sources: ODFW and USGS.

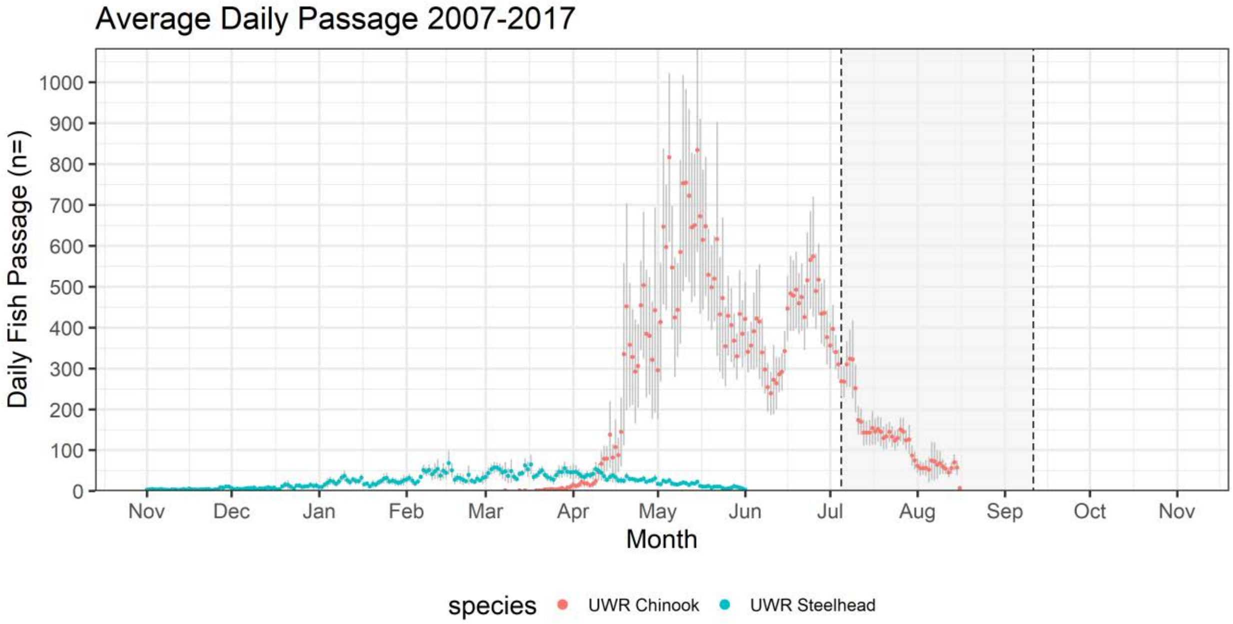
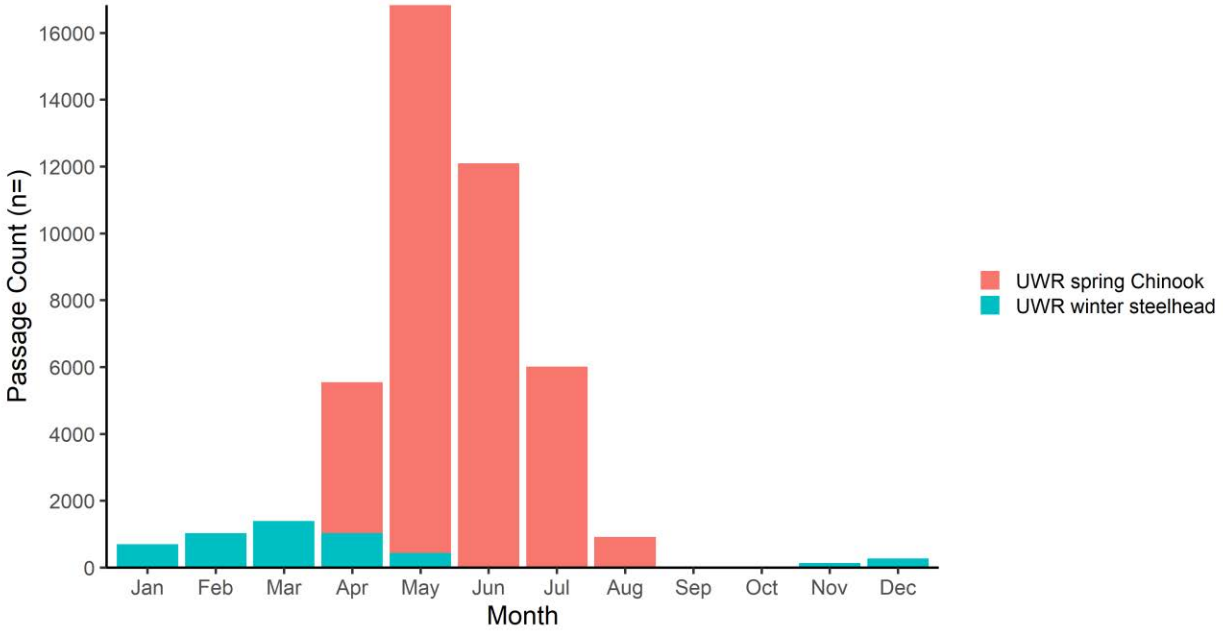


Figure 4-7 Monthly sum of UWR Chinook salmon and UWR steelhead fish passage, from average daily counts for 2007-2017. Data source: ODFW.



4.3.3.1 Lower Columbia River Chinook

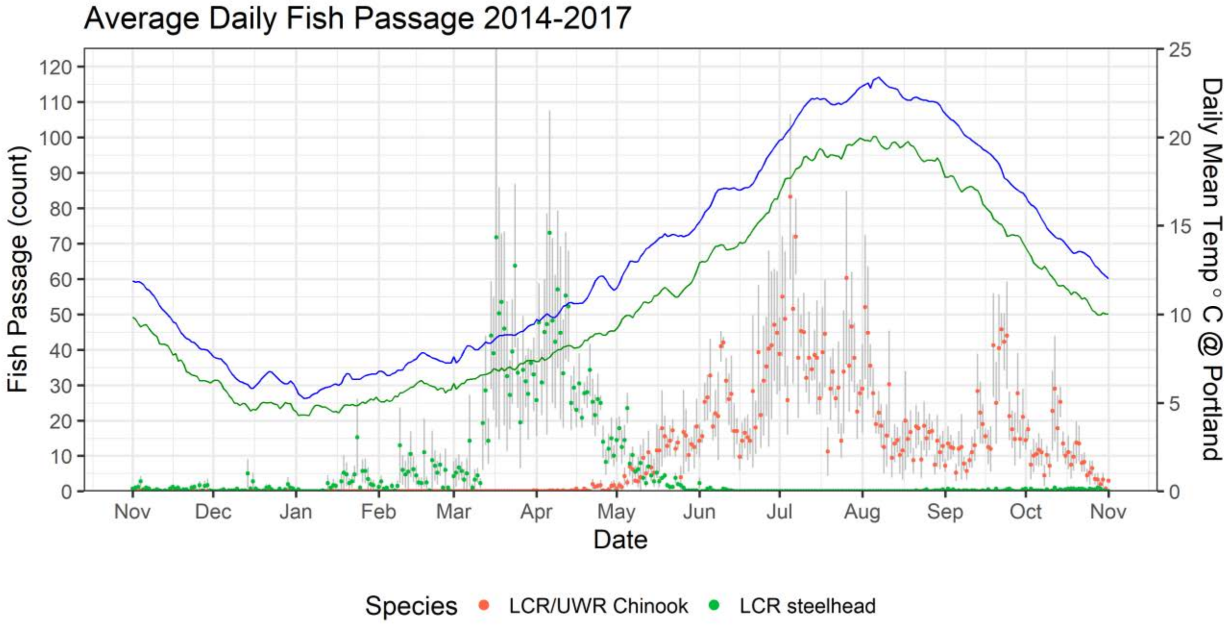
DEQ was not able to identify any run timing information (ODFW) or fish count information for Willamette Falls (RM 26.7) or North Fork dam (RM 29.9 on the Clackamas River) (ODFW, PGE) that could be used to quantify fish passage timing, thermal exposure, or run size of LCR Chinook salmon resident in tributaries of the Willamette River below the falls. Both adult and juvenile Chinook salmon of uncertain origin have been observed in lower Willamette tributaries Johnson Creek, Miller Creek, Stephens Creek, and Tryon Creek in low numbers at various times of year (Tinus et al. 2003a, Silver et al. 2017b). Whether these were resident to these tributaries or migrating individuals from other populations of UWR or LCR Chinook salmon is not possible to determine from currently existing data.

4.3.3.2 Lower Columbia River steelhead

Lower Columbia River winter steelhead are part of the Columbia River domain and use the Willamette migration corridor from RM 0 to an area just below the Willamette Falls (RM 26.7) to reach their spawning grounds in the Clackamas River basin. The current runs of winter steelhead include a high proportion of non-native steelhead derived from Skamania stock hatchery fish and introduced in the 1970s (Keefer and Caudill 2010). Peak migration of LCR steelhead from the Clackamas River population is complete by April or June (NMFS 2015).

Current data for Lower Columbia River winter steelhead shows passage at the North Fork fish ladder (Clackamas river mile 29.9) between mid-January and June (Figure 4-8). ODFW run tables show LCR winter steelhead presence in the segment of the lower Willamette from the Confluence with the Columbia River (RM 0) to Willamette Falls (RM 26.7) to be the same as for UWR winter steelhead (Figure 4-5). We may assume that run timing in this segment of the migration corridor is similar to UWR steelhead. Since the LCR winter steelhead run is complete at the North Fork Dam prior to the onset of main stem temperatures greater than 20°C, it is not possible for this run to encounter these temperatures when they would be transiting the lower Willamette reach from the Columbia to Willamette Falls.

Figure 4-8 Long-term average of UWR/LCR Chinook and steelhead passage timing at North Fork Dam, Clackamas River (RM 29.9), 2014-2017. Grey bars show standard error of the mean. Blue line shows daily mean water temperature at USGS gage Portland, green line shows daily mean water temperature at USGS gage Clackamas. Grey rectangle shows average period when the Willamette main stem at Portland exceeds 20°C. Data source: PGE[8], USGS.



4.3.4 Interannual run timing variability

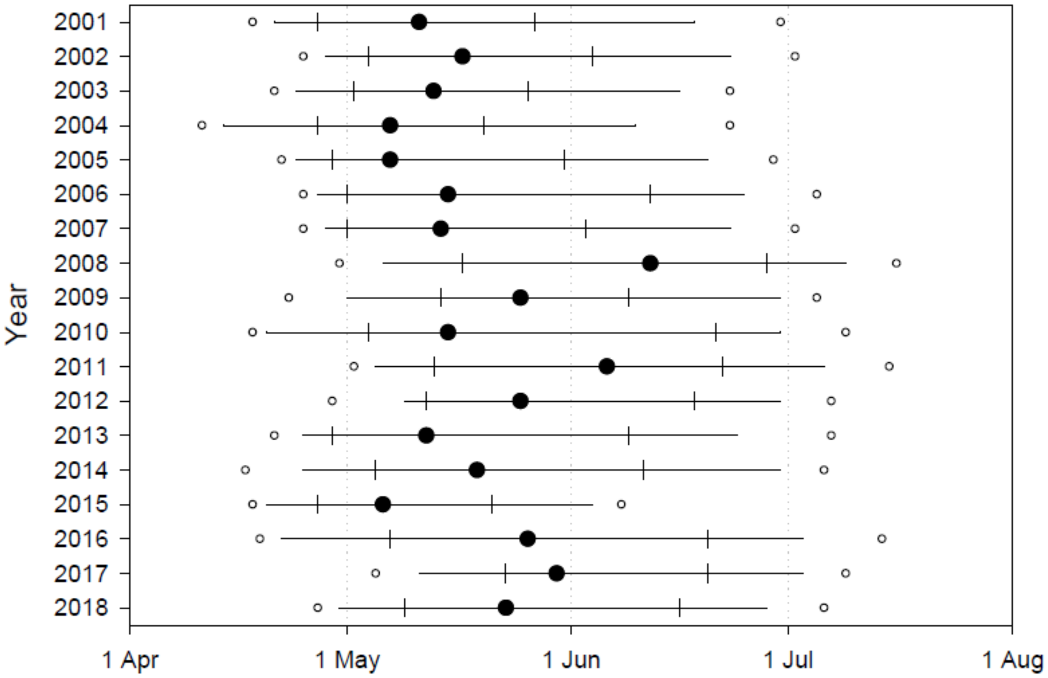
4.3.4.1 Upper Willamette River Chinook

Typical start and end dates for yearly migration of UWR spring Chinook salmon (clipped and unclipped individuals) are generally within the second week of April to the first or second week of July. However, the use of set start and end dates to define the spring run may reduce the possible variability around these dates. Median run timing, when half the number of fish in the annual run passed Willamette Falls, varies by as much as five or six weeks from year to year between 2001 and 2014 (Figure 4-9). The unusually warm year of 2015 showed markedly early and compressed migration timing in UWR spring Chinook. This is consistent with expectations that Chinook salmon start and speed up migration to cues of early warming, warmer daily river temperatures, and low flows (Jepson et al. 2015).

---

[8] https://www.portlandgeneral.com/corporate-responsibility/environmental-stewardship/water-quality-habitat-protection/fish-counts-fish-runs/clackamas-fish-runs (Accessed Dec 8, 2018) and Garth Wyatt (personal communication).

Figure 4-9 Recent annual upstream migration timing distributions for adult spring Chinook salmon counted at Willamette Falls Dam (RM 26.7), 2001 to 2018. Includes fin-clipped and unclipped individuals. Symbols shown are medians (closed circles), quartiles (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (open circles). Figure from (Keefer et al. 2019).



4.3.4.2 Upper Willamette River steelhead

The start of yearly migration for steelhead varies by almost 4 weeks, while end dates are within a week in May. This may be a remnant of the genetic and behavioral adaptation to avoid the migration barrier historically created by low summer flows at Willamette Falls (Figure 4-10).

Run distribution trends for native UWR winter steelhead are different from run timing distributions when introduced and hatchery steelhead are included Figure 4-11. Median passage dates for native unclipped UWR steelhead center in January and February, rather than in mid-March when hatchery fish are also considered.

Median migration timing of UWR steelhead (Figure 4-11) has similar interannual variability of about one month compared to combined timing of both unclipped and clipped (hatchery) steelhead (Figure 4-10). However, the duration of the unclipped UWR steelhead run considered by itself is earlier and shorter relative to the run timing that includes hatchery steelhead. Comparing the data for years 2012, 2013, 2014 in Figure 4-11 shows that ninety percent of the annual unclipped UWR steelhead migration is complete within as little as two to three weeks in recent years.

Fish passage at Willamette Falls for clipped steelhead and unclipped UWR winter steelhead are both complete prior to the summer warm period in the lower Willamette migration corridor. In both cold and warm years (2012, 2015, 2016), the variability in passage dates is lower than in more average years (2013, 2014).

Figure 4-10 Annual upstream migration timing distributions including both fin-clipped (hatchery) and unclipped (natural production) adult winter steelhead counted at the Willamette Falls fish ladder, 2002 to 2012. Data includes counts of Symbols show median (•), quartile (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (o). Figure from (Jepson et al. 2015).

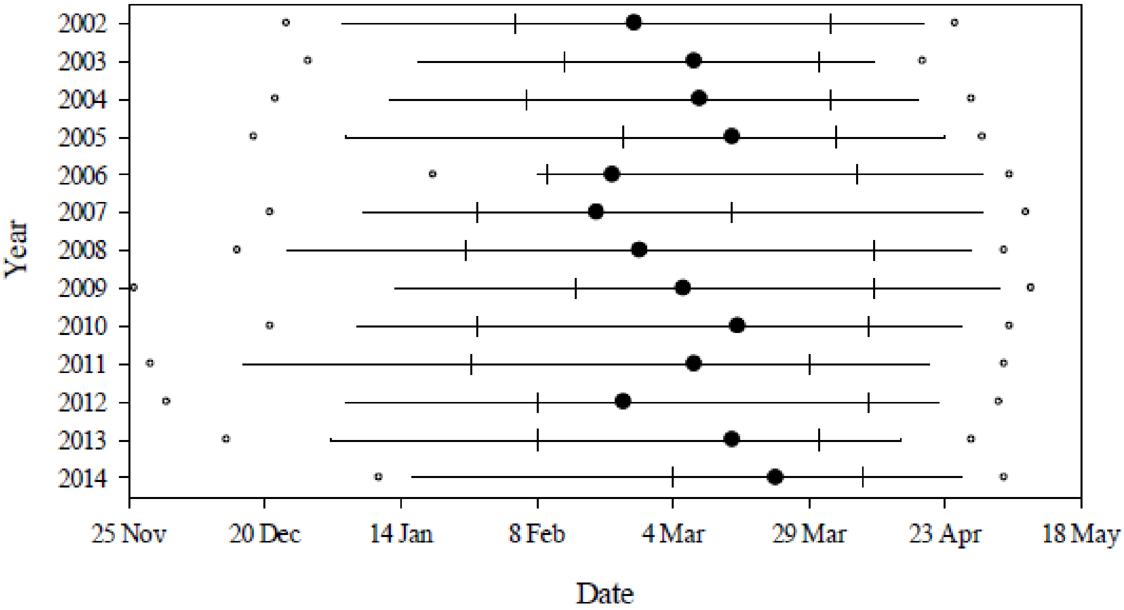
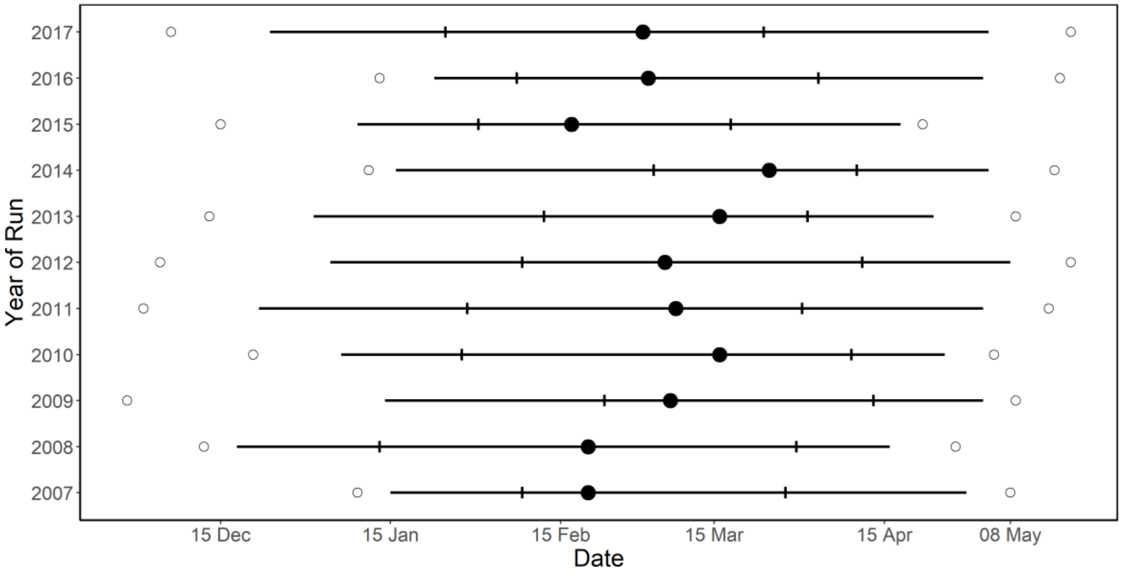


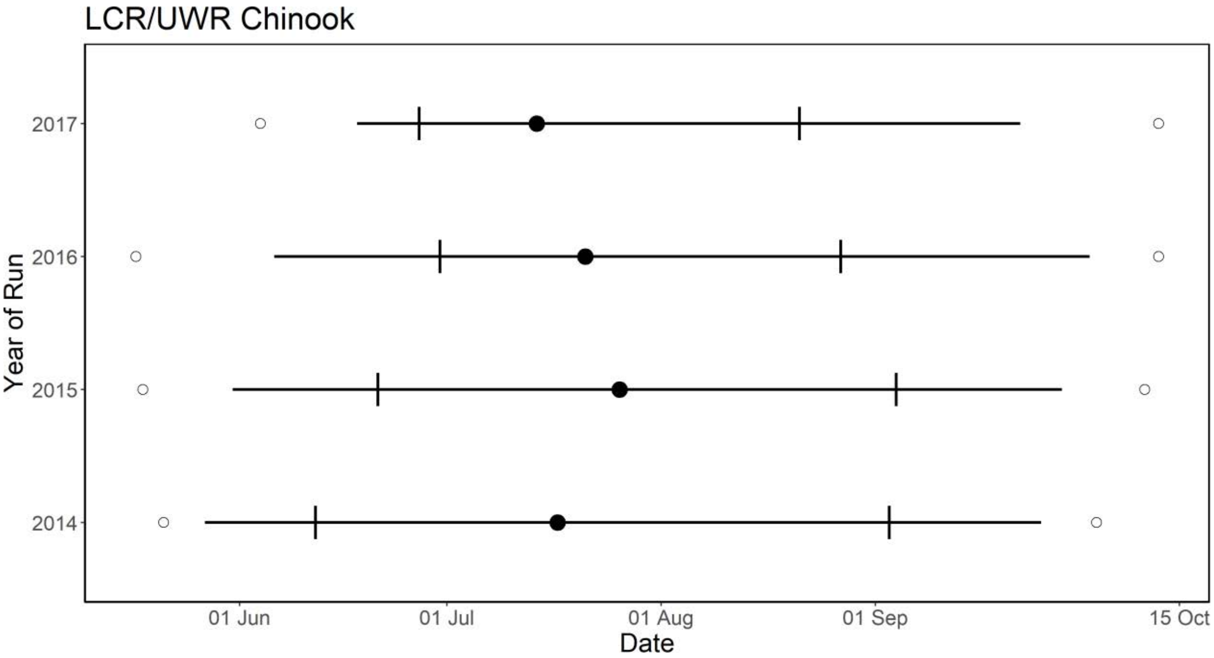
Figure 4-11 Annual upstream migration timing distributions for adult UWR winter steelhead counted at Willamette Falls fish ladder (RM 26.7), 2012 to 2017. Data for unclipped individuals only. Symbols show medians (•), quartiles (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (o). Data source: ODFW



4.3.4.3 Lower Columbia River Chinook

Figure 4-12 shows passage timing of UWR and LCR Chinook at North Fork Dam. Median passage times at North Fork dam occur from July 15 – August 1 and are consistent between years. Water temperatures in the Clackamas River are rarely greater than 18°C and not above 20°C under current conditions. There is no currently available data for the timing and abundance specific to LCR fall Chinook while in the Willamette migration corridor or their temperature exposure. It is possible for as much as half of the annual Clackamas spring/fall Chinook run to be present in the Willamette migration corridor in July and August, when water temperatures are above 18-20°C. However, any LCR Chinook present at those times should gain immediate temperature relief upon entering the Clackamas River. Similar run timing at North Fork dam in hot years (2015) versus cool years (2014) suggests that Chinook may hold in the cooler Clackamas River and wait for additional cues to migrate past North Fork Dam. This behavior could smooth out variability in interannual passage timing from different year-to-year entry or migration rates caused by temperature variability in the Willamette River.

Figure 4-12 Annual upstream migration timing distributions for adult LCR Chinook counted at North Fork fish ladder, 2014 to 2017. Data for spring and fall Chinook. Symbols show medians (•), quartiles (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (o). Data source: PGE

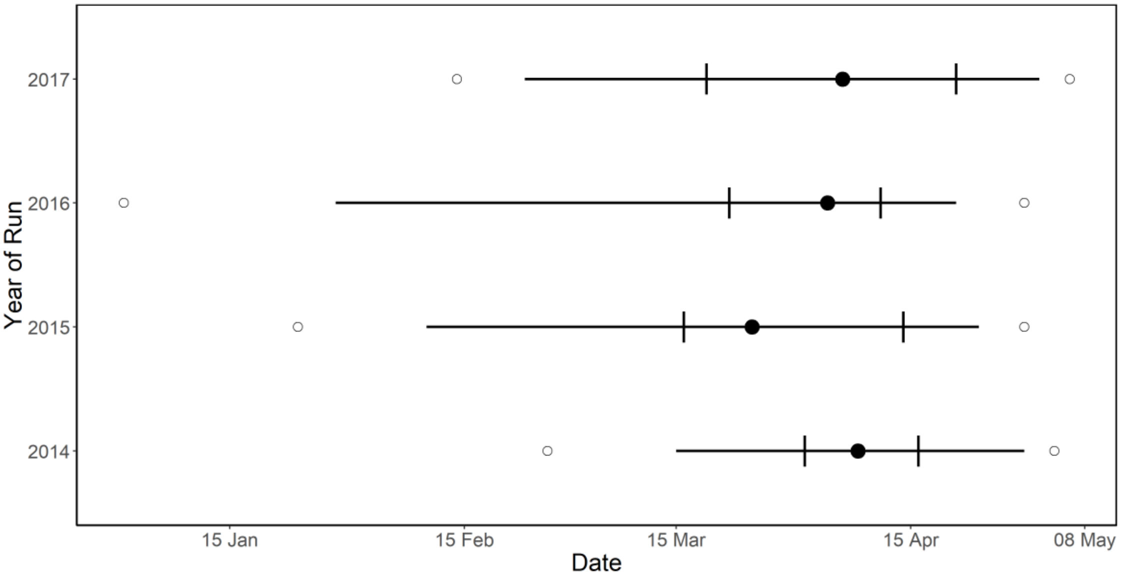


4.3.4.4 Lower Columbia River steelhead

Figure 4-13 shows passage timing distribution of LCR winter steelhead at the North Fork Dam. The ODFW timing tables for the lower Willamette from the Columbia River confluence to Willamette Falls for LCR steelhead was identical to the timing for UWR steelhead (Figure 4-5), but the peak fish passage counts at North Fork have a time lag two months later than UWR steelhead at Willamette Falls. This suggests that steelhead may also hold for an extended period in the Clackamas River before passing North Fork Dam. This is a knowledge gap and source of uncertainty about LCR winter steelhead behavior. It is likely that the time and temperature conditions for which LCR steelhead are in the Willamette River is not reflected by the time distribution of passage at North Fork Dam.

Median LCR steelhead passage at North Fork Dam centers on the first week of April and 90% of the run passes within a short window of 2-3 weeks in recent years. A small number of early individuals pass starting as early as mid-January or early February. Median passage time may be slightly earlier during warm years (2015, 2016), but the range of passage times is not markedly different from more average years (2014).

Figure 4-13 Annual upstream migration timing distributions for adult LCR winter steelhead counted at North Fork fish ladder (Clackamas river mile 29.9), 2014 to 2017. Data for unclipped individuals only. Symbols show medians (•), quartiles (vertical lines), 10th and 90th percentiles (ends of horizontal lines), and 5th and 95th percentiles (o). Data source: PGE



4.3.5 Comparison of migration patterns with main stem temperature and flow

Changes in annual migration rates and the number of daily fish passage counts for UWR Chinook salmon and UWR steelhead coincides with changes in two key environmental factors known to affect salmon and steelhead migration behavior in the lower Willamette: temperature and flow rates. Both factors are recognized to predict run timing and migration behavior in salmon and steelhead and strongly correlate in the migration corridor (Hodgson et al. 2006, Keefer et al. 2008a, Beer and Anderson 2013) Fish passage numbers and passage rates are lower during the summer warm period of July – September.

Cumulative annual fish passage of Chinook salmon slows during the warm period. Cumulative migration of UWR Chinook salmon reaches 85% of annual passage by July, but the passage rate slows during the warm period between July and August before the spring Chinook cut-off date on August 15 (Figure 4-14). The warm period coincides with a steady increase in water temperature to the annual maximum and a gradual decrease in flows to the annual minimums between July and September (Figure 4-14).

Steelhead migration primarily takes place between January and March, with 70% of the annual run of UWR steelhead passing by April 1 (Figure 4-14). Annual UWR winter steelhead passage is naturally complete except for straggling individuals by the cut-off date, and well before the period when water temperatures exceed the criteria in July (Figure 4-14).

Upper Willamette River Chinook salmon and UWR steelhead are also sensitive to flow-related cues. There is evidence these populations stop or slow migration during periods of high flow (Schreck et al. 1994). Salmon can adapt behaviorally to high flows by delaying migration until flows are moderate in order to reduce the energy expenditure of swimming against high currents (Anderson and Beer 2009). Turbidity, a co-variate with discharge, may also affect migration rates. Movement of UWR Chinook salmon was observed to slow both during highly turbid conditions and during daytime periods of low turbidity (Schreck et al. 1994).

Annual patterns of higher temperature and lower flows are coupled in the lower Willamette. Extremes in high temperatures and low flow rates are correlated within the migration corridor, especially at water temperatures above 15°C (

Figure 4-15). Chinook salmon runs historically would have been constrained during periods of low flow at Willamette Falls. Due to construction of the fish ladder, fish passage is now possible year round. Low flows may reduce fish passage rates to the extent that lows flows still act as a behavioral cue with a genetic basis (Myers et al. 2006). However, because the LCR winter steelhead counts (Figure 4-13) include naturally propagating stock introduced from other basins in addition to the native stock, the genetic cue may not be a factor for all the fish included this data. Due to the extent to which low flows and high temperatures are correlated (

Figure 4-15), it is difficult to determine if either is individually more important as an environmental cue (Figure 4-6).

Figure 4-14 10-year average of fish passage for Chinook salmon and steelhead showing cumulative percent (top panel) and daily counts (bottom panel) of fish passage. Black line shows daily mean water temperature, and blue line shows mean discharge, at USGS Portland gage. Data sources: ODFW, USGS.

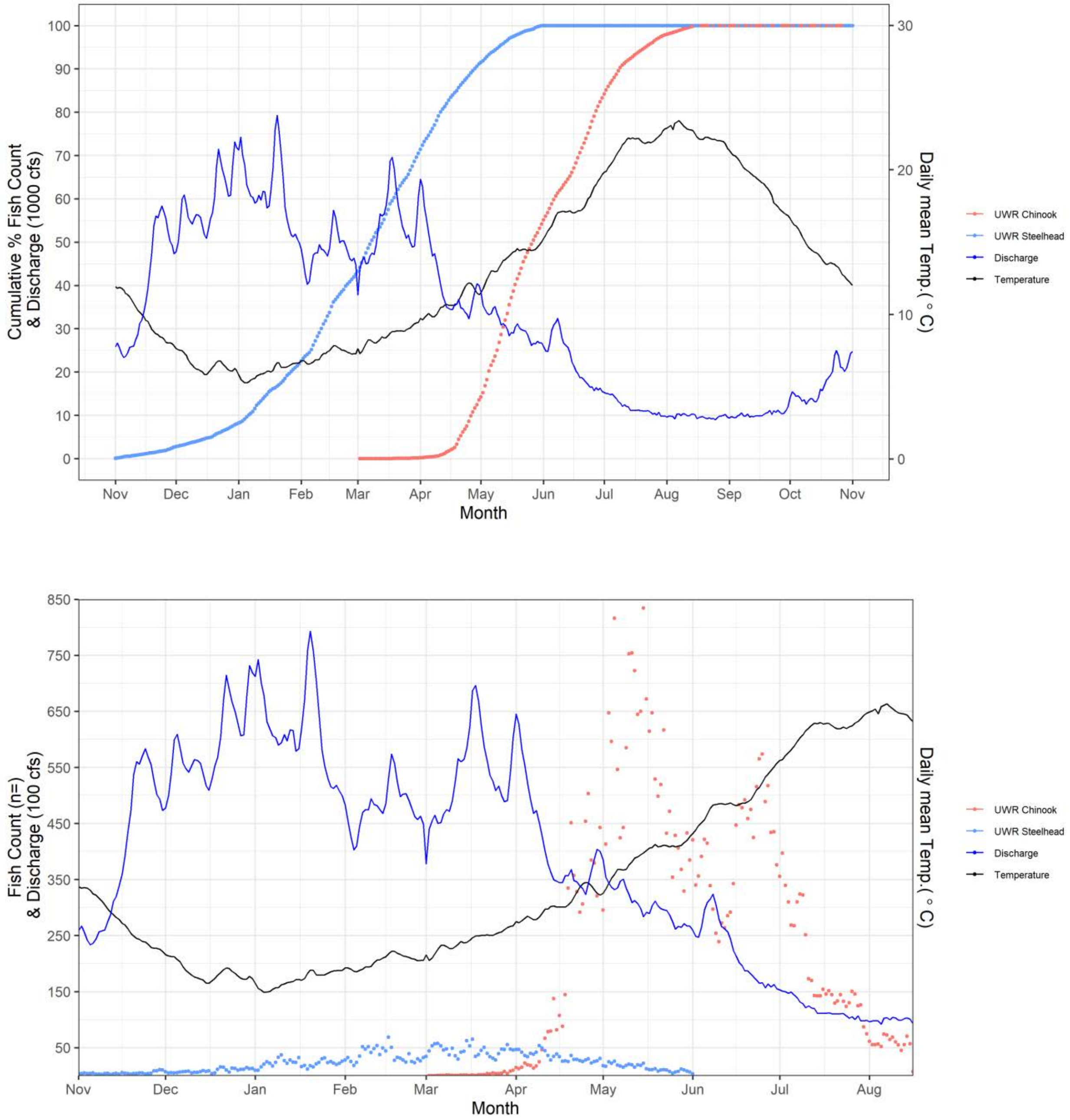
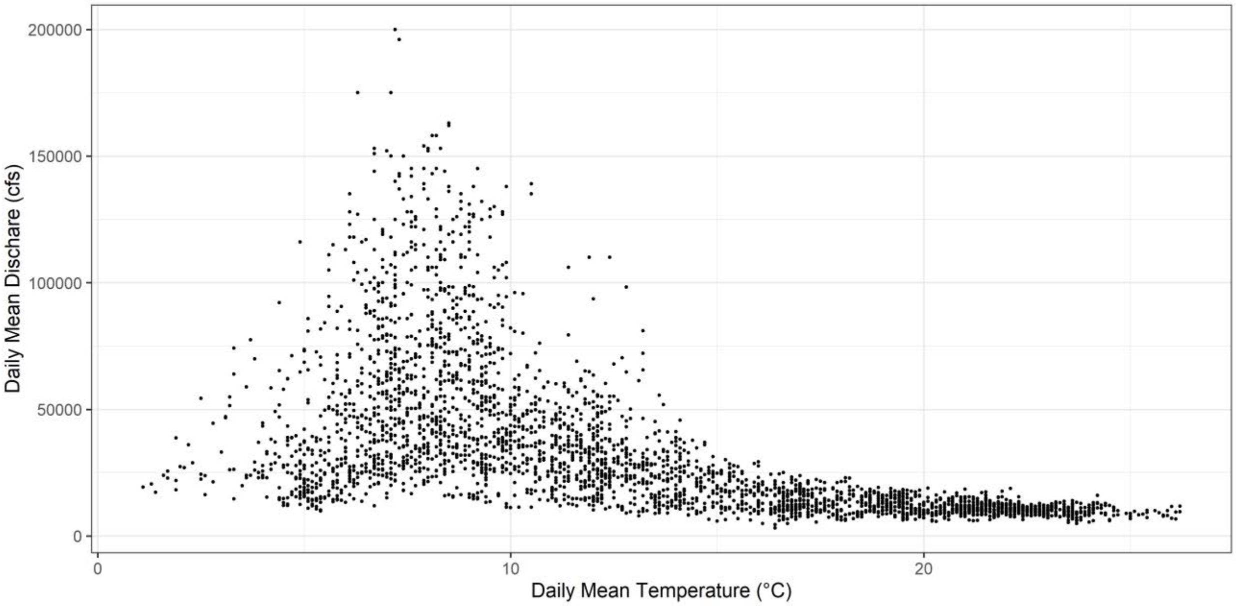


Figure 4-15 Daily mean temperature vs. daily mean discharge at USGS Portland gage, daily for 2007-2017. Data source: USGS-NWIS



4.3.5.1 Upper Willamette River Chinook

Seasonal variability in springtime flow and temperature conditions are also correlated with the dates of median and peak migration in Chinook. Higher than average April flow and lower than average March water temperatures tended to result in later run timing in Columbia river Chinook salmon populations (Keefer et al. 2008b). Chinook salmon migration in the Willamette seem to follow this pattern. Onset of Chinook salmon migration begins earlier in years with warmer spring water temperatures (Jepson et al. 2015, Keefer et al. 2019).

Upper Willamette River spring Chinook salmon migrate past Willamette Falls in largest numbers when daily mean water temperatures are between 10°C and 15°C(Figure 4-15). UWR spring Chinook may cue the start of migration at the time when water temperatures exceed 10°C (Mattson 1948, Howell et al. 1985, Nicholas 1995, as cited in (NMFS 2018)).There is a sharp increase in passage counts as temperatures rise above 11°C according to the data shown in Figure 4-16. No Chinook salmon individuals have been counted passing the fish ladder when water daily average temperatures are less than 9°C or greater than 25°C (Figure 4-16). Chinook salmon passage counts peak at 14°C and begin to decline at temperatures above 16°C.

Run timing is in part a response to stream-flow characteristics (Myers et al. 2006). Fish passage counts decrease sharply when flows drop below 10,000 cfs. No UWR spring Chinook salmon have been counted passing the Willamette Falls fish ladder in flows greater than 75,000 cfs during the period 2007-2017 (Figure 4-18).

Figure 4-16 UWR spring Chinook salmon daily fish passage counts at Willamette Falls dam (RM 26.7) and main stem water temperature at Portland (RM 12.8), daily for 2007-2017. Data source: ODFW and USGS.

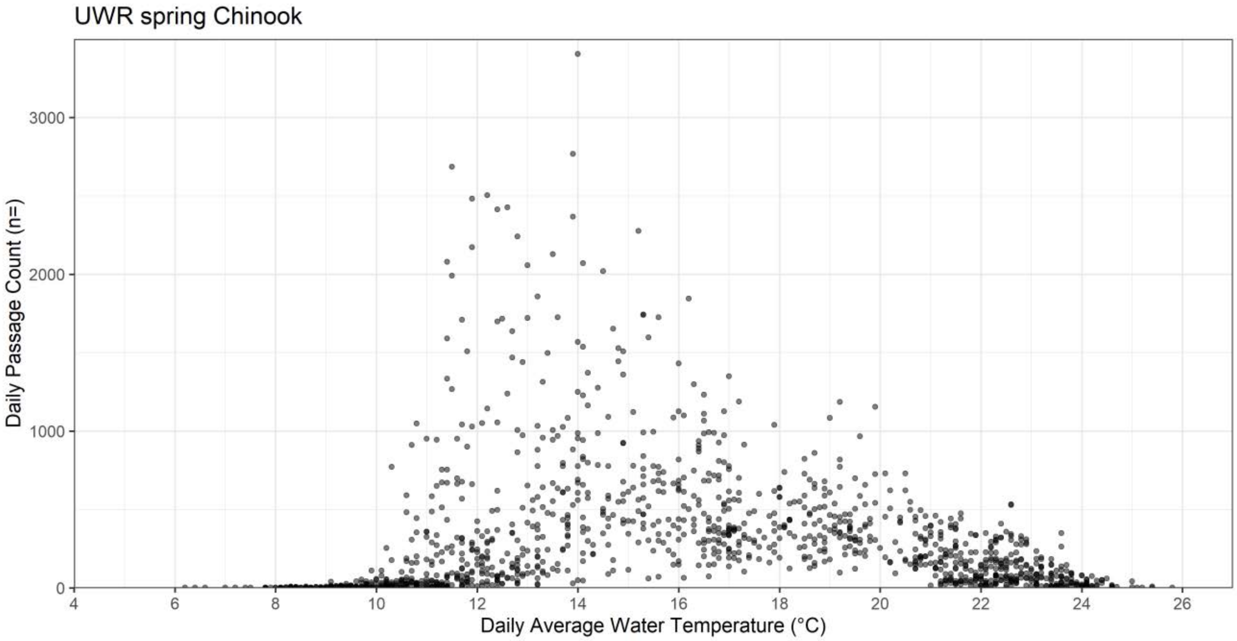


Figure 4-17 Relationship of median passage date at Willamette Falls (RM 26.7) and mean March water temperature at Portland (RM12.8). (Keefer et al. 2019)

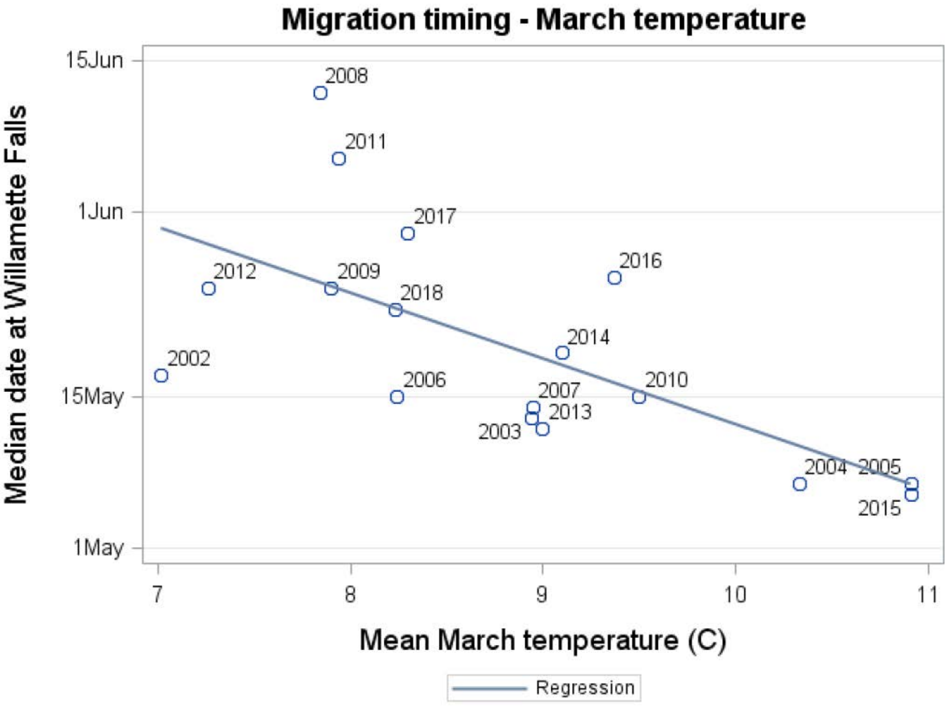


Figure 4-18 **UWR Chinook salmon daily passage counts at Willamette Falls dam (RM 26.7) and main stem discharge at Portland (RM 12.8), 2007-2017. Data source: ODFW and USGS.**

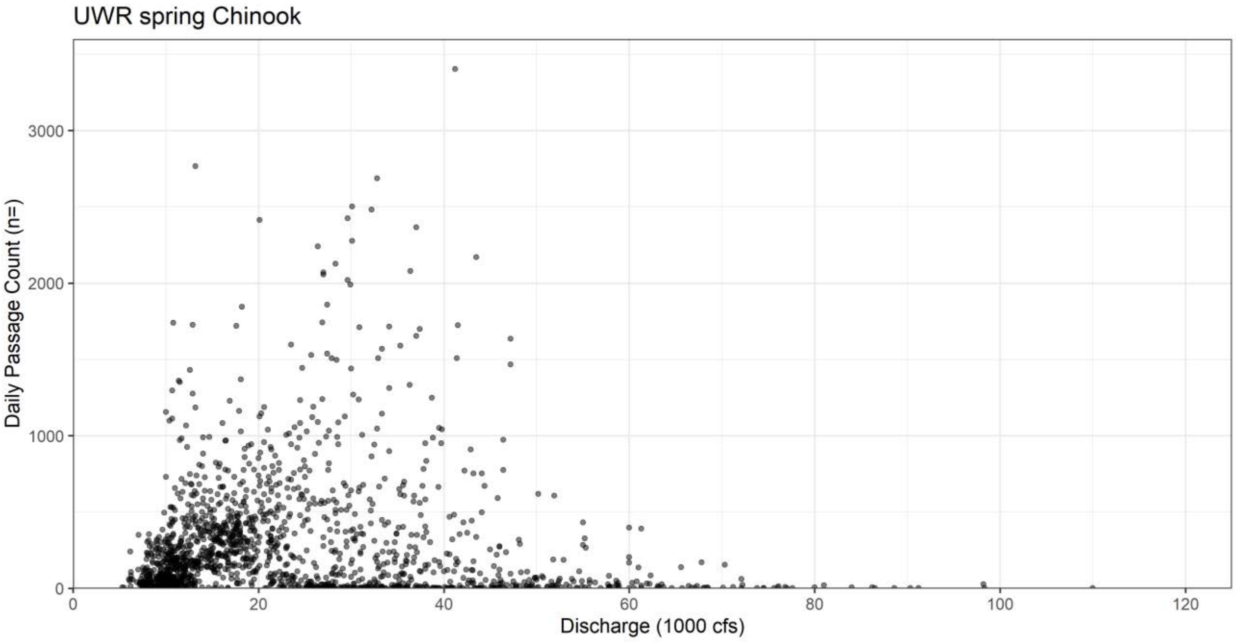
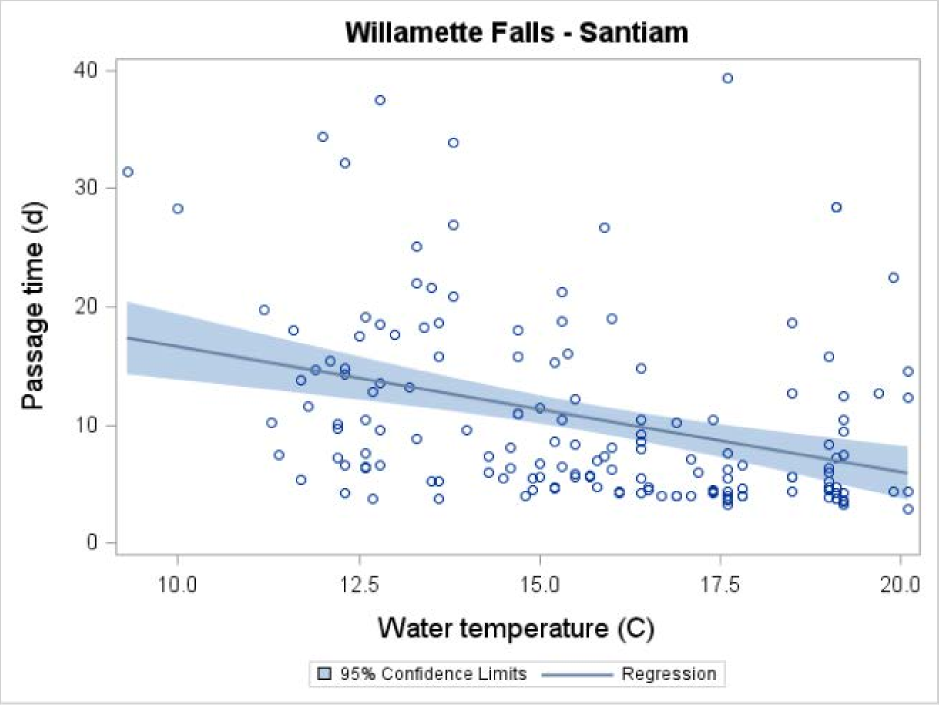


Figure 4-19 Relationship between passage time and main stem water temperature for UWR Chinook from Willamette Falls (RM 26.7) to the Santiam River (RM 108) (Keefer et al. 2019)



4.3.5.2 Upper Willamette River steelhead

Upper Willamette River winter steelhead migrate past Willamette Falls in largest numbers when water temperatures are between 5°C and 10°C, but individuals have been counted passing the fish ladder at almost any temperature within the temperature range that occurs during the migration. The UWR winter steelhead run was not exposed to temperatures much greater than 17°C on any day in the last 10 years. (Figure 4-20).

Fish passage counts are lower at flows approaching > 100,000 cfs. Few UWR winter steelhead have been counted passing the Willamette Falls fish ladder in flows greater than 120,000 cfs (Figure 4-21).

Figure 4-20 UWR steelhead daily passage counts at Willamette Falls dam (RM 26.7) and the main stem temperature at Portland (RM 12.8), daily from 2007-2017. Data source: ODFW and USGS.

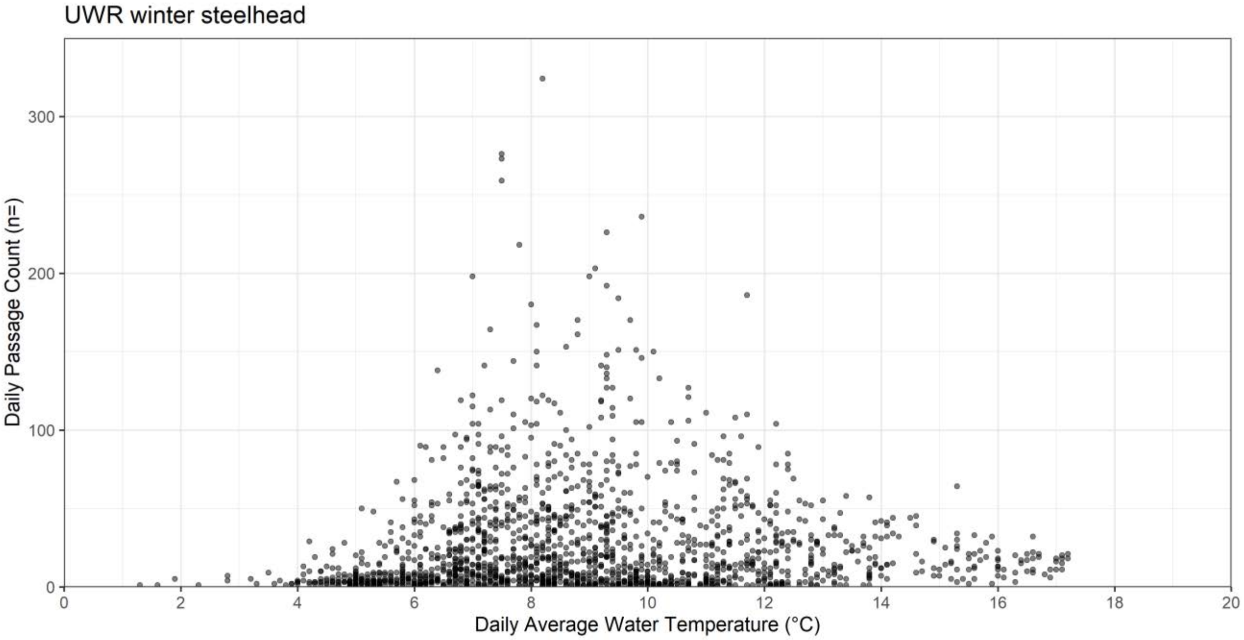
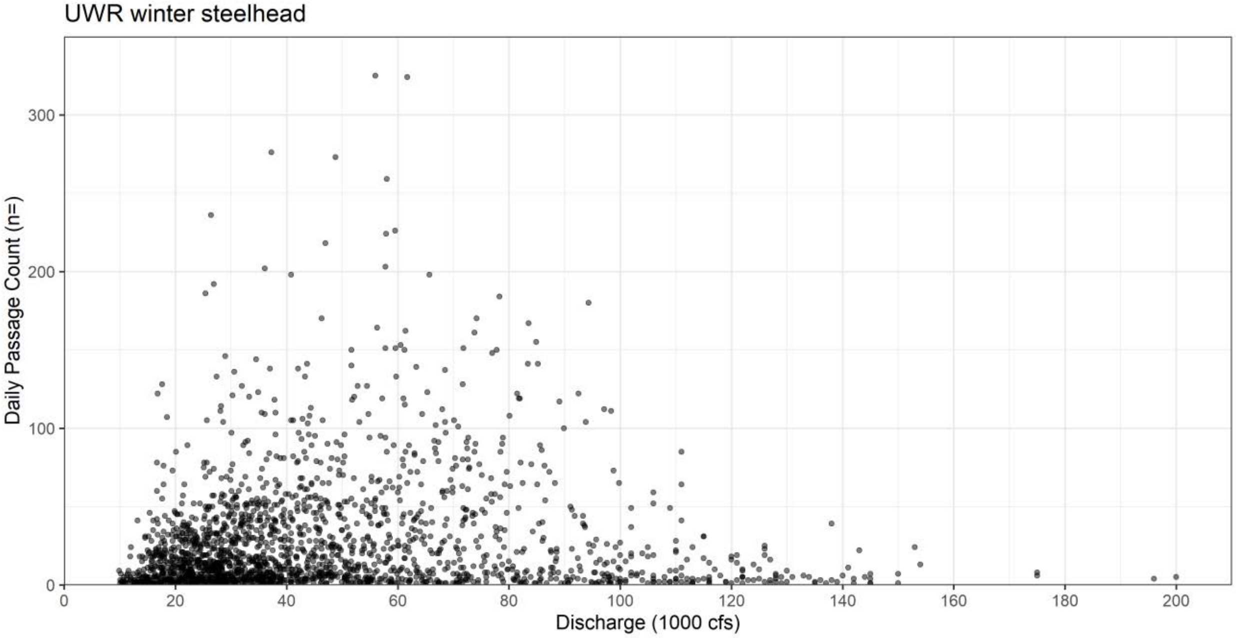


Figure 4-21 UWR steelhead daily passage counts at Willamette Falls dam (RM 26.7) and main stem discharge at Portland (RM 12.8), daily from 2007-2017. Data source: ODFW and USGS.



4.4 Thermal exposure to temperatures above biological thresholds under different temperature conditions

4.4.1 Proportion of runs exposed to high temperatures under current conditions

4.4.1.1 Chinook salmons thermal exposure

As a 10-year average, 9% of UWR spring Chinook salmon are exposed to water temperatures above the migration corridor criterion. (see Table 4-1). This reflects the unique earlier run timing characteristics of the UWR spring Chinook salmon population relative to introduced genetic stock derived from Columbia River populations. Summer water temperatures that exceed the 7-dADM extend well into September. The results in (Table 4-1)are similar to results from a study of UWR Chinook showing the proportion of simulated individual thermal histories that 7% on average experienced acutely high temperatures (>21°C) (Keefer et al. 2019).

It is important to note that this does not take into account the proportion of the population that experiences mortality, strays, falls back, or is otherwise blocked from passing Willamette Falls dam due to temperature and flow conditions.

4.4.1.2 Steelhead thermal exposure

None of the UWR winter steelhead migrating within the date range defined by ODFW and the ESU is exposed to high summer temperatures in the Willamette under current conditions.

Table 4-1 Ten-year average of run exposure to days above key temperature thresholds. Run dates for each population as defined by ODFW. Data sources: ODFW, Fish Passage Center, USGS.

	UWR spring Chinook	UWR winter steelhead
Days of run > 20°C 7-DADM	56	0
First date exceeded	Jul 5	Jul 5
Last date exceeded	Sept. 11	Sept. 11
% run exposed >20°C 7-DADM	9.0%	0%
% run exposed >18°C daily average	25%	0%
% run exposed >20°C daily average	14%	0%

Table 4-2 Proportion of annual runs (2009-2017) exposed to days above 18°C average or 20°C maximum. Temperatures are for USGS Portland gage. Data sources: ODFW, Fish Passage Center, USGS.

				% exposed >18°C daily mean		% run exposed >20°C 7-DADM	
Year of Run	Days exceeded	First date exceeded	Last date exceeded	UWR spring Chinook	UWR winter steelhead	UWR spring Chinook	UWR winter steelhead
2009	52	7/5/2009	9/8/2009	45.4 %	0 %	15.9 %	0 %
2010	49	7/14/2010	9/1/2010	15.7 %	0 %	4.0 %	0 %
2011	32	8/1/2011	9/8/2011	13.7 %	0 %	0.9 %	0 %
2012	47	7/13/2012	9/4/2012	10.4 %	0 %	7.5 %	0 %
2013	71	7/4/2013	9/12/2013	47.7 %	0 %	23.2 %	0 %
2014	69	7/7/2014	9/13/2014	40.7 %	0 %	11.4 %	0 %
2015	99	6/8/2015	9/14/2015	17 %	0 %	5.9 %	0 %
2016	72	6/10/2016	9/11/2016	46.9 %	0 %	43.4 %	0 %
2017	80	6/29/2017	9/16/2017	23.3 %	0 %	14.6 %	0 %

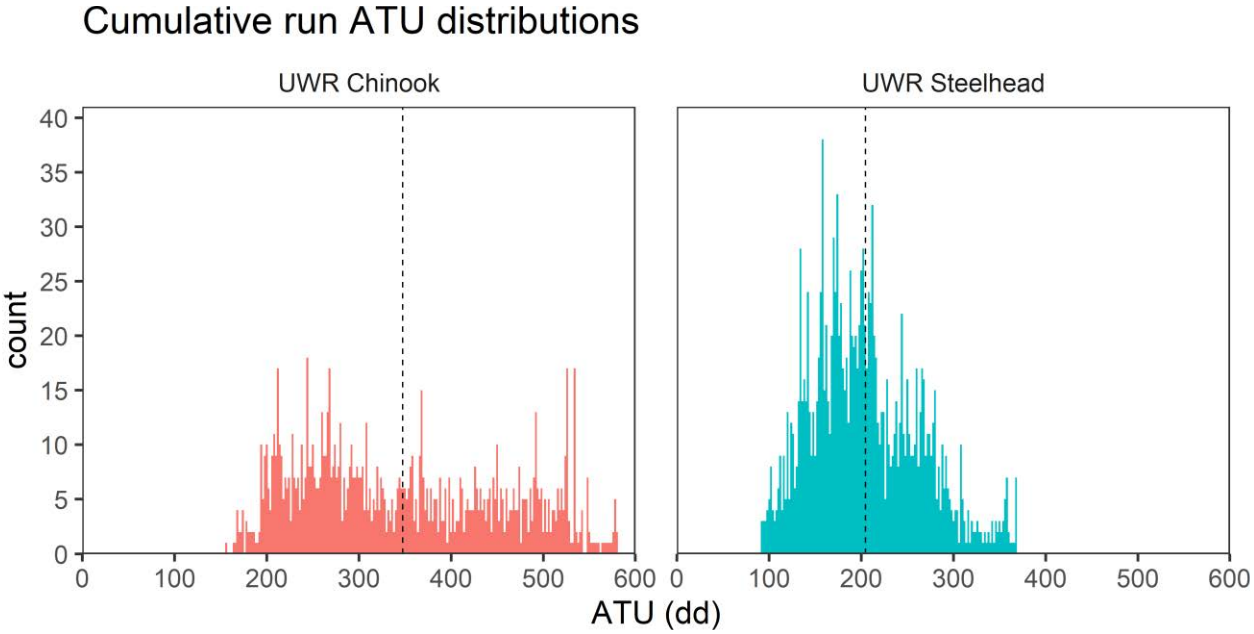
4.4.2 Accumulated thermal exposure under current average conditions

Maximum residence time in the lower Willamette migration corridor during migration for UWR Chinook salmon and UWR steelhead may be approximately three weeks (Friesen, personal communication; see Section 4.5.1). The worst-case range of ATU accumulation based on daily average temperatures for rolling 23-week periods for years 2009-2017 is 157-579 ATU with an average of 348 ATU during UWR spring Chinook runs, and 92-369 ATU with an average of 204 ATU during UWR winter steelhead runs (Figure 4-22). These estimates assume that fish remain in the migration corridor for the maximum estimated residence time of 23 days.

The expected range of total migration ATU accumulation for Chinook salmon for travel from Willamette Falls to the farthest spawning grounds or collection facilities in the North Santiam River is 500-2000 ATU depending on the year and whether individuals migrate early or late in the run (Keefer et al. 2015, 2019). There is an average of 22.0 ATU/d accumulated when weekly average of daily maximum temperatures are greater than the 20°C migration corridor criterion. This means at worst case, a Chinook spending a full 23 days in the lower migration corridor would accumulate 9%-36% of total migration ATU in just this portion of the Willamette River.

Biological thresholds of degree-day (ATU) accumulation for pre-spawn mortality for UWR Chinook salmon have not been identified. Hypothetically, a threshold of total accumulation of 500 ATU during migration in the main stem, and 2,000 ATU for total pre-spawning time, have been proposed to predict increased disease incidence and pre-spawn mortality in adult Chinook due to multiple thermal stressors, but these values have not been tested (Wagner et al. 2005a, Mathes et al. 2010, Keefer et al. 2015). No studies to date have proposed any threshold for UWR winter steelhead.

Figure 4-22 Distribution of ATU (degree-days) for rolling 23-day periods during the respective migration date ranges for UWR Chinook and UWR steelhead. Calculated from daily average temperature in the migration corridor (RM 0-50.8) at Portland for current conditions, 2007-2017. Dashed vertical line shows mean value. Data source: USGS.

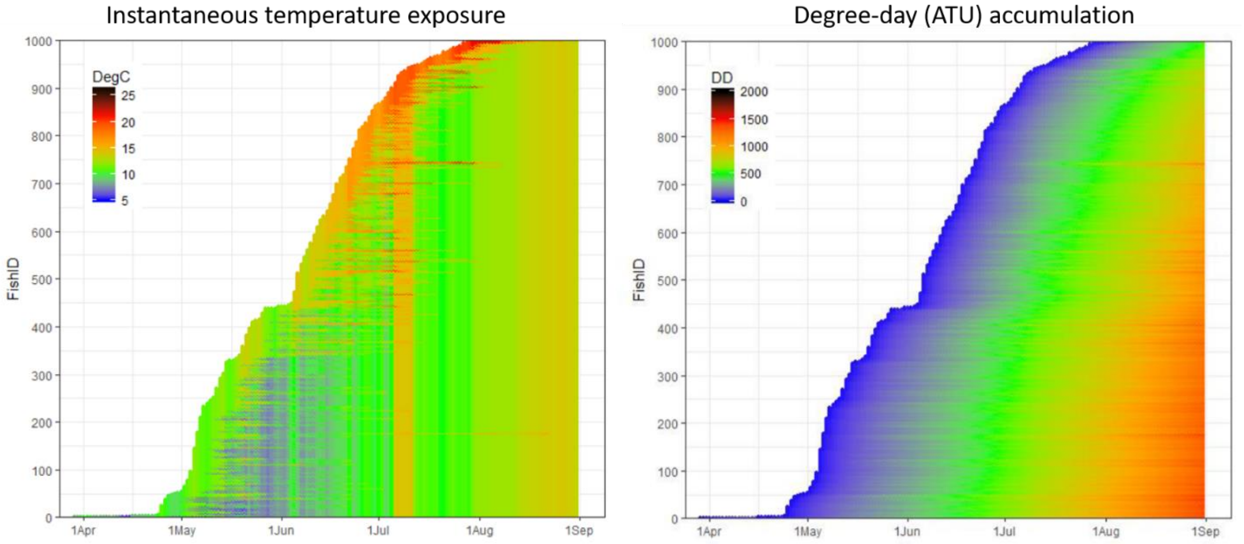


4.4.2.1 Upper Willamette River Chinook

Upper Willamette River Spring Chinook salmon accumulate a wide range of thermal units during their migration, depending on timing and annual weather variability. Chinook salmon were observed accumulating a range of 150-200-1,500 ATUs for their migration between Willamette Falls and upstream holding destinations or adult collection sites (Keefer et al. 2015). In a simulated migration exposure study, UWR Chinook salmon that were present at Willamette Falls in late spring and early summer had ATU accumulation near the upper end of that range, while Chinook salmon present at the falls later in the summer had ATU accumulation nearer the lower end of that range (Figure 4-234-23).

Keefer and others modeled Chinook migration behavior at different time of year from Willamette Falls to the North Santiam basin (Keefer et al. 2019). They created an agent-based simulation model using the run timing distribution for Willamette Falls and radio-telemetry data for 1,000 simulated individuals running from March 1 – August 31. They found divergence in both acute and chronic thermal exposure related to migration timing and behavior. Simulated Chinook salmon that migrated early tend to move at slower rates. They experienced less exposure to instantaneously high temperatures (Figure 4-234-23, left panel), but accumulated more ATU for the duration of their migration (Figure 4-234-23, right panel) until August 31. Early migrating Chinook tended to experience cooler instantaneous temperatures while in the migration corridor but warmer instantaneous temperatures in holding and spawning tributaries for longer duration at the end of their migration. Chinook that migrated late in the season tended to migrate more quickly. They experienced more short-term exposure to higher instantaneous temperatures in the migration corridor, but accumulated less ATU for the overall migration. (Figure 4-234-23).

Figure 4-234-23 Modeled thermal exposures to water temperatures (left panel) and degree-day accumulation (i.e. ATU, right panel) for 1,000 migrating adult Chinook salmon randomly sampled from run timing distribution at Willamette Falls (RM 26.7) to the North Santiam basin (RM108) in 2011. Data source: (Keefer et al. 2019)



4.4.2.2 Upper Willamette River steelhead

As UWR winter steelhead are not exposed to temperatures above the 20°C migration corridor criterion, their accumulated thermal exposure in the period when the migration corridor criterion is exceeded under these conditions is zero. The 23-day ATU accumulation during the steelhead migration period (November – June) ranges from 92 ATU to 369 ATU with an average of 204 ATU for current conditions (2007-2019). Again, no studies in the current literature suggest an ATU tolerance threshold for UWR steelhead.

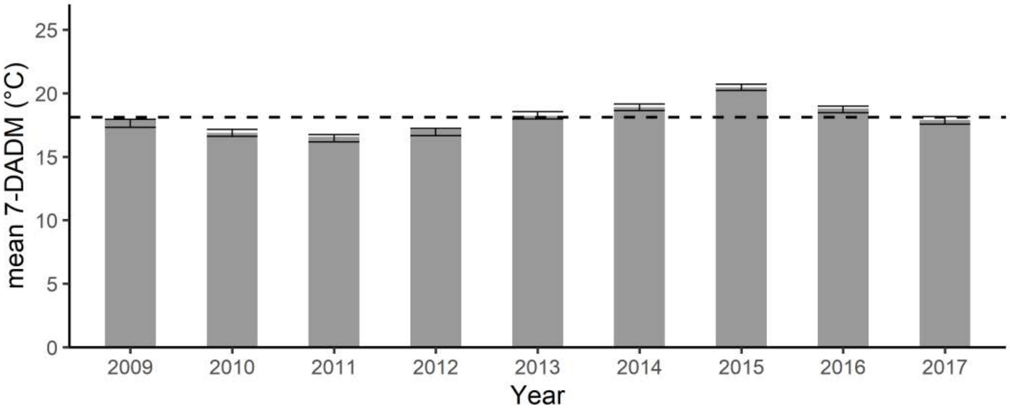
4.4.3 Interannual thermal exposure variability

Figure 4-10 and Figure 4-11 show that there is considerable inter-annual variability in run timing for both UWR Chinook salmon and UWR steelhead populations. Migration is triggered by, and responds to, environmental cues and conditions. We have seen that river temperature and water flow are two important factors that interact and affect migration start dates and rates.

Summer (June 1 – September 31) daily mean temperatures have varied in recent years from 16.6°C in 2011 to 20.5°C in 2015 (Figure 4-24). To compare degree-day accumulation (ATU) and thermal exposure of Chinook salmon and steelhead runs above biological thresholds, we selected three reference years representing recent cold, average, and hot summers for comparison.

Year	Summer Thermal Conditions
2012	“Cold”
2013	“Average”
2015	“Hot”

Figure 4-24 Annual summer average of 7-day average daily maximum (7-dADM) temperature for the Willamette main stem at Portland for years 2009-2017. Summer dates are June 1 – September 31. Error bars show standard error of the mean. Dashed line shows 10-year summer average (2007-2017) of the 7-day average daily maximum (7-dADM) temperature of 18.1°C. Data source: USGS-NWIS.



The year 2012 was characterized by a summer warm period with 49 days above the migration corridor criterion. The criterion was exceeded on 49 days between July 13 and September 9, 2012. Flows remained relatively high, above 50,000 cfs, until April and did not reach annual minimums until July. Water temperatures first exceeded 10°C in April.

The year 2013 was characterized by a summer warm period with 73 days above the migration corridor criterion between July 3 and Sept. 13th, 2013. Flows were less than 50,000 cfs as early as January and reached annual minimums in early June. Water temperatures first exceeded 10°C in April.

The year 2015 is noteworthy for early and prolonged warming with a 100-day period of summer water temperatures above the criterion from June 8 to September 15, 2015. Average daily temperatures also reached an unusually high 26°C peak for several days in early July (Figure 3-2). The onset of high summer temperatures were a full month earlier than the 10-year average. Fish passage counts for Chinook salmon dropped off quickly at the end of June at the same time water temperatures began to exceed the criterion (Figure 4-26).

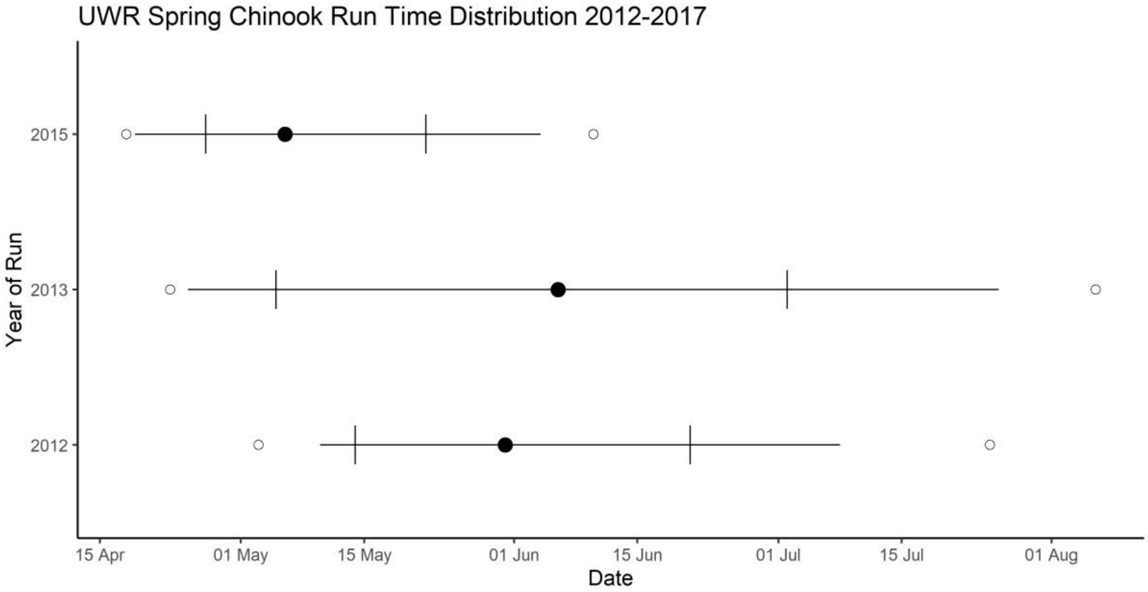
Run timing of spring Chinook salmon was much earlier in the hot year (2015) than the cold and average years (2012, 2013) (Figure 4-25). Median run timing in 2015 occurred in early May. The duration of the run was also compressed and completed by mid-June. In contrast, the cold year run in 2012 had a delayed start, but median and end run dates were similar to the average year 2013. In all three years, Chinook salmon counts at Willamette Falls quickly increased as main stem water temperatures warmed to 10°C (Figure 4-26).

Passage counts at Willamette Falls spike in the spring as temperatures warm, followed by an abrupt drop in daily passage counts around the time weekly maximum temperatures exceed the criterion of 20°C in June-July. While passage may be either conclude or be blocked during maximum summer water temperatures, it did not halt altogether in the selected years except for the extremely warm year of 2015. A smaller late spike in Chinook passage often occurs during August in each of the selected years as temperatures start to decrease.

Run timing of winter steelhead was concentrated from late January to mid-February in all three years. Winter steelhead were not exposed to temperatures above 20°C. Winter steelhead passage counts appear to reduce during winter surges in flow, from either dam releases or storm events. Apparent peaks and nadirs in steelhead passage numbers follow peaks and nadirs in the hydrograph for all three reference years (Figure 4-26). Steelhead passage drops to only infrequent, usually solitary, fish in May-June. For the last 10 years, passage always concluded before the onset of weekly maximum temperatures that exceed the 20°C criterion.

Figure 4-25 Run timing distribution for reference years 2012, 2013, and 2015. Data source: ODFW.

Panel A



Panel B

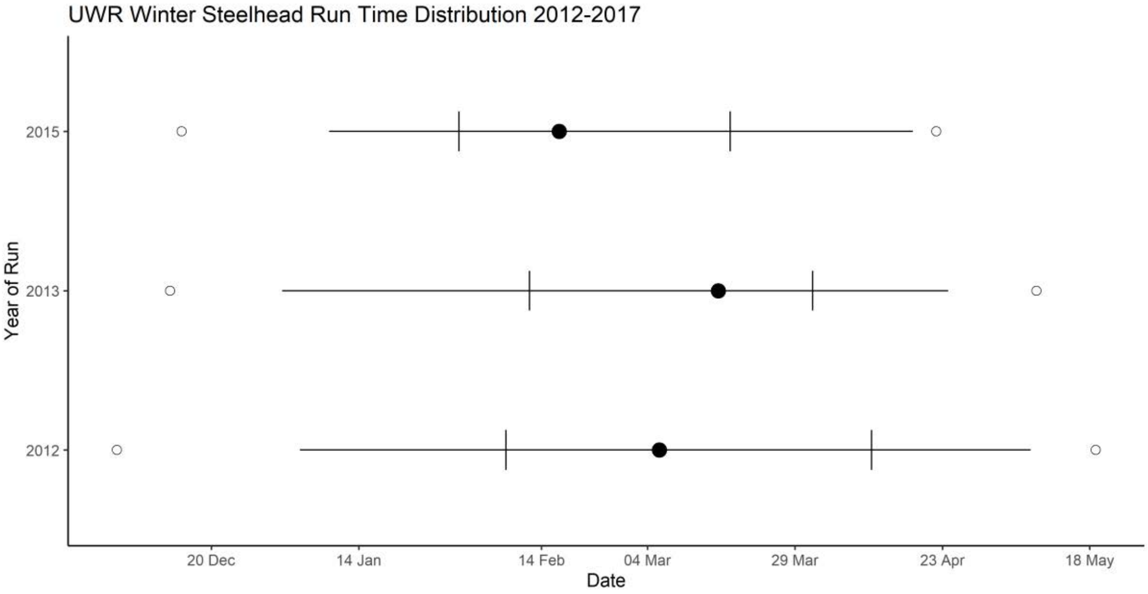


Figure 4-26 Interannual comparison of fish passage for UWR Chinook salmon and UWR steelhead at Willamette Falls dam and 7-day average daily maximum temperature and daily average discharge at Portland. Grey rectangles show time periods when the weekly maximum temperature (7-DADM) was over the 20.0°C migration corridor criterion.

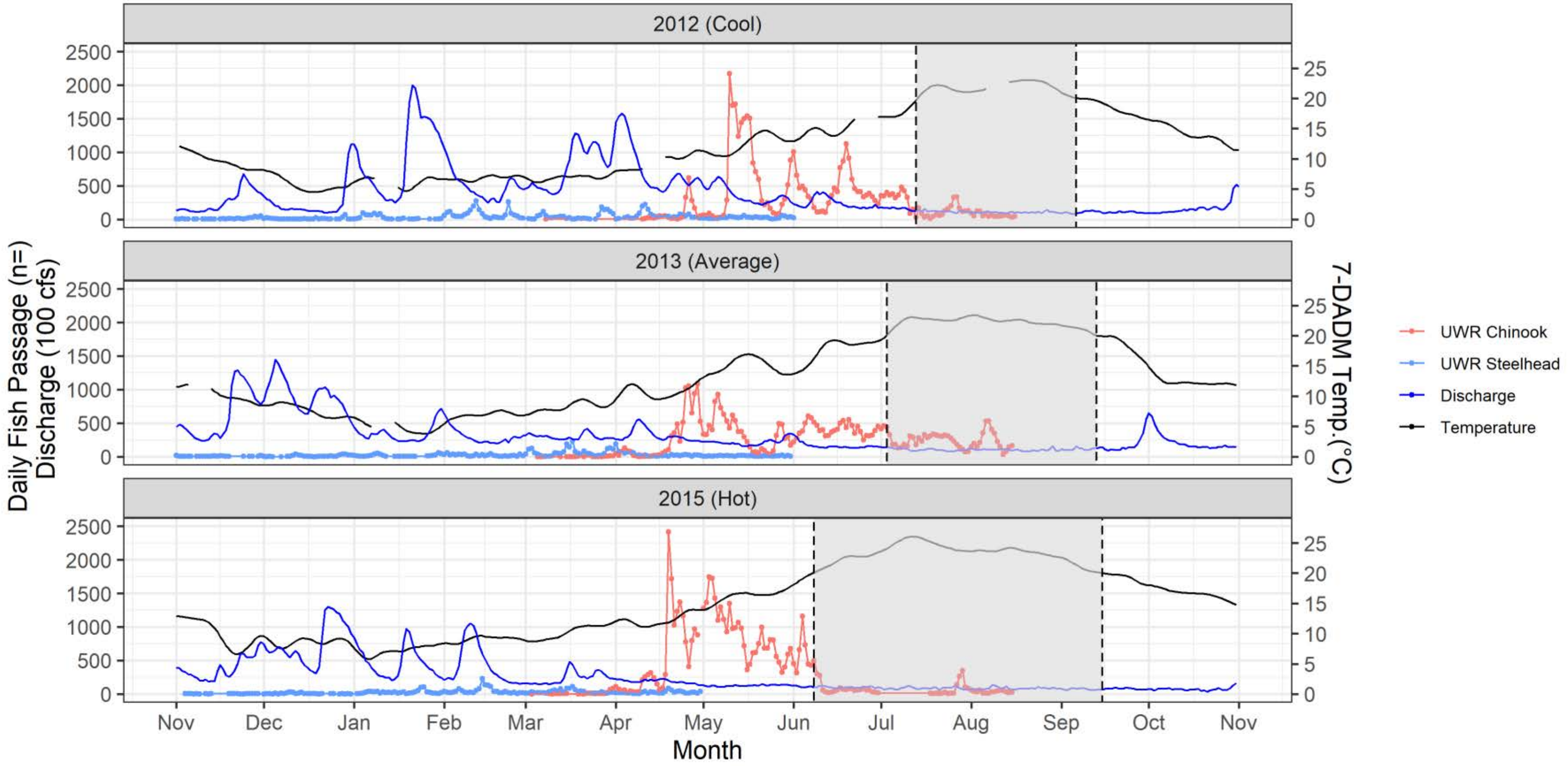
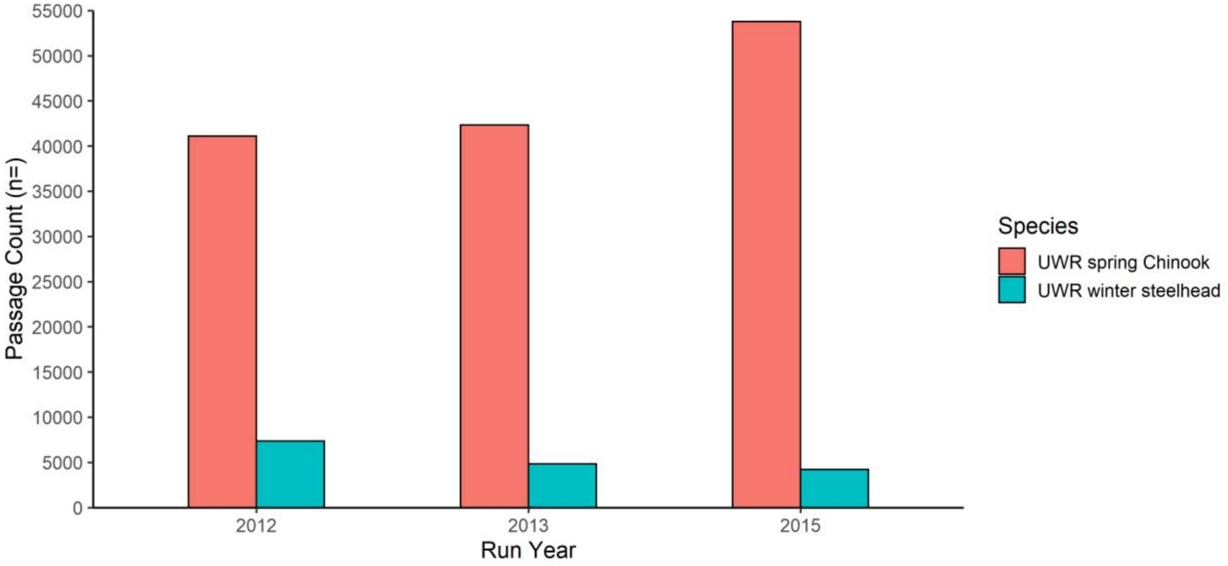


Figure 4-27 Total fish passage for UWR Chinook and UWR steelhead for reference years 2012, 2012, 2015. Data source: ODFW and fish passage center.



4.4.4 Interannual variability in thermal exposure

4.4.4.1 Portion of run exposed to temperature exceedances

The percentage of each pf the three UWR spring Chinook salmon runs exposed to water temperatures exceeding the migration corridor criteria varies annually (Table 4-3). The UWR spring Chinook run in 2013 had the highest proportion of individuals passing Willamette Falls during the period when water temperatures exceeded the migration corridor criterion –24%. Even though 2015 had almost double the duration of time when temperatures exceeded the migration corridor criterion, only 6.9% of UWR spring Chinook salmon passed Willamette Falls during the time the criterion was exceeded. Since blockage of Chinook salmon passage due to lethal temperatures was theoretically possible in 2015, it is unclear how many more adults would have passed Willamette Falls in June, and this low proportion may be misleading. Estimated Chinook en route mortality below Willamette Falls in 2015 was 11.2%, but includes all causes including sea lion predation (see also Table 5-1). The 10-year average en route mortality was 9.4% but increased from an average of <1% in recent years mainly attributed to sea lions (ODFW and WDFW 2018).

However, total UWR spring Chinook passage at Willamette Falls for 2015 was approximately 30% higher than the previous year and greater than the 1980-2015 average (ODFW and WDFW 2016). The consequences are uncertain for the viability of the population as a whole from any potential migration blockage that occurred due to temperature. Because current runs are smaller than historical, it is unknown whether the percentage that passes Willamette Falls would be less or greater before the river temperatures rise above 18-20°C, were larger runs restored.

4.4.4.2 Accumulated thermal exposures

The range of potential ATU exposure for rolling three-week periods during migration varied by year and species (Figure 4-28). The range of variability of migration period ATUs for Chinook is wider than for steelhead. Average potential 3-week ATU exposures were within 35 units for Chinook and 26 units for steelhead.

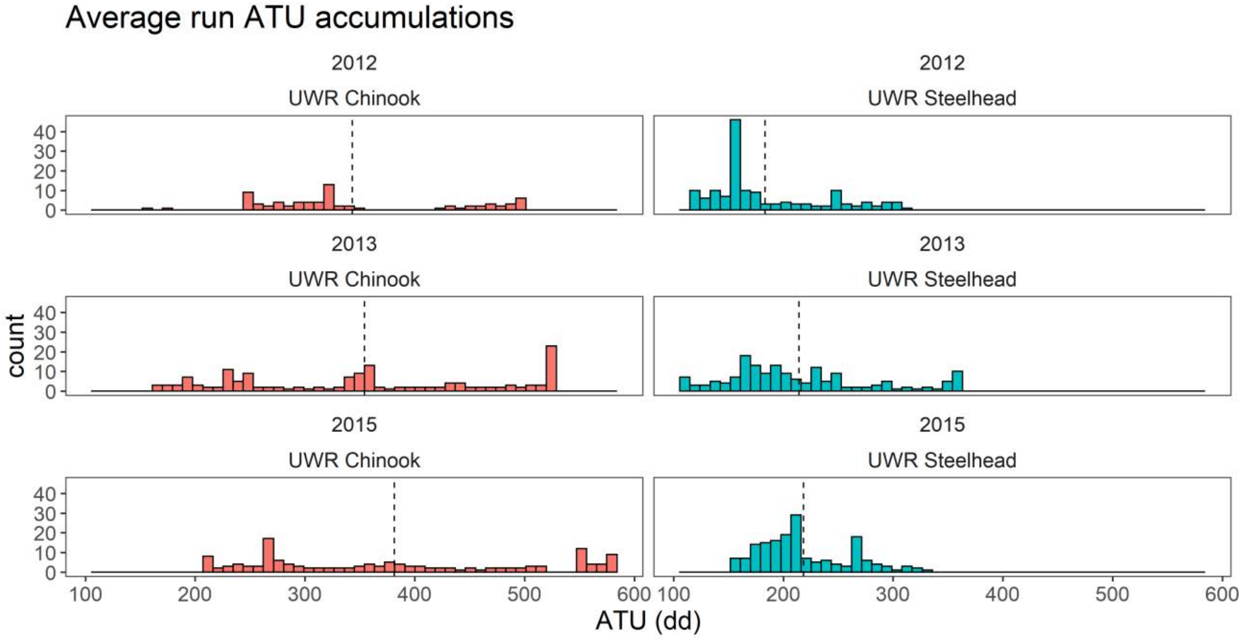
The cold year of 2012 experienced 27 days above the criterion threshold. The average 3-week ATU during the UWR Chinook salmon run period was 315 ATU at a rate of 15 ATUs per day. The UWR Chinook salmon run during the hot year of 2015 experienced 70 days above the criterion threshold and average 3-week ATU during that run period was 350 ATU at a rate of 16.6 ATUs per day.

The UWR winter steelhead run is not exposed to water temperature conditions above the migration corridor criterion.

Table 4-3 Upper Willamette River Chinook salmon and steelhead migration exposure to temperatures above criteria for reference years 2012, 2013, and 2015. Data sources: ODFW, USGS.

	UWR spring Chinook				UWR winter steelhead		
	2012	2013	2015	10-Yr Ave	2012	2013	2015
Days of run >20°C 7-DADM	27	45	70	56	0	0	0
First date of run exceeded	Jul 13	July 3	Jun 08	Jul 5	—	—	—
Last date of run exceeded	Sep 06	Sep 13	Sep 15	Sep 11	—	—	—
% run exposed >20°C 7-DADM	7.5%	24%	5.9%	9.0%	0%	0%	0%
% of run exposed >18°C mean	10.4%	47.7%	17%	25%	0%	0%	0%
Mean thermal exposure (ATU/d)	21.8	22.8	23.9	22.0	—	—	—

Figure 4-28 Distribution of degree-days (ATU) for rolling 3-week periods during migration for Chinook and steelhead under average conditions for years 2012, 2013, 2015. Vertical dashed lines are average 3-week ATU. Data source: USGS gage at Portland (RM 12.8).



4.5 Evidence of refuge use by migrating Adult salmon and steelhead

Based on studies of Columbia and Snake River populations, if Chinook salmon and steelhead use CWR they should exhibit slowed migration rate and delay by holding in CWR as daily water temperatures exceed 18°C average and 20°C maximum. (Torgersen et al. 1999, Goniea et al. 2006, High et al. 2006, Keefer et al. 2009, 2018, Keefer and Caudill 2016). In the Klamath River, California (Strange 2012) and the Puntledge River, British Columbia, (Hasler et al. 2012), Chinook salmon and steelhead have not been observed seeking CWR even when water temperatures are greatly above 20°C. In the British Columbia example, the researchers concluded that there was not CWR available for use by the fish even if needed.

It is not clear from fish passage patterns at Willamette Falls and the relationship between fish counts and main stem temperatures whether low fish passage counts during periods of warm summer temperatures are a result of adaptive run timing to avoid exposure to these temperatures, or a sign that migration temporarily halts while fish seek refuge. Direct observation of fish using CWR during periods of warm water temperature in the lower Willamette is limited.

4.5.1 Migration rate and residence time

4.5.1.1 Timing from the Willamette River mouth to Willamette Falls

Data from fish tag and telemetry studies shows how long individual fish spend in different portions of the migration corridor. To date, all fish tag and telemetry studies have marked fish captured in the fish way at Willamette Falls (RM 26.7). DEQ could identify no existing studies that measure residence time of migrating adult Chinook or steelhead beginning with capture at the mouth of the Willamette near the confluence (RM 0). This is a significant knowledge gap as migrating adults are known to enter the lower Columbia River and hold before entering the Willamette River (Friesen 2005, Myers et al. 2006, Schroeder et al. 2007, Keefer and Caudill 2010, Wargo-Rub et al. 2011). Migrating Chinook and steelhead are thought to spend the majority of their time in the lower Willamette migration corridor in the reach downstream of Willamette Falls (RM 0 – 26.7), and little time in the reach from the falls to Newberg (RM26.7-50.8), before migrating further upstream.

Best professional estimates of UWR and LCR salmon and steelhead residence time in the migration corridor range from ~5 to 21 days below Willamette Falls from (RM 0 – 26.7). Residence time around 5 days may be typical and expected to be more common during warm temperatures. Residence time increases during cooler conditions (Friesen, Gregory, & Keefer, personal communications).

4.5.1.2 Timing from Willamette Falls to Newberg

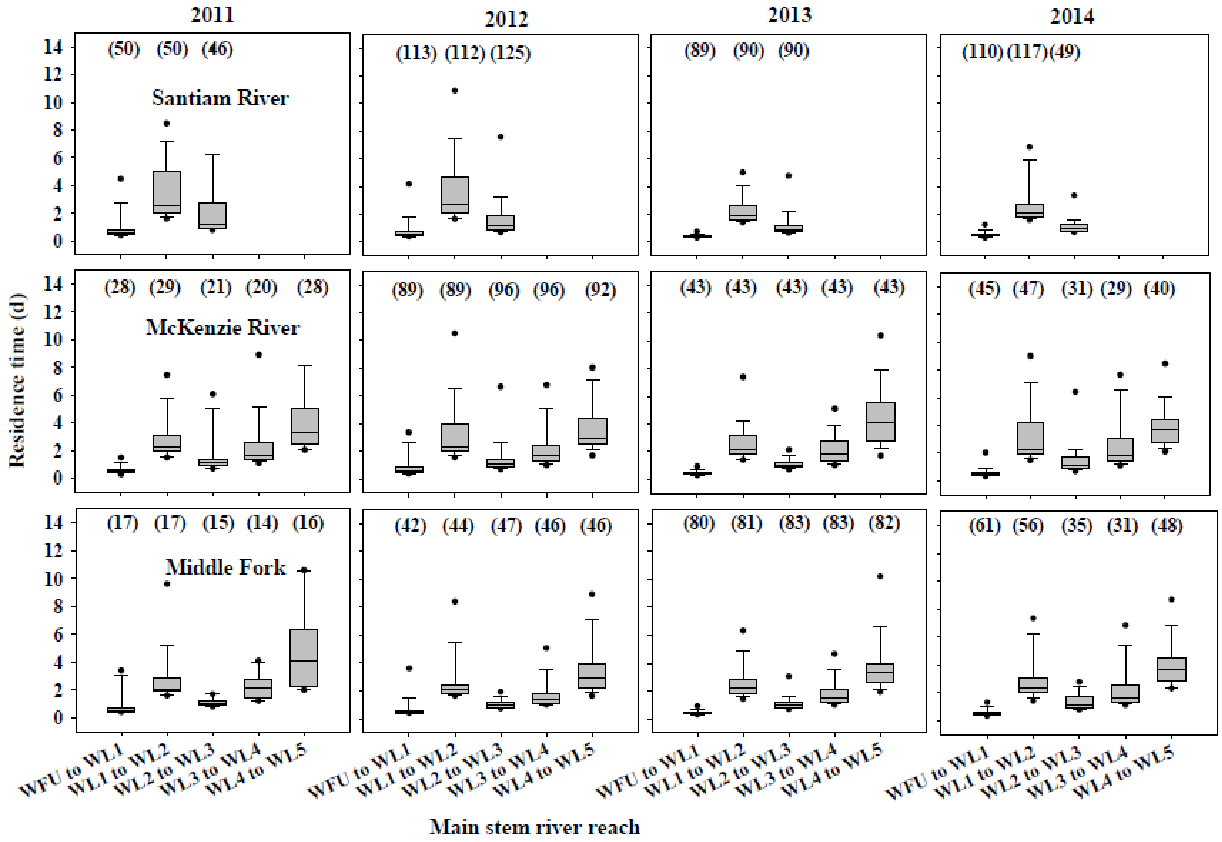
Telemetry studies have measured residence time for both salmon and steelhead in the reach from Willamette Falls to Newberg (RM 26.7 – RM 50.8) to range from less than 1 day to 4 days (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015).

UWR Chinook salmon residence time

Jepson and others used radio-tags to study run timing, composition, and behavior for spring Chinook salmon, winter and summer steelhead, and Coho Salmon over multiple years (Jepson et al. 2011, 2012, 2014, 2015). They tagged adults at the Willamette Falls fish way and monitored their migration into the spawning tributaries.

The authors estimated residence time in the migration corridor from Willamette Falls to a telemetry receiver stationed at Champoeg Creek near Newberg. Residence time ranged from <1 day to 5 days (Figure 4-29). This was consistent across multiple years for Chinook salmon. The highest Chinook migration rates in the Willamette basin occurred within the lower Willamette migration corridor. The mean migration rate for spring Chinook salmon ranged from 22.2 km/day in to 27.3 km/d.

Figure 4-29 Residence time distribution of tagged spring Chinook salmon in main stem reaches of the Willamette River in 2011 – 2014. Each row shows fish heading to different natal areas, indicated in the column of graphs for 2011. Numbers in parenthesis are the number of fish tracked. Stations WFU to WL1 is the reach within the migration corridor from the antenna at Willamette Falls (WFU) to Champoeg Creek (WL1). Other antennas are for reaches outside the corridor at Eola (WL2), Buena Vista (WL3), Corvallis (WL4), and Harrisburg (WL5). Data source: (Jepson et al. 2015).

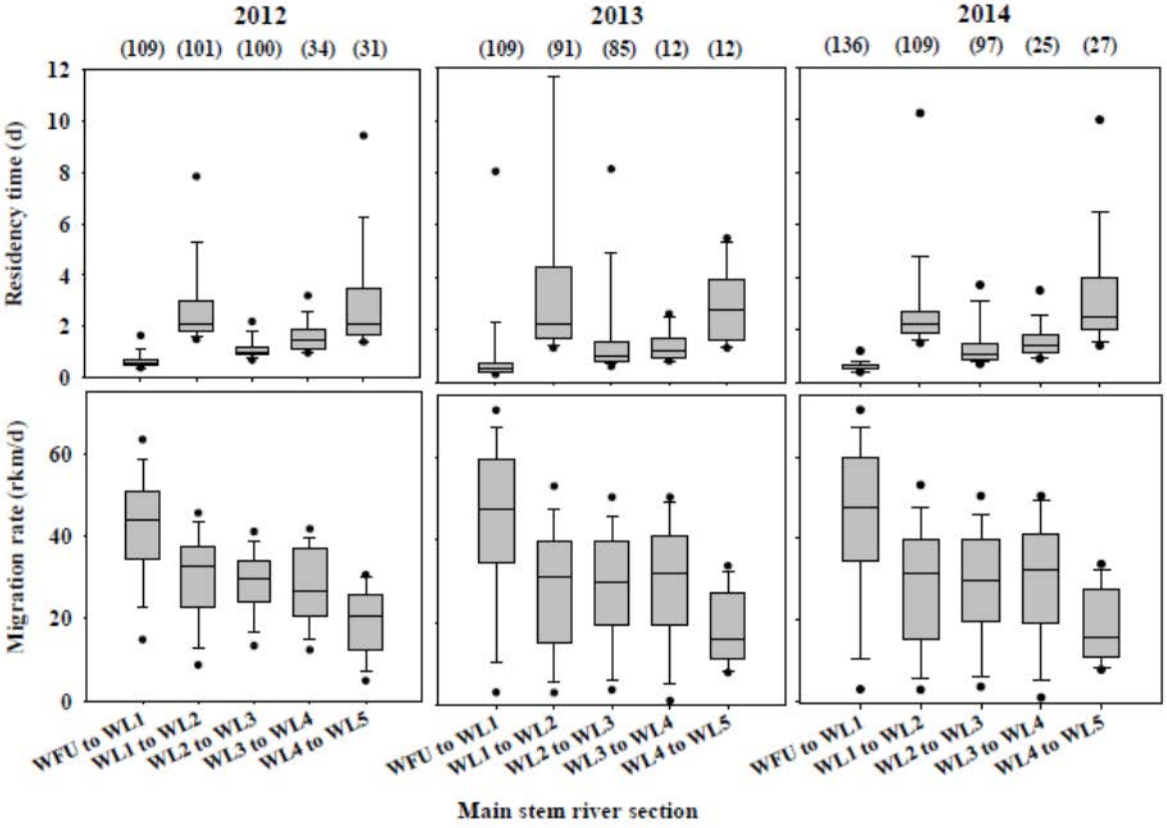


UWR winter steelhead residence time

The Jepson series of reports are one of the few studies that has included radio telemetry tagging for winter steelhead in the lower Willamette basin. Residence time and migration rates are similar to those for spring Chinook salmon in the lower Willamette migration corridor from Willamette Falls to Champoeg Creek (Figure 4-30). Even though migrating adult UWR winter steelhead do not encounter main stem temperatures >20°C in the migration corridor, median residence time within the lower reach is less than one day. At mean migration rates of ~45 km/d, winter steelhead should transit the entire lower Willamette migration corridor within 2 days.

Steelhead migration is faster in the migration corridor than the rest of the main stem upstream of RM 50.8. This data suggests there is more potential evidence for cold-water refuge use by steelhead in the upper main stem and tributaries than in the migration corridor. Steelhead in tributaries have been observed to slow migration to as little as 1-1.5km/day as temperatures exceeded 20°C as a daily average during pre-spawn holding (Hulse et al. 2007).

Figure 4-30 Residence time (top) and migration rate (bottom) of tagged winter steelhead in main stem reaches of the Willamette River in 2012-2014. Numbers in parentheses are the number of fish tracked. WFU to WL1 is the reach within the Lower Willamette migration corridor from the antenna at Willamette Falls (WFU) to Champoeg Creek (WL1). Other antennas for reaches outside the corridor shown are Eola (WL2), Buena Vista, OR (WL3), Corvallis (WL4), and Harrisburg (WL5).Modified from (Jepson et al. 2015)



4.5.2 Surveys of fish spatial distribution and habitat use

4.5.2.1 Hulse and Gregory, 2010

Researchers from the Oregon State University Department of Fisheries and Wildlife conducted surveys of native and non-native fish communities in the Willamette River from 2010 through 2017. They conducted boat and backpack electrofishing surveys of adult salmon and steelhead, recording abundance within each of 1km wide floodplain transects or "slices" of the Willamette main stem. Sampling progressed in a downstream direction approximately 4 to 10 m from shore and in depths of 1 to 4 m. The sampling protocol for these surveys allowed sampling when water temperatures were up to 20°C. Protocols typically limit researchers from electrofishing in temperatures above 18°C to prevent inducing stress on listed salmonids (NMFS 2000).

Salmon and steelhead congregating in cold-water patches is an indicator of CWR use (Torgersen et al. 1999). Data from the SLICES framework fish surveys shows adult Chinook salmon congregating in locations throughout the entire migration corridor during surveys on dates in May, June, July, and October from 2011-2013 (Figure 4-31). Adult steelhead were only found in two locations– with one individual in each slice. Both of these locations were upstream of the migration corridor. The sampling dates are later than end dates for steelhead migration under current conditions. Water temperatures in the main stem ranged from 14°C – 20°C for these samples.

Chinook adults and juveniles more frequently congregated in locations in the lower reach of the migration corridor downstream of Willamette Falls (RM 0 – RM 26.7). While some congregation sites coincided with candidate CWR tributaries, with the exception of the Clackamas River and Johnson Creek, Chinook did not congregate near the largest tributaries. Many of the congregation sites were either near smaller CWR sites– those with mean August flows less than 1 cfs not suitable for adults– or at locations where no CWR was identified (Figure 4-32). Fish were sampled where water temperatures where not more than 2°C cooler than the main stem (Figure 4-32). These locations may address different habitat needs than CWR, such as flow relief, feeding, or concealment.

In the lower reach of the migration corridor from the mouth to Willamette Falls (RM 0 – 26.7), salmon and steelhead were observed congregating in locations that correspond to potential cold-water refuge locations at Balch Creek (n=5-7), Marquam Bridge (Interstate-5) (n=12–16), Johnson Creek (n=2–4), and Meldrum Bar / Clackamas River mouth (n=17–27).

In the southern half of the migration corridor from Willamette Falls upstream to the confluence with the Yamhill River (RM 26.7 – 51.8), salmon and steelhead were observed congregating in locations that correspond to potential cold-water refuge locations. These were the back-channel complex above and below Rock Island (n=12-16), the bend near Hidden Creek upstream of the Molalla River (n=5-7), Boeckman Creek (n=2-4), the vicinity of Jim Tappman Creek (n=5-7), the mouth of Ryan Creek (n=8-11), and downstream of the mouth of Champoeg Creek (n=5-7).

These data are highly suggestive that Chinook salmon are not making widespread use of CWR in temperatures less than or equal to the 20°C migration corridor criterion. In temperatures up to 20°C, adult Chinook are observed using habitat less than a 2°C difference of the main stem temperature. This does not fit our definition of CWR use. Because fish were not sampled in temperatures greater than 20°C, the SLICES surveys do not provide insight into Chinook behavior during the times of year when temperatures exceed the criterion.

Figure 4-31 Salmon and steelhead abundance in channel and floodplain transect "SLICES" in the Willamette main stem river, 2010-2013. Data source: (Hulse et al. 2010) and (Stanley Gregory, unpublished data).

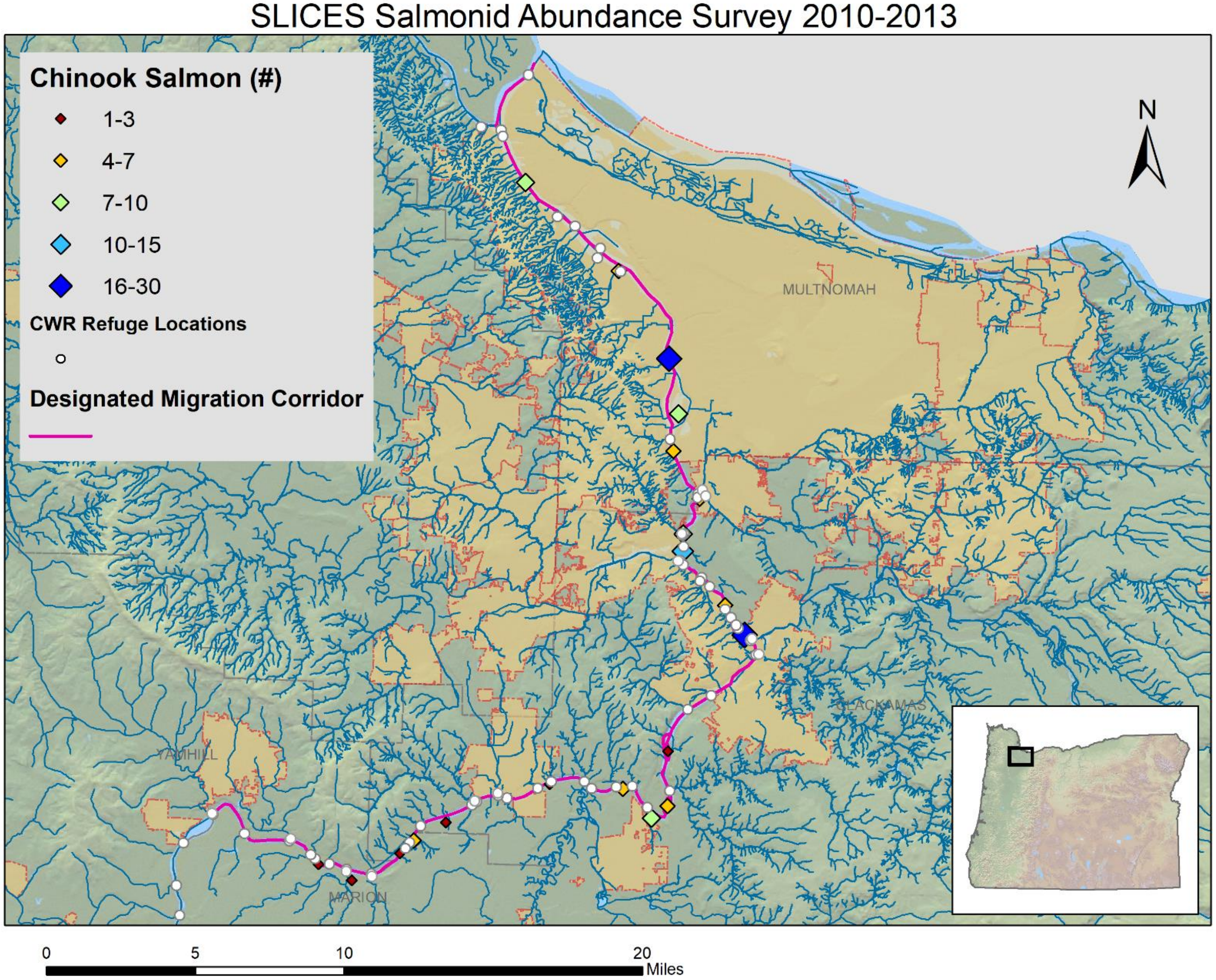
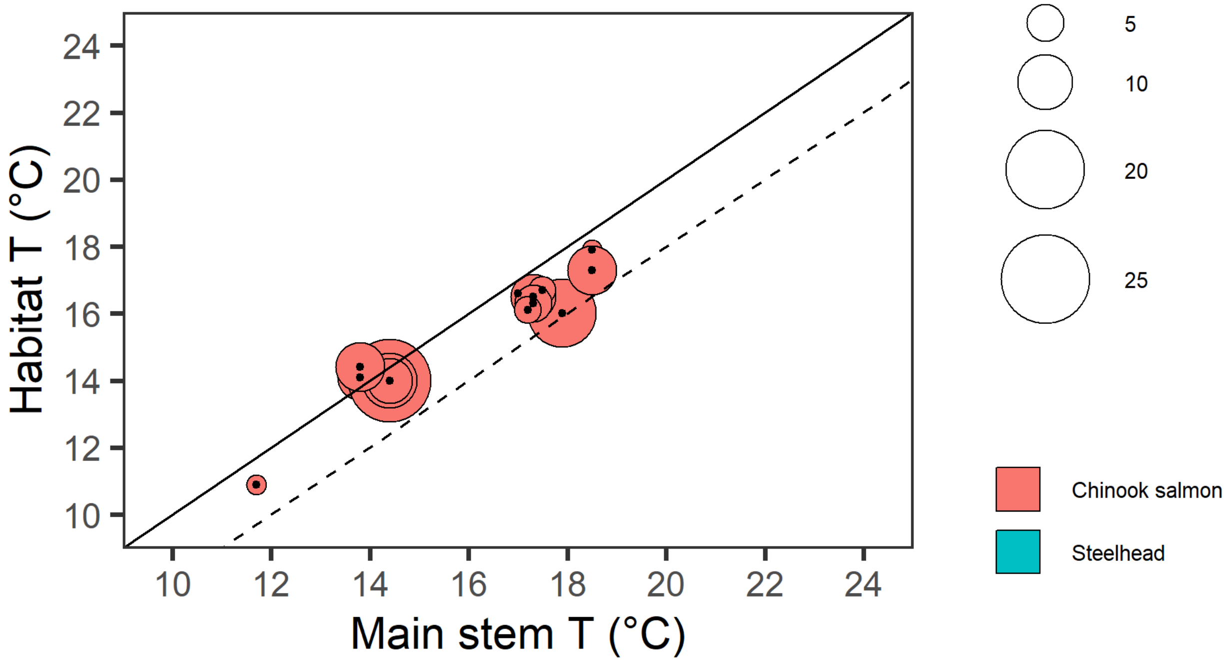


Figure 4-32 Salmon and steelhead abundance counts in 100m floodplain transect "slices" showing the habitat temperature where fish were sampled and daily maximum main stem water temperatures measured at USGS gage Portland. Solid line shows where habitat temperature = main stem temperature. Area below dashed line shows where habitat temperatures were more than 2°C cooler than the main stem. Black dots indicate center of bubbles, area of bubbles indicates sample count of fish for n= 164 fish. Data source: (Hulse et al. 2010), USGS, and Stanley Gregory (unpublished data, personal communication).

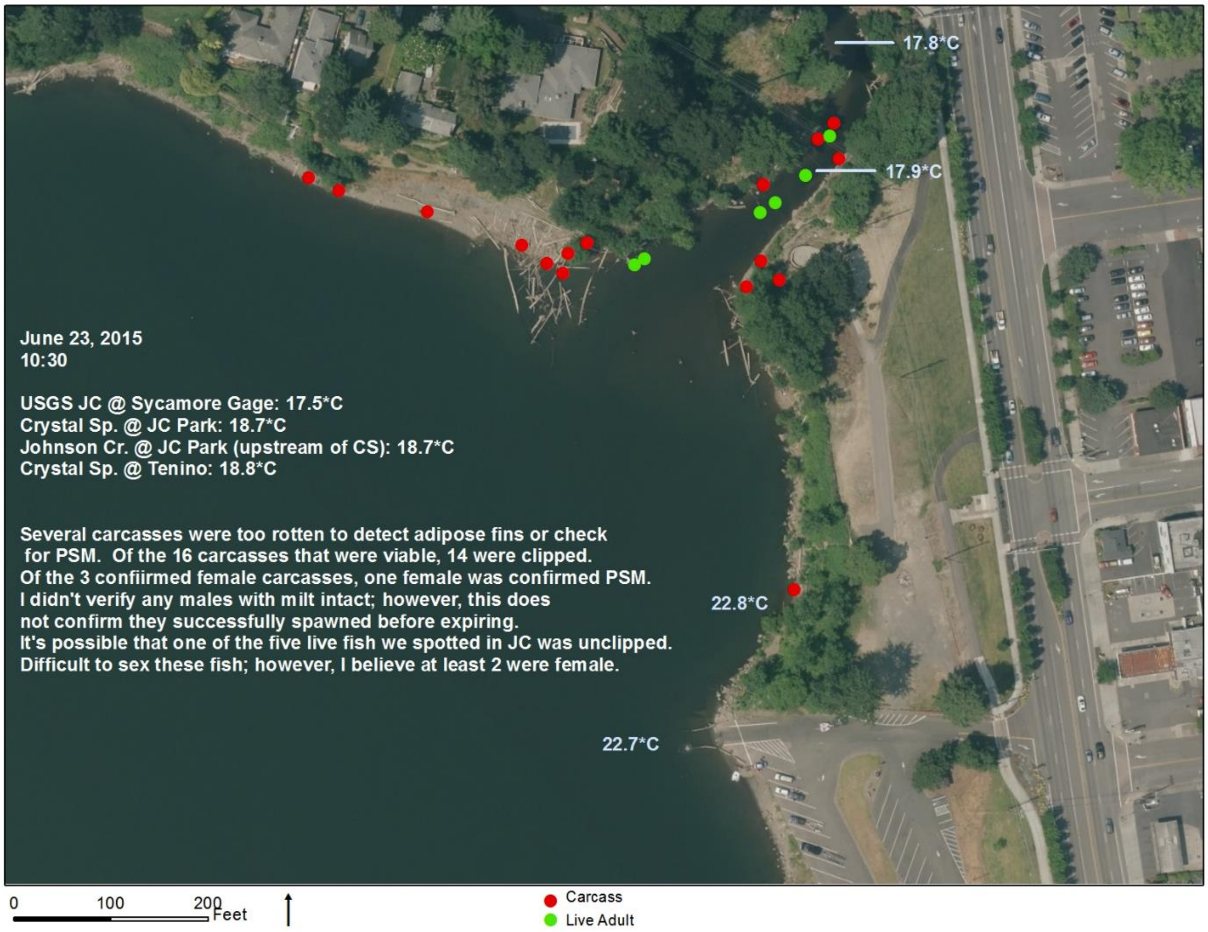


4.5.2.2 Portland Bureau of Environmental Services, 2015

During unusually warm spring temperatures in 2015, the Portland Bureau of Environmental Services conducted an ad hoc carcass survey in Johnson Creek and observed adult Chinook salmon in the CWR on June 23, 2015 (Figure 4-33). Temperatures in the mouth of Johnson Creek were ~17°C while the nearby main stem temperatures were above 22°C. They counted six live Chinook, many showing signs of physical distress or disease, and 16 Chinook carcasses.

Fish passage counts at Willamette Falls dam on the 10 days preceding this observation were an average of 45 fish per day. Passage counts dropped to zero per day within three days following BES's observation. It is probable that the fish observed in CWR at Johnson Creek during this event were moribund fish seeking any available relief because they were in too poor condition to ascend the falls, while healthy fish proceeded over Willamette Falls. Because this observation only provides a snap shot, it is not known if healthy fish used the refuge for short periods to aid their migration but did not hold for a long period and delay. This observation suggests that, if used, healthy Chinook did not spend extensive time holding in CWR even as temperatures in the main stem warmed beyond 22°C.

Figure 4-33 Cold-water refuge use and carcass survey during extreme temperature event June 23, 2015. Source: (Melissa Brown, Portland Bureau of Environmental Services, unpublished data). PSM refers to mortality with egg skeins retained.



June 23, 2015
10:30

USGS JC @ Sycamore Gage: 17.5*C
Crystal Sp. @ JC Park: 18.7*C
Johnson Cr. @ JC Park (upstream of CS): 18.7*C
Crystal Sp. @ Tenino: 18.8*C

Several carcasses were too rotten to detect adipose fins or check for PSM. Of the 16 carcasses that were viable, 14 were clipped. Of the 3 confiirmed female carcasses, one female was confirmed PSM. I didn't verify any males with milt intact; however, this does not confirm they successfully spawned before expiring. It's possible that one of the five live fish we spotted in JC was unclipped. Difficult to sex these fish; however, I believe at least 2 were female.

4.5.2.3 Silver and others, 2017

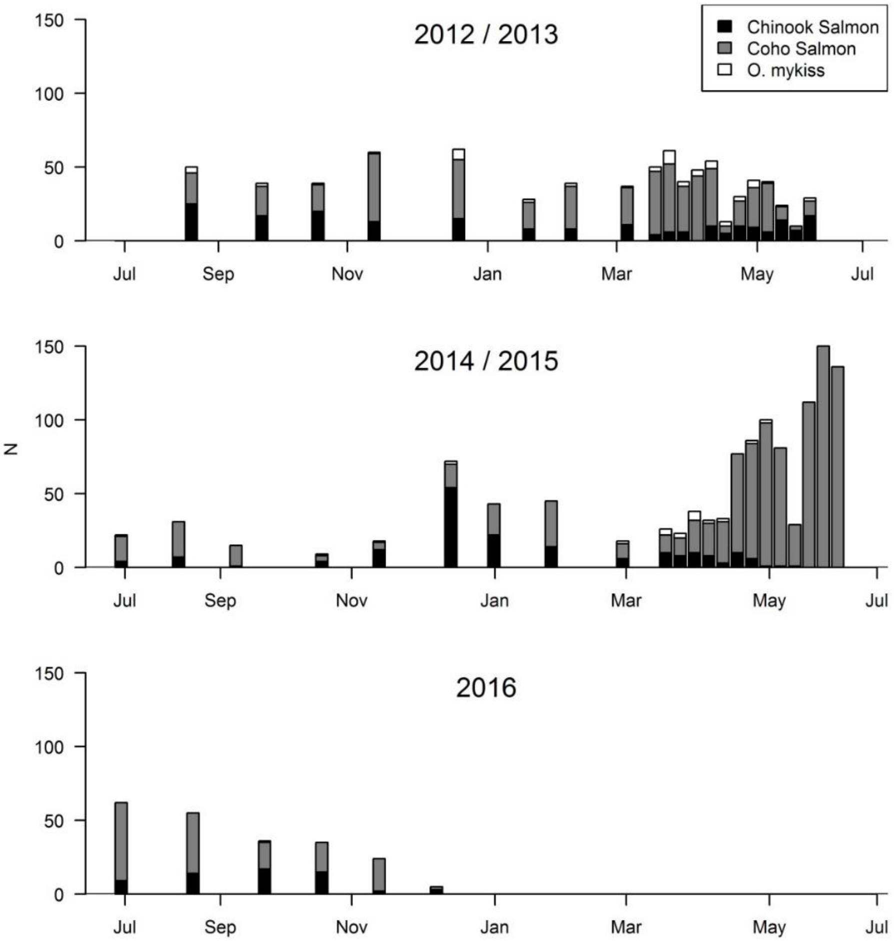
Silver and others in a partnership between the U.S. Fish and Wildlife Service and the City of Portland conducted electrofishing and seine surveys of adult and juvenile salmon and steelhead that use the mouth and adjacent channel of Tryon Creek. Survey frequency was weekly from March – June and monthly from July-February. As part of restoration monitoring, a PIT tag interrogation antenna is maintained just above the mouth of Tryon Creek near the confluence with the Willamette River. Migrating adult Chinook have been detected by PIT tag using Tryon Creek during the upstream migration (Silver et al. 2017a). Both adult and juvenile Chinook salmon use the creek. The number of Chinook observed is highest during winter months and are predominantly juveniles (Figure 4-34). Counts of adult and juvenile steelhead are low, but small numbers are detected in Tryon Creek mainly from March to May.

There were not qualitatively more Chinook detections during the “hot” year of 2015 than 2012. Tryon Creek did not exceed 18°C in the years sampled, permitting surveys in Tryon creek even during summer months when the Willamette main stem exceeded 18°C. Therefore, low survey counts during these months are accurate. Chinook detections in Tryon Creek were near zero for May – June during the “hot” 2015 year, relative to tens of fish counted per week during the same period in the cooler year of 2013. Fish counts at Willamette Falls were simultaneously at their peaks during the last weeks of May and early

June 2015 (Figure 4-26). Therefore, there were large numbers of migrating Chinook in this reach of the Willamette River at the time that could have held in Tryon as CWR, but did not.

This pattern suggests that migrating adult or even juvenile Chinook do not hold for long periods of time in Tryon Creek as CWR, even during months when the main stem temperature is above 20°C. The researchers attribute low counts of Chinook in June and July 2015 to absence of adults and low abundance of juvenile Chinook because of heavy out-migration during this time (Brook Silver, personal communication).

Figure 4-34 Counts of adult + juvenile salmon and steelhead collected during weekly surveys at Tryon Creek. Data source: (Silver et al. 2017a).



4.5.3 Radio telemetry and thermal logger studies

4.5.3.1 Schreck and others, 1994

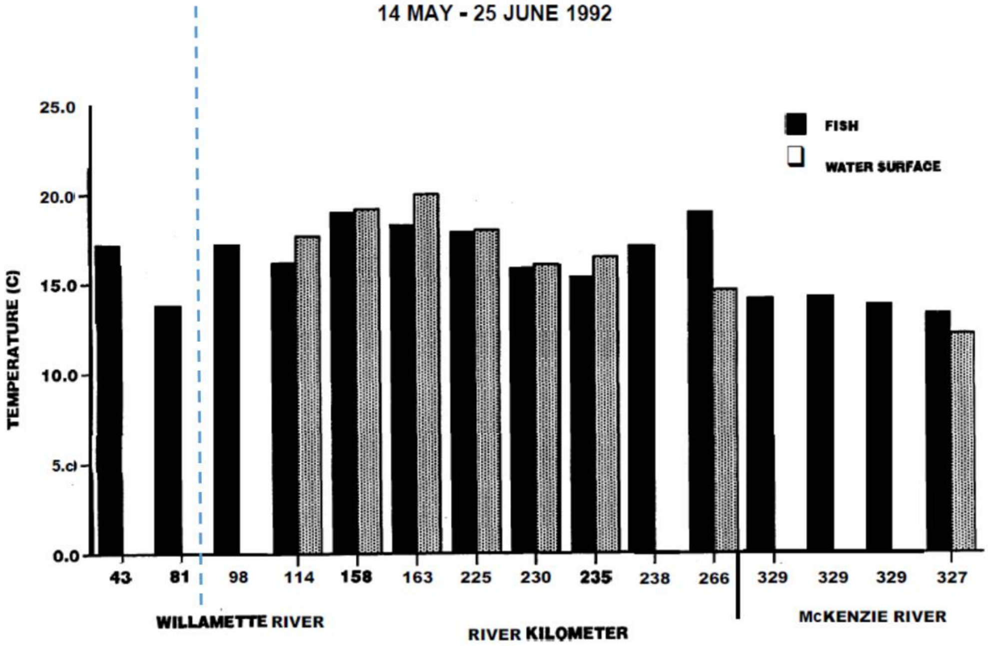
This study is possibly the first study in the Willamette basin to use radio-telemetry and body thermal loggers to measure Chinook salmon migration timing and patterns (Schreck et al. 1994). They attached radio-transmitters to adult Chinook salmon in groups of 5-30 individuals at the Willamette Falls fish ladder from 1989-1992. Passage time, and migration path tracking were recorded for a total of 224 individuals distributed over early (April), middle (May) and late (June) portions of the spring Chinook salmon migration. They attached body thermal logger tags to a subset of 10 individuals. The authors did not identify whether tagged individuals were from hatchery stock or naturally propagating populations.

They observed that late run Chinook, passing the falls during the middle and late groups, including during the warmest times in June and July, migrated faster compared to Chinook tagged earlier in the season. Some late run fish were observed ceasing migration or falling back downstream after migrating l0-200 km up the Willamette River or tributaries. Falling back was associated with the warmest summer temperatures in the tributaries and resulted in high rates of mortality. Residence times at the falls for Chinook salmon was longest during flood events when turbidity and discharge were high and water temperature was low.

Body temperatures of Chinook salmon did not exceed 18°C in the migration corridor from the Willamette Falls fish ladder to Newberg (RM 26.7 – 50.8) and were the same as main stem water temperature (Figure 4-35). The authors concluded that there was not cold-water refuge use. Either there were no cold-water refuge available or their equipment was not sensitive enough to record subtle temperature differences that were important to the fish.

This study does not provide evidence of CWR use by migrating spring Chinook salmon in migration corridor upstream of Willamette Falls (RM 26.7-50.8). Migration rates for late run Chinook salmon increased, rather than decreased, during high temperature conditions. Prolonged exposure to high temperatures resulted in continued migration, migration fallback, or mortality, rather than refuge-seeking or holding behavior. However, the findings do suggest potential that CWR use and refuge-seeking behavior occurs in the main stem and tributaries farther upstream from the migration corridor and our study area.

Figure 4-35 Temperature history of a tracked spring Chinook salmon individual in the Willamette main stem, 1992. Area to the left of the dashed line shows body temperatures (black bars) when within the lower Willamette migration corridor. Grey bars show surface water temperature when it was different than body temperature. Modified from (Schreck et al. 1994)



4.5.3.2 Keefer and others, 2015 / Jepson and others, 2015

Keefer and others is the most extensive radio-tag and body thermal logger study of Chinook salmon in the Willamette basin to date (Keefer et al. 2015). The data for this effort are the same as those collected over multiple years for (Jepson et al. 2011, 2012, 2014, 2015). The Jepson reports also include radio-tag data studies of run timing, composition, and behavior for spring Chinook, winter and summer steelhead, and Coho salmon.

Keefer and others captured and implanted radio-telemetry tags in 419 wild Chinook salmon and 530 hatchery Chinook salmon at the Willamette Falls fish ladder across multiple years from 2011-2013. Thermal loggers were also implanted in 310 of the salmon and 68 were later recovered. Because fish were captured at Willamette Falls, only a very few Chinook salmon that fell back from the falls provide data from the migration corridor downstream of Willamette Falls (RM 0–26.7). Tag and thermal loggers were mainly recovered outside of the migration corridor in the rest of the Willamette main stem and in the tributaries.

These studies found that most salmon experienced a wide range of body temperatures. Sixty-five percent of the recovered thermistors showed that Chinook encountered potentially stressful conditions with body temperatures of at least 18°C. The warmest body temperatures recorded were for Chinook in the lower Willamette main stem, including the migration corridor between Willamette Falls and Champoeg Creek (RM 26.7 – 45.0). The authors observed that some fish exhibited short-duration behavioral thermoregulation by locating and holding in cold water. This holding behavior only occurred in main stem reaches and tributaries upstream of the migration corridor, especially just below tributary dams.

Depending on time of migration and inter-annual variability, cumulative temperature exposure of UWR Chinook in this study ranged from 208-1,498 ATUs. About 28% of total ATU exposure and the majority of stressful instantaneous temperatures (>18°C) experienced by individuals occurred in the main stem. The remaining majority of ATUs accrued during holding in tributaries. This result aligns with our analysis of run-timing exposure in Section 4.4.

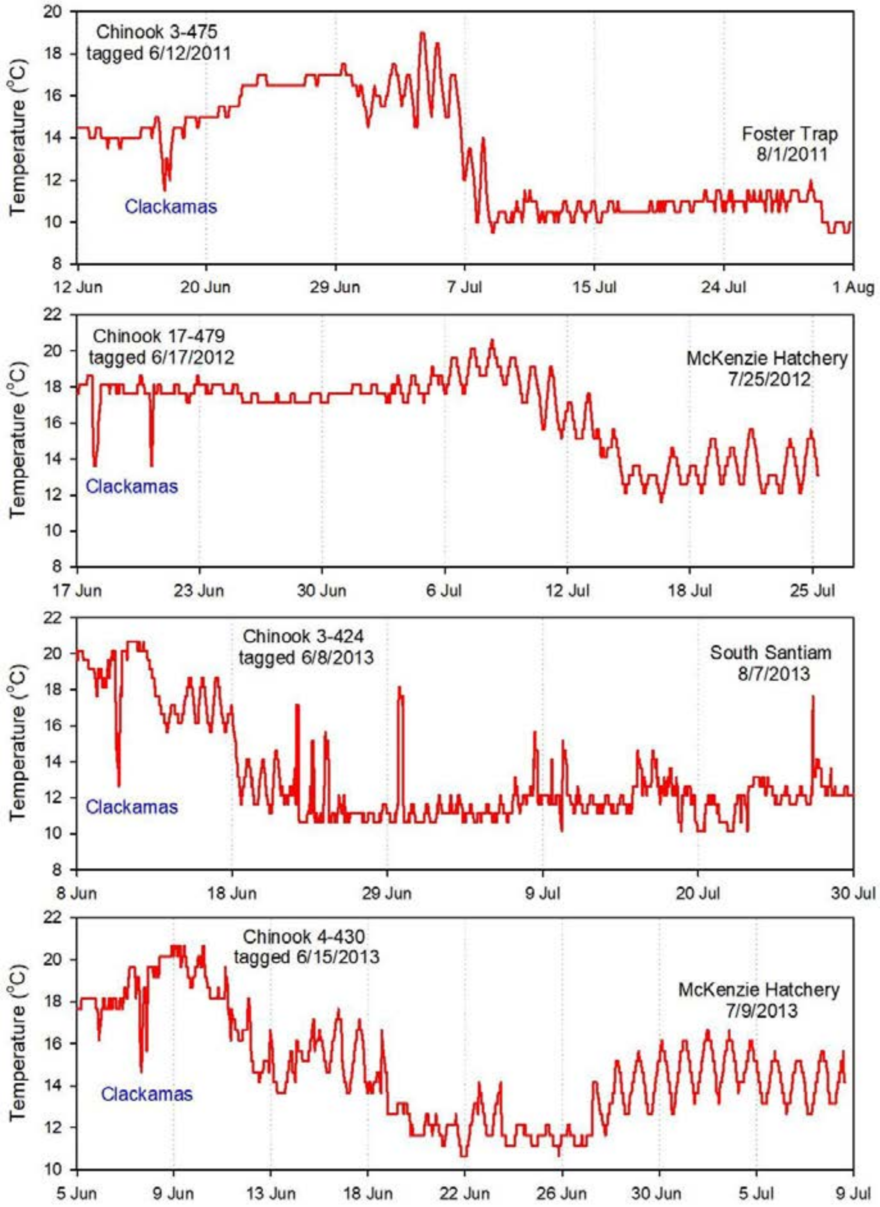
Unpublished data collected during this study showed five of 68 recovered temperature loggers (7.3%) for Chinook entering the Clackamas River after release at Willamette Falls. These fish spent an average of 12 hours in the colder water before resuming upstream migration. Some individuals remained in the Clackamas for up to 36 hours during times when main stem temperatures were >20°C (Matthew Keefer, personal communication).

Two examples of thermal logger histories for Chinook individuals that entered the Clackamas River after release in the Willamette Falls fish ladder are shown below (Figure 4-36). Chinook number 17-479 (second from top panel) and Chinook number 4-430 (bottom panel) were ultimately recovered at the McKenzie Hatchery. They each entered the Clackamas River when temperatures in the main stem were near 18°C. Chinook number 3-475 (top panel) was ultimately recovered at the Foster Dam fish trap. It entered the Clackamas River even though main stem temperatures were less than 15°C. Neither individual experienced prolonged body temperatures in excess of 20°C and within ~6 days entered tributary waters considerably cooler than the main stem. Chinook 3-424 entered the Clackamas River when main stem temperatures were at or above 20°C, but held for less than a day, and within 10 days entered and remained in water near 14°C until recovered in the South Santiam River. In each case, Chinook that traveled far enough upstream of Willamette Falls experienced a large decrease in water temperature.

The Jepson report concluded that tagged Chinook salmon did not appear to slow or cease migration even when exposed to temperatures >20°C, and their body temperature rarely diverged from the ambient main stem temperatures. Chinook salmon use of the Clackamas River by a few individuals that fell back after tagging was the only direct evidence of cold-water refuge use for the migration corridor from river mile 25–50.8. There were no recorded instances of fish using cold-water refuge from Willamette Falls to Newberg. The authors of the Jepson et al. reports stated that they did not observe widespread straying to tributaries when main stem temperatures exceeded 20°C and concluded that it is likely that Chinook salmon are not seeking CWR in the reach of the migration corridor upstream of Willamette Falls (RM 26.7-50.8).

These studies corroborated the findings of (Schreck et al. 1994) that Chinook salmon migration rates increase with higher temperatures. Jepson and others hypothesize that a behavioral strategy for faster migration rates during warm temperatures in the migration corridor may offset greater risk of mortality from accumulated main stem temperature exposure. Recovered temperature data usually shows that Chinook enter much cooler water as they move upriver to tributaries at higher elevation within the basin.

Figure 4-36 Thermal history of spring Chinook salmon individuals observed in 2011–2013. Temperature measurements recorded at 30-minute intervals. Unpublished data (Personal communication, Matthew Keefer, University of Idaho, 9/10/2019. From data collected for (Keefer et al. 2015)



4.5.4 Summary and conclusions for evidence of cold-water refuge use in the migration corridor

Table 4-4 summarizes the studies that have tracked Chinook salmon and steelhead migration and behavior of individual fish in the lower Willamette River and the evidence for cold-water refuge use we may derive from their data and conclusions.

Table 4-4 Summary of evidence for CWR use in the lower Willamette migration corridor

Study	Evidence of Cold-water refuge use >18°C	Absence of cold-water refuge use >18°C	Inconclusive
Shreck et al., 1994		X	
Hulse and Gregory, 2010			X
Keefer et al, 2015 / Jepson et al, 2015	X (incidental or occasional use of Clackamas River)	X (Upstream of Willamette Falls; RM 26.7-50.8)	X
Portland BES, 2015	X		
Silver et al. 2017			X

4.6 Summary and conclusions on CWR use

The conclusions DEQ draws based on the analysis of adult Chinook salmon and steelhead migration behavior, fish passage data, migration timing, and previous tracking and tag studies are summarized below. DEQ indicates the supporting information from this chapter below each summarized conclusion.

In many cases, differences in fish behavior upstream or downstream of Willamette Falls, the study designs for data collection, and limitations on temperature conditions when researchers can collect fish, means we separate our evaluation of the evidence for CWR to match the geographic and data constraints. Conclusions about behavior for the portion of the migration corridor upstream and downstream of Willamette Falls, and during times when water temperatures are above the criterion or below the criterion, are evaluated separately (see also Table 6-1).

4.6.1 Adult UWR spring Chinook

4.6.1.1 Thermal Exposure

1. Under current conditions (2007-2017), an average of 9%, with a range of <1%–43%, of the UWR Chinook run that pass Willamette Falls dam are exposed to daily maximum temperatures exceeding the 20°C criterion. We cannot account for any proportion that *would pass* Willamette Falls dam but may have been blocked, strayed, or otherwise prevented by thermal and flow conditions.
    - Chinook passage counts at Willamette Falls vary annually in their overlap with the period of days that exceed the 20°C migration corridor criterion. See Section 4.4.1 Tables 4-1, 4-2; Figures 4-22, 4-27
2. Under current conditions (2007-2017), an average of 28%, with a range of 10%–48%, of the UWR Chinook run that passes Willamette Falls dam is exposed to daily average temperatures above 18°C. This is a threshold observed to trigger the start of refuge seeking behavior in other Chinook populations.
    - Chinook passage counts at Willamette Falls vary annually in overlap with the period of days that exceed 18°C as daily mean temperature. See Table 4-2; Figure 4-26
3. The response of upstream migrating UWR Chinook to higher mainstem temperatures and/or low flows has been a tendency to migrate earlier in the season and at faster rates.
    - Chinook passage at Willamette Falls begin and peak earlier in warmer years. See Section 4.4.1 and Figure 4-6, Figure 4-9, Figure 4-25, Figure 4-26, (Jepson et al. 2015, Keefer et al. 2019)

- The duration of both modeled and observed migration time decreases with higher temperatures. See Figure 4-17,Figure 4-19, Figure 4-234-23 and (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015, 2019)
- The behavioral response of migration timing likely evolved to adapt to seasonal migration blockage caused by low flows Willamette Falls. See Section 4.2.1 and (Meyers et al. 1998).

4. Travel times of adult UWR spring Chinook salmon in the lower Willamette migration corridor is 5-21 days below Willamette Falls (RM 0–26.7) and <1–4 days above the falls (RM 26.7–50.8).
    - Observed migration travel times are <1-4 days in the corridor between Willamette Falls to Newberg. See Section 4.5.1, (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015, 2019).
    - Travel times for have not been measured downstream of Willamette Falls. Professional opinion is that Chinook spend 5-21 days in the migration corridor before passing Willamette Falls, depending on water temperature and flow. Fish tend to move through this reach more quickly when the water temperature is warmer and flows are lower. Fish tend to move more slowly when the water temperature is cooler and flows are higher. Personal communications- Thomas Friesen (ODFW) and Matthew Keefer (University Idaho). See also Section 4.3.5.1, 4.4.2.1, Figure 4-19, Figure 4-234-23, and (Jepson et al. 2015, Keefer et al. 2015, 2019).
5. The spatial distribution of CWR are sufficiently spaced to be accessible by individual adult UWR Chinook salmon within a day or less if traveling at least the median observed migration rate of UWR Chinook. While data shows adult Chinook are capable of these rates, typical rates of migration while downstream of Willamette Falls have not been measured.
    - The average density of CWR is 1 per 0.23 km (1 per 0.39 miles). See Section 3.5.2and Table 3-5.
    - Observed migration rates are ~22-27 km/d (13-16 mi/d). See Section 4.5.1.2 and Figure 4-29.
6. The size or volume of CWR needed to support a given population is unknown. There are no existing studies that measure the volume of CWR needed at the population level in any river system.

4.6.2 Habitat Use

4.6.2.1 Below Willamette Falls (RM 0 – 26.7)

1. Due to lack of data, there is uncertainty whether the adult UWR Chinook run uses CWR below the falls or would use CWR if more were available, when exposed to average daily river temperatures above 18°C, or maximum weekly temperatures above 20°C.
    - The majority of the annual Chinook run avoids exposure to high temperatures. See Section 4.3.5; Figure 4-14, Figure 4-26, Table 4-2
    - UWR Chinook continue to pass Willamette Falls in temperatures greatly exceeding daily maximums of 20°C. See Figure 4-16, Figure 4-26.
    - There is inconclusive evidence whether Chinook hold in CWR during extremely warm conditions, due to lack of data. Few surveys exist for extremely warm years. See Section 4.5.24.5.2 and Figure 4-31, Figure 4-32, Figure 4-33, Figure 4-34.

2. There is strong evidence for temporary holding by migrating adult Chinook in the Clackamas River-Meldrum Bar area. Because temporary holding behavior is also observed when the mainstem temperatures are less than 18-20°C, it is unclear whether this area serves primarily as CWR or for other habitat functions.
    - Surveys show Chinook congregate near the Clackamas River – Meldrum Bar in the area across a range of temperature conditions. See Section 4.5.2, Figure 4-31
    - Tag and body thermal logger studies track Chinook to cooler water near the mouth of the Clackamas River. See Section 4.5.1 and Figure 4-36.
3. **During water temperatures up to and including the 20°C criterion** there is inconclusive evidence of regular or widespread CWR use by UWR Chinook except for the Clackamas River confluence.
    - Few studies have directly addressed this question and little monitoring has been done in this reach of the corridor to date.
    - The main channel fish surveys currently available show a tendency by adults and juveniles to use habitat of similar temperature to the mainstem temperatures under these conditions. See Figure 4-32 and published and unpublished data from (Hulse et al. 2010).
    - Currently available surveys conducted in CWR tributaries show low occupancy in warm months during the Chinook migration period. See Figure 4-34 and (Silver et al. 2017a).
4. **Under conditions when the 20°C criterion is exceeded** a lack of available data prevents drawing firm conclusions about UWR Chinook CWR use due to limitations in study design and fish sampling restrictions.
    - There are few available studies conducted downstream of Willamette Falls and limitation on fish handling protocols when water temperatures exceed 18°C. See Section 4.5.2 and (NMFS 2000).
    - The currently available data shows mixed evidence of refuge use and non-refuge use by migrating UWR Chinook during warm conditions. See Section 4.5.2and Figure 4-33, Figure 4-34.
    - Modeled and observed migration times decrease with high temperature, suggesting Chinook do not hold for long in CWR, if used, in response to warmer temperatures. See Figure 4-17,Figure 4-19, Figure 4-234-23, and (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015, 2019).
5. **Under conditions when the 20°C criterion is greatly exceeded** there are isolated observations of CWR use in Johnson Creek (RM 18.5) during extreme temperatures (>22°C); such as June/July 2015. This behavior was not observed in nearby CWR at Tryon Creek (RM 20.1) during the same time period. Due to mortality observed in fish using the refuge there is high uncertainty about the risk or benefits of this CWR use to the population.
    - The currently available survey data shows mixed evidence for refuge use and non-refuge use during warm conditions. See Section 4.5.2 and Figures Figure 4-33, Figure 4-34. Chinook migration does not appear to be blocked by extreme temperatures. Migration past the falls began about a month earlier in a hot year than comparable cooler years. See Section 4.4.4, Figure 4-9, Figure 4-17, Figure 4-26, and (ODFW and WDFW 2016).
    - Modeled and observed migration times decreases with high temperatures suggest at the population level Chinook do not hold for long in CWR, if used, in response to warmer

temperatures. See Figure 4-17, Figure 4-19, Figure 4-234-23, and (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015, 2019).

4.6.2.2 Above Willamette Falls (RM 26.7-50.8)

1. **During water temperatures up to and including the 20°C criterion,** available evidence indicates little to no CWR use by migrating adult UWR Chinook in the migration corridor between Willamette Falls and Newberg (RM 26.7 – 50.8).
    - Tag and thermal logger data of fish movement and temperature experience above Willamette Falls do not indicate fish enter water cooler than the main stem above Willamette Falls. See Section 4.5.2; Figure 4-35, Figure 4-36, and (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015).
    - Researchers conclude in published studies that UWR Chinook body thermal logger data does not indicate CWR use between the Falls and Newberg (RM 26.7-50.8). See (Schreck et al. 1994, Jepson et al. 2015).
2. **Under conditions when the 20°C criterion is exceeded,** opportunities to observe CWR use and migration behavior are limited due to existing study design and fish sampling restrictions.
    - Collection of fish for tag and body thermal logger implantation to track fish movement above Willamette Falls are restricted to times when water temperatures are less than 18°C (Schreck et al. 1994, NMFS 2000, Jepson et al. 2015, Keefer et al. 2015)
    - The consensus of this study's expert panel is that there is not currently sufficient data to characterize the migration behavior of UWR Chinook above Willamette Falls when temperatures exceed the criterion.

4.7 Adult UWR winter steelhead

4.7.1 Thermal Exposure

1. Current migration behavior and timing of adult UWR winter steelhead in the lower Willamette migration corridor shows no exposure of this population to temperatures above the criterion or to thresholds expected to trigger CWR seeking behavior or present thermal risks to migration in the Willamette migration corridor.
    - Winter steelhead passage at Willamette Falls concludes before daily mean water temperatures exceed 18°C for all years under current conditions (2007-2017). See Section 4.3.3, 4.4; Figure 4-6, Figure 4-14, Figure 4-20.

4.7.2 Habitat Use

1. There are no direct observational data showing UWR steelhead holding in CWR in the lower Willamette migration corridor (RM 0 -50.8) for purposes of temperature relief.
    - Listed steelhead populations are not present in the migration corridor during spring or summer conditions, the seasons when fish surveys are conducted. See Figure 4-6, Figure 4-26, Figure 4-34, and (Hulse et al. 2010, Jepson et al. 2015).
2. Lack of exposure to daily mean temperatures above 18°C, expected to trigger CWR seeking behavior or present additional risks during migration, indicates there is not currently a need for CWR by this population.

- Winter steelhead passage at Willamette Falls concludes before water temperatures exceed 18°C under current conditions (2007-2017). See Section 4.3.3.2, 4.4, and 4.4.4.1; Figure 4-14, Figure 4-6, Figure 4-20.

4.8 Adult LCR fall Chinook

4.8.1 Thermal Exposure

4.8.1.1 Below Willamette Falls (RM 0 -26.7)

1. There are not sufficient data to characterize the run timing or thermal exposure of LCR Chinook salmon or UWR Chinook salmon (Clackamas River population) that migrate between the mouth of the Willamette River and the mouth of the Clackamas River (RM 0 – 24.9).
2. Current run timing at North Fork dam suggests a large proportion of the UWR spring or LCR fall Chinook run is potentially present in the migration corridor below Willamette Falls (RM 0 – 26.7) during times temperatures may exceed the criterion or thresholds expected to trigger CWR seeking behavior. Better run timing for entry of these fish to the Clackamas River mouth is needed to evaluate this risk.
    - Passage timing at North Fork Dam relative to Willamette River and Clackamas River temperatures. See Section 4.3.3.1 and Figure 4-8.
3. UWR spring and LCR fall Chinook do not experience temperatures greater than daily maximums of 20°C , but do experience daily maximums above 18°C in the Clackamas River under current conditions.
    - Water temperatures in the Clackamas River are at least 2°C cooler than the Willamette main stem during Chinook passage at North Fork Dam. See Section 4.3.3.1; Figure 3-12, Figure 4-8.

4.8.2 Habitat Use

1. **During water temperatures up to and including the 20°C criterion** there is inconclusive evidence for regular or widespread CWR use by Chinook salmon between the mouth of the Willamette River and Willamette Falls (RM 0 – 26.7), except for the Clackamas River confluence.
    - Lack of observed use of habitat that differs from mainstem temperatures by Chinook. See Figure 4-31 and Figure 4-32 for published and unpublished data from (Hulse et al. 2010).
    - Examples of low or no CWR habitat use by Chinook during peak migration times. See Figure 4-34 and (Silver et al. 2017a).
2. **Under conditions when the 20°C criterion is exceeded** there is a lack of available data which prevents drawing conclusions on LCR Chinook CWR use due to limitations in study designs and fish sampling restrictions.
    - UWR spring and LCR fall Chinook counts at North Fork Dam occur days to weeks after the fish were present in the Willamette River. This prevents direct comparison of passage counts to thermal exposure these fish experienced while in the Lower Willamette migration corridor. See Section 4.3.3.1 and Figure 4-8.
    - No available data shows UWR spring or LCR fall Chinook timing and abundance upon entering the mouth of the Clackamas River (RM 24.9).

4.9 Adult LCR winter steelhead

4.9.1 Thermal Exposure

1. There are not sufficient data available to characterize the run timing and temperature exposure of adult LCR winter steelhead (Clackamas River population) that migrate between the mouth of the Willamette River and the mouth of the Clackamas River Falls (RM 0 – 24.9).
2. Under current conditions, upstream migrating LCR winter steelhead complete passage of North Fork Dam on the Clackamas River (Clackamas river mile 29.9) even before water temperatures in the Willamette migration corridor measured at Portland exceed daily mean temperatures of 18°C, or daily maximum7-day average daily maximum temperatures above 20°C.
    - See Section 4.3.3.2 and Figure 4-8.

4.9.2 Habitat Use

1. There are no studies or surveys that focus on LCR steelhead habitat use in the lower Willamette migration corridor (RM 0 -50.8).
    - Steelhead are not present in the corridor during times of year when surveys are conducted in the spring and summer. At times steelhead are present, according to North Fork and Willamette Falls dam passage counts, main stem temperatures do not meet the biological thresholds recognized to trigger CWR use. See Section 4.5.2, Figure 4-32, Figure 4-34; (Jepson et al. 2015).
2. Lack of exposure to daily mean temperatures above 18°C, or daily maximum7-day average daily maximum temperatures above 20°C, that would be expected to trigger refuge seeking behavior or present additional thermal risks to migration, suggests there is not a need for CWR in the migration corridor by this population.
    - Passage at North Fork Dam concludes before water temperatures exceed 18°C in the Willamette River at Portland under current conditions (data available only for 2014-2017). See Section 4.3.3.2 and Figure 4-8.

4.10 Knowledge gaps about CWR habitat use

Telemetry studies and fish surveys to date have primarily focused on areas of the Willamette basin upstream of Willamette Falls and in the spawning and rearing tributaries. There are few direct observations of salmon and steelhead abundance, habitat use, and mortality within the 50 miles of the migration corridor. Without direct observation of Chinook salmon or steelhead thermoregulatory behavior in the migration corridor, it is difficult to draw strong conclusions about CWR use. Especially in the reach downstream of Willamette Falls (RM 0 – 26.7).

Most of the available survey, tag, and thermal history data collected to date begin with fish collection and tagging at the Willamette Falls fish ladder. Additionally, for most, but not all, studies the active sampling protocols restrict handling of fish when water temperatures are above 18°C. Since this is also the reach where experts expect migrating populations spend a longer portion of time within the migration corridor, we cannot assume that we can extrapolate the behavior observed upstream of Willamette Falls to the lower reach. This is also the only reach used by the Lower Columbia River populations of winter steelhead and spring/fall Chinook salmon that spawn in the Clackamas River or historically spawned in other tributaries downstream of Willamette Falls.

4.10.1 General knowledge gaps and research needs for CWR use by migrating adults.

1. Counts or estimates are needed of the number and timing of fish of each species entering the Willamette River from the Columbia River.
2. Monitoring conducted in identified CWR areas during times the main stem temperature exceeds 18°C could positively establish fish use and abundance in CWR during warm conditions.
3. Repair and maintenance of the PIT tag antenna array in the fish way at Willamette Falls.
4. Data connecting thermal experience in the migration corridor with ultimate en-route mortality, pre-spawn mortality, or reproductive failure at the end of migration.

4.10.2 Adult UWR spring Chinook data needed

1. Fish tag and body thermal logger studies to establish residence time, thermal exposure, and migration from the confluence with the Columbia River to Willamette Falls (RM 0-26.7).
2. Surveys of fish presence and abundance in refuge sites and other habitat when mainstem temperatures exceed 18-20°C (RM 0 – 26.7).
3. Evaluate CWR use in minor tributaries and fine-scale CWR sources of thermal heterogeneity, other than the Clackamas River, for conservation value to UWR Chinook, especially juveniles.
4. Mortality rates within the migration corridor from the mouth of the Willamette River to Newberg (RM 0 – 50.8).
5. Abundance and duration of CWR use and/or pre-passage holding time near the Clackamas River-Meldrum Bar and Willamette Falls (RM 24–26.7).

4.10.3 Adult UWR winter steelhead data needed

1. Fish tag data to establish residence time, thermal exposure, and migration behavior from the mouth of the Willamette River to Willamette Falls (RM 0–26.7).
2. Duration of pre-passage holding time near the Clackamas River-Meldrum Bar and Willamette Falls (RM 24-26.7).
3. Mortality rates within migration corridor from the confluence with the Columbia River to Newberg (RM 0 – 50.8) - especially from other causes than pinniped predation at Willamette Falls.

4.10.4 Adult LCR fall Chinook data needed

1. There are significant knowledge gaps about LCR Chinook habitat use and behavior during the portion of their run in the lower Willamette migration corridor (RM 0 – 26.7).
2. Fish tag, thermal history, run timing, and run size data for migration and spawning from the confluence with the Columbia River to the Clackamas River mouth (RM 0 – 24.9) and/or North Fork Dam on the Clackamas (Clackamas river mile 29.9).
3. Surveys of fish presence and abundance in CWR and other habitat between Willamette RM 0 – 26.7 when mainstem temperatures exceed 18°C as a daily average and 20°C as a daily maximum.
4. DEQ did not evaluate thermal exposure for Chinook salmon that may stray, spawn, or rear further upstream in tributaries of the lower Willamette River beyond the main stem of the migration corridor.

4.10.5 Adult LCR winter steelhead data needed

1. Data on fish passage timing and abundance on entry to the Clackamas River (Willamette RM 24.9).
2. Fish tag and thermal history for migration from the Columbia River confluence to Willamette Falls (RM 0 – 26.7).
3. DEQ did not identify information to evaluate thermal exposure for steelhead that may spawn or rear in tributaries along the lower Willamette River that are outside the migration corridor.

5. Benefits and risks associated with CWR use by migrating adult salmon and steelhead

5.1 Objective:

To describe the expected benefits and adverse effects or risks associated with CWR use in the Willamette migration corridor for UWR and LCR populations of salmon and steelhead relative to water temperature. To evaluate whether there is evidence that CWR use in the migration corridor is improving the likelihood of successful upstream migration and spawning in the Willamette River.

5.2 Approach:

1. Use available data, published studies, and the expertise of biologists who study the Willamette River.
2. Complement information for the Willamette with information from the Columbia and other northwest rivers and the general literature.
3. Identify the level of certainty or uncertainty of any findings or conclusions.

Key Metrics: Thermal unit accumulation (ATUs), pre-spawn mortality, and professional judgement.

5.3 Tasks:

1. Gather and summarize existing research linking CWR use, to risks or benefits to salmon and steelhead survival and spawning success related to water temperature within the lower Willamette migration corridor.
2. Prioritize studies conducted in the Willamette Basin with a nexus to temperatures and conditions in the lower Willamette migration corridor. Inference can be drawn from studies conducted in the Columbia River and other basins in the Northwest
3. Successful migration is measured by en route mortality in the Willamette main stem and major tributaries
4. Spawning success is measured by returns to spawning grounds, pre-spawn mortality and possibly redd counts, if data are available.
5. Identify by species, what data would help fill knowledge gaps

5.4 Assumptions and limitations:

1. Data on refuge use and coincident mortality, pre-spawn mortality, and spawning success, are limited for the lower Willamette migration corridor.

2. Credible assumptions will be need to be made using the best available data and professional expertise where data are not available.
3. Information obtained from the Columbia and other western rivers and in the general literature is relevant and should be informative.
4. Since under current conditions adult UWR winter steelhead do not encounter river temperatures expected to trigger CWR use during their migration in the lower Willamette migration corridor, we focus discussion in this section on adult UWR spring Chinook.

5.5 Assessing benefits and risks

The analysis of evidence for UWR spring Chinook, UWR winter steelhead, and LCR winter steelhead use of cold-water refuge in the lower Willamette migration corridor in Chapter 4 strongly suggests that CWR is not used for long duration, if any, by upstream migrating adults of these populations for the temperature conditions when surveyed.

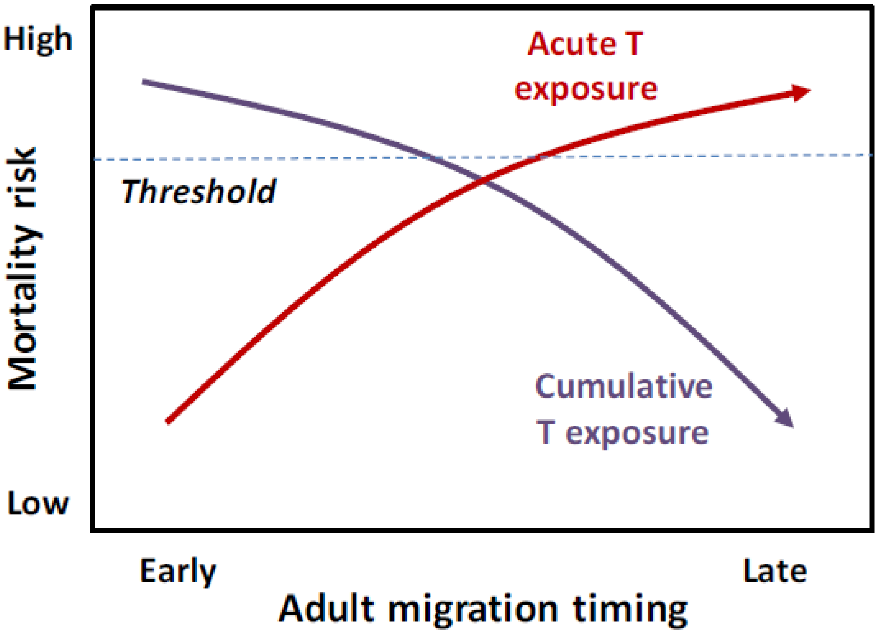
Because they do not encounter temperatures greater than 18°C–20°C during their migration in the lower Willamette migration corridor, UWR steelhead and LCR steelhead are unlikely to use CWR and therefore not expected to derive either a net benefit or risk from CWR use related to water temperature. Please see Section 4.5 for discussion of CWR use by steelhead. Therefore, we will focus our review of potential risks and benefits of cold-water refuge use in this Chapter on UWR Chinook.

Only a portion of the UWR Chinook salmon run (~14% on average) is exposed to either daily maximum or average water temperatures above 18-20°C in the migration corridor. However, in specific years this percentage is as high as 48% (see Section 4.4). The portion of the Chinook population exposed to water temperatures near this threshold may benefit from CWR use. However, benefits for UWR Chinook are theoretical because the available information does not yet show whether there is extensive refuge use by migrating adult UWR Chinook. See Section 4.5 for discussion of evidence of Chinook CWR use.

5.5.1 Biological tradeoffs of CWR use

Migrating salmon and steelhead can use CWR to regulate body temperature and reduce exposure to stressful temperatures in the surrounding waterbody. However, CWR use increases residence time, reduces migration rate (Goniea et al. 2006, Hasler et al. 2012, Keefer et al. 2018), and can expose fish to additional hazards such as predation, harvest, and toxicants (Coutant 1987). Cold-water refuge use provides short-term relief from high temperatures for migrating fish and reduces risk of exposure to high temperatures if the surrounding environment cools during the period of refuge use. If surrounding water temperatures continue to rise during refuge use, it can increase risk of exposure to high temperatures when leaving the refuge. Fish avoiding short-term exposure to high temperatures may accumulate greater overall long-term ATU exposure if main stem temperatures continue to rise while the fish delays (Figure 5-1). Early-run spring Chinook migrants in both the Upper Willamette and Columbia River tend to have slower migration rates and longer transit times than late-run migrants (Myers et al. 2006, Salinger and Anderson 2006). Fish with longer residence times accumulated the most ATU because of longer exposure to temperatures in the main stem (Hasler et al. 2012, Keefer et al. 2015, 2019). In the Willamette River, late-run UWR spring Chinook migrants encounter the highest instantaneous temperatures experienced by individuals en route, but also have some of the lowest total thermal accumulations (ATU) for the migration period.

Figure 5-1 Risk-benefit tradeoffs of salmon migration timing and temperature exposure (Keefer et al. 2019).



5.5.2 Potential benefits of adult CWR Use:

- Reduced acute thermal exposure to stressful or lethal temperatures.
- Reduced ATU accumulation (if surrounding system cools during refuge use).
- Reduced en route mortality.
- Reduced pre-spawn mortality.
- Reduced disease prevalence and effect.

5.5.3 Potential risks of adult CWR use

- Migration delay leading to longer residence time
- Increased en route mortality
    - Acute thermal exposure
    - Predation
    - Harvest
- Increased pre-spawn mortality
    - Long term accumulated thermal exposure (ATU)
    - Acute thermal stress
    - Disease prevalence and effect

5.6 Analysis of benefits of adult CWR use in the lower Willamette migration corridor

5.6.1 Effects on en route mortality in the migration corridor

En route mortality is mortality that occurs during the migration before salmon and steelhead arrive at pre-spawn holding sites or spawning tributaries. En route mortality is most likely from predation, injury, disease, and acute thermal stress (i.e. >22°C). En route mortality rates for UWR Chinook from natural causes, excluding harvest but including sea lion predation, are estimated to range from <1 – 11% below Willamette Falls since 2007(Table 5-1). The en-route mortality for Chinook is above average for the most recent years 2014-2017. ODFW attributes much of the shift in baseline mortality to sea lion predation. The run year 2015 had extreme and unusually early warm temperatures during the spring Chinook migration and shows an elevated mortality rate. The extreme temperatures in 2015 no doubt contributed to the increase, but the relative influence of temperature and sea lion predation cannot be separated from this data.

The estimated mortality rate for Chinook and steelhead migration for the entire migration in the Willamette main stem, including upstream of the migration corridor, is 10-40%. This is partly based on observed mortality rates for Chinook salmon in the Columbia river (Wargo-Rub et al. 2011, Jepson et al. 2015, Keefer et al. 2017). The available data suggests en route mortality is more severe upstream of the migration corridor than within it.

Table 5-1 Run size and percent natural mortality of spring Chinook entering the Willamette River below Willamette Falls. Data source: ODFW Joint Stock Report, (ODFW and WDFW 2018)

Run Year	Run size entering Willamette R.	% mortality below Willamette Falls
2007	38,130	0.7
2008	27,052	1.5
2009	37,677	1.2
2010	101,844	1.6
2011	75,859	2.4
2012	59,595	2.0
2013	43,796	2.4
2014	48,228	9.0
2015	81,040	11.2
2016	47,414	9.7
2017	51,071	6.8

The mortality of migrating spring Chinook in the main stem of the Willamette has not been strongly linked to temperature under average conditions (Keefer et al. 2017). A number of data sources provide at least incidental evidence that fish enter the lower Clackamas River and, to a lesser extent, Johnson Creek and Tryon Creek during summer months (see Section 4.5, above). However, outcomes for survival or morality cannot be linked to fish use of these tributaries at this time. The Portland Bureau of Environmental Services has direct observation of UWR Chinook use of CWR at Johnson Creek during an extreme water temperature event in 2015 (BES, 2015), but surveys conducted by the Fish and Wildlife Service at nearby CWR in Tryon Creek observed Chinook adults and juveniles leaving the refuge during the same time. Lack of data for fish presence/absence and abundance in CWR during warm temperatures, and high mortality of individuals in the few observations of Chinook using CWR during extreme temperature events, makes it difficult to conclude from the available data whether there is either a benefit or risk to CWR use in avoiding en route mortality.

5.6.2 Effects on pre-spawn mortality

Pre-spawn mortality (PSM) is mortality of adult salmon that occurs after completing migration to spawning areas but prior to successful reproduction. To identify whether using CWR in the migration corridor would benefit migrating fish by reducing PSM we need to identify:
1). Is there a link between temperature in the migration corridor and PSM?
2). Would using CWR in the migration corridor reduce that risk and provide a benefit?

5.6.2.1 Possible connections of CWR use with pre-spawn mortality

If PSM correlates with high temperatures in the migration corridor, this can provide insight into possible need and benefit of CWR use.

Strong positive correlation between increased PSM and higher temperature in the migration corridor suggest high temperatures in the migration corridor are contributing to mortality. The ability for CWR to offset this mortality depends on availability of CWR and whether fish delay migration to use it.

10.

Strong negative correlation, between increased PSM with lower temperatures in the migration corridor suggest low temperatures are contributing to mortality. In this case, mortality would not be due to high temperatures in the corridor and availability and use of CWR would not be expected to reduce risk for migrating fish.

Weak or neutral correlation between migration corridor temperature and PSM suggests either that migration corridor temperature is not contributing to PSM or that CWR, if available and used, potentially offsets mortality risk.

11.

5.6.2.2 Evidence for correlation of migration corridor temperatures with pre-spawn mortality

Evidence linking PSM with high temperatures in the lower Willamette migration corridor is mixed. We identified two studies for the Willamette basin that compared pre-spawn mortality in holding/spawning tributaries to main stem temperatures in the migration corridor at Newberg (Figure 5-2, top panel).

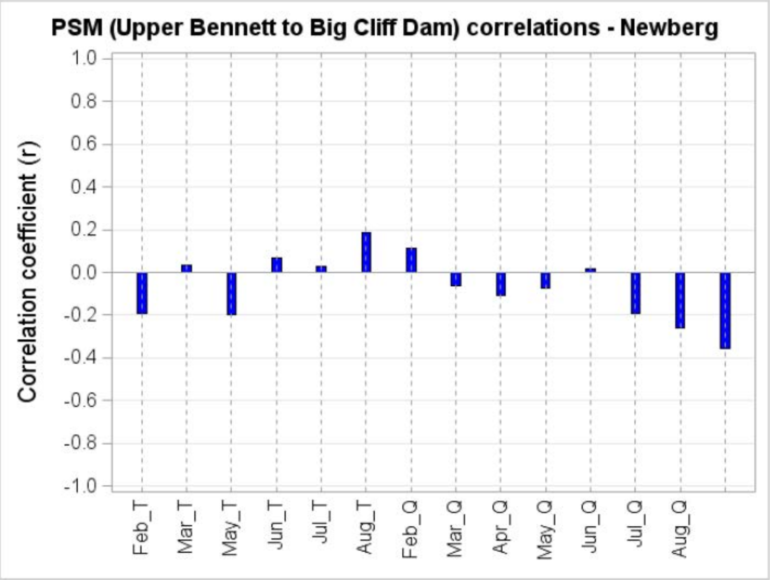
One study (Keefer et al. 2019), showed correlation of pre-spawn mortality with temperature is higher for locations closer to the spawning and holding sites in tributaries than the main stem. The authors found that PSM in the North Santiam Basin was not highly correlated with summer water temperatures at Newberg (Figure 5-2, top panel). Pre-spawn mortality had stronger positive correlation with high temperatures in September at Niagara, OR, near the Minto Fish Collection Facility (Figure 5-2, bottom panel). High temperatures at Niagara in June and July were negatively correlated with PSM. Migrating salmon and steelhead congregate below Minto Dam in late summer/fall before collection and transport upstream for release (Keefer et al. 2010).

The difference in correlation coefficients is likely related to the relative duration that UWR Chinook spend in the main stem versus the tributaries. Most fish spent weeks to months in the tributaries while many fish were only in the migration corridor for a few days. At least two studies using PSM data from the Clackamas, North and South Santiam, McKenzie and Middle Fork Willamette also found high correlation of PSM with elevated water temperature in the upstream holding and spawning reaches (Benda et al. 2015, Bowerman et al. 2018)..

Another study, in the Middle Fork Willamette Basin (Keefer et al. 2010) found low correlation of PSM with temperatures in the migration corridor at Newberg in June, but high correlation with temperatures at Newberg in May, July, and August (Figure 5-3). It also simultaneously found high correlation of temperature with PSM at further upstream locations in the main stem and tributaries; at Albany, Dexter, and Jasper. Since temperatures at different sites within the main stem co-vary, it complicates interpreting potential benefits of CWR use at a particular location when the fish presence and subsequent temperature impact may occur at a different time and location. Separating the influence of temperatures in the migration corridor from temperature farther upstream in the main stem and holding tributaries is not possible from these data sets.

Without affirmative evidence whether CWR is used in the lower Willamette migration corridor, it is difficult to conclude whether CWR use would provide a net benefit or net risk to migrating adult UWR Chinook from these correlations. If CWR was used, and provided a benefit, it would match the observed weak or negative correlation pattern between PSM and water temperatures at Newberg. This scenario would suggest that migrating Chinook are benefiting from the current availability and distribution of CWR. If refuge is not used, the lack of correlation suggests that PSM is not predicted by temperatures in the migration corridor, and migrating Chinook would not derive additional benefit from creation of more refuges. More data on residence time and thermal exposure of UWR Chinook in the lower Migration corridor, use or absence of use of CWR habitat, and outcomes on pre-spawn mortality is required.

Figure 5-2 Correlation of pre-spawn mortality of UWR Chinook in the North Santiam basin to Big Cliff Dam with temperature (_T) and flow (_Q) for 5 months at USGS gage Newberg (top panel) and Niagara (bottom panel) Data source: (Keefer et al. 2019).



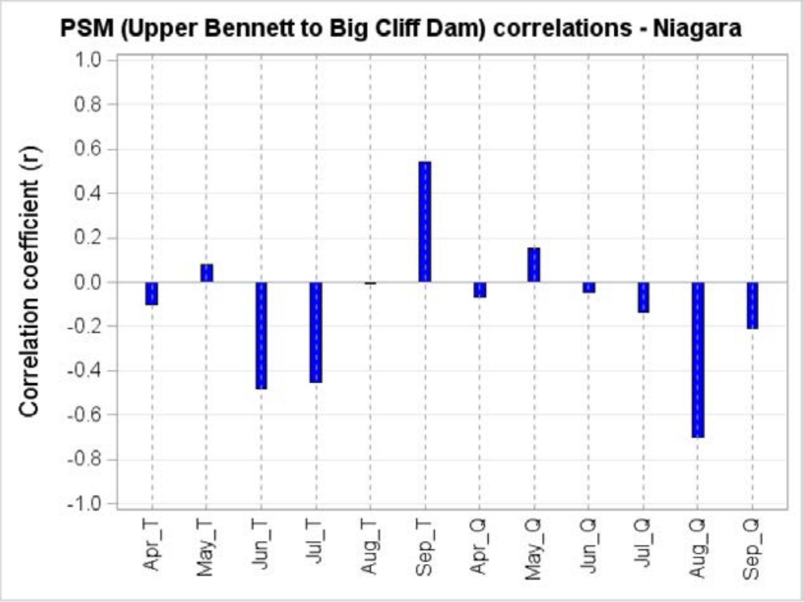
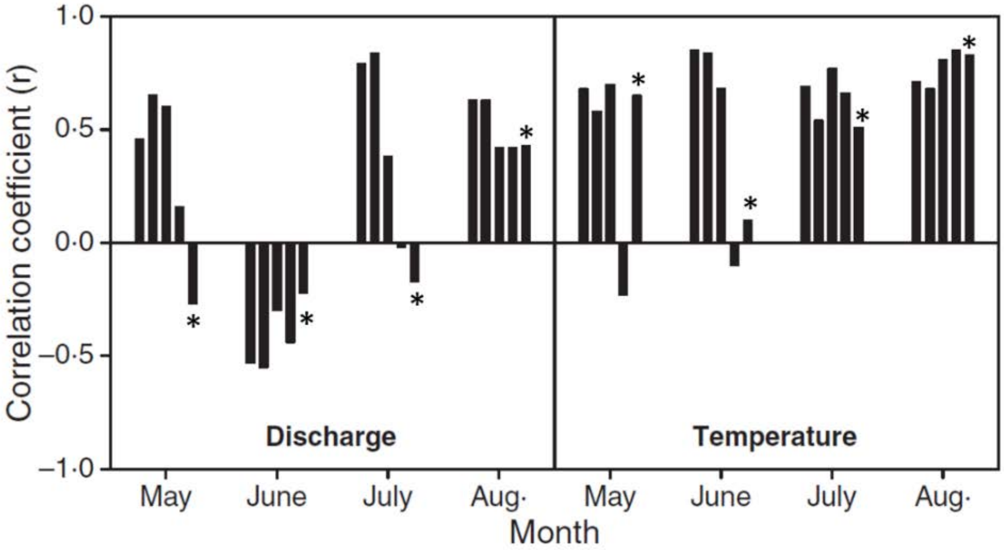


Figure 5-3 Correlation of pre-spawn mortality of UWR Chinook in the Middle Fork Willamette basin with temperature and flow at USGS gages (bars, left to right): Dexter, Jasper, Harrisburg, Albany, and Newberg (starred, emphasis added). Data source: (Keefer et al. 2010)



5.6.3 Conclusions for CWR use benefits

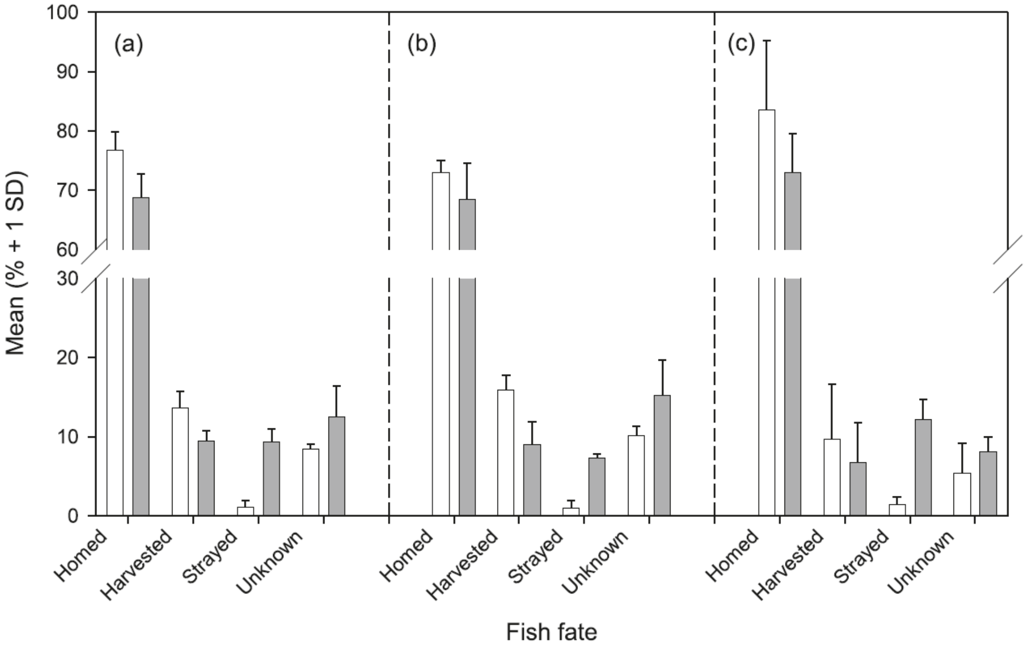
Given lack of strong direct evidence of regular cold-water refuge use by migrating UWR Chinook within the lower Willamette Migration corridor:

- Temperature in the migration corridor is not strongly correlated with pre-spawn mortality. Evidence connecting them is mixed and may be basin or year dependent.
- Temperature in holding and spawning tributaries is highly correlated with measures of pre-spawn mortality. If stronger, this effect may mask the correlation of migration corridor temperatures with PSM.
- Cold-water refuge use in the migration corridor may increase in extremely hot years (such as 2015), but the effect on reducing en route mortality is unclear. Many fish observed in the CWR in 2015 perished, and it is unknown whether or how many fish that used CWR were able to survive and spawn because of the refuge use.
- From the uncertainty in the available information, DEQ cannot conclude whether or not UWR Chinook would derive a net benefit from either current or additional CWR availability, or use, in the migration corridor under current conditions.

5.7 Analysis of risks of adult CWR use in the lower Willamette migration corridor:

Cold-water refuge use that increases residence time in the lower Willamette migration corridor may have potential risks that must be balanced against the benefits of immediate avoidance of warm temperatures. In studies from the Columbia River, radio-tagged steelhead that recorded CWR use were less likely to survive migration to their natal tributaries (Figure 5-4). The increased risk of mortality in this study was attributed to harvest or handling from fishing in the refuges. Fish that strayed had significantly higher survival if they used refuges, but strays had low survival rates overall.

Figure 5-4 Survival rates of radio-tagged Columbia River steelhead that were observed to use cold-water refuge (grey bars) and not use cold-water refuge (white bars). Panel (a) shows all fish, (b) wild fish, and (c) hatchery fish. Data source: (Keefer et al. 2009)



5.7.1 Migration delay

A characteristic of CWR use is longer time spent in migration because fish cease making upstream progress while holding in the refuge (Salinger and Anderson 2006, Goniea et al. 2006, High et al. 2006, Keefer et al. 2008a, 2018, Howell et al. 2010, Hasler et al. 2012). Early in the season, river temperatures will continue to rise during the delay. As a consequence, longer residence time increases total migration ATU in UWR spring Chinook, even when migration begins early in the run period (see Section 4.4 and Figure 4-234-23). Main stem water temperatures are higher than in the tributaries at the same time of year. Faster migration rates and shorter travel times may offset increased mortality risk associated with short-term warm water exposure in the main stem (Jepson et al. 2015) and reduces long-term ATU accumulation. Longer travel times are also correlated with increased pre-spawn mortality in UWR spring Chinook (Jepson et al. 2015, Keefer et al. 2015). Historically, migration delay could also result in migration blockage at Willamette Falls as flows dropped in summer (Dimick and Merryfield 1945, Myers et al. 2006, McElhany et al. 2007b). Under current conditions, migration blockage does not appear to result from onset of even acutely high temperatures (e.g. 2015).

5.7.1.1 Insights from the Columbia River Chinook populations

The Columbia River runs of Chinook differ from the Willamette River in annul run timing. Chinook salmon population in the Columbia River are summer and fall runs while the Willamette run is a spring run. See discussion of migration behavioral strategies in Section 4.2.2.3. The Willamette River run evolved in response to Willamette Falls becoming a seasonal migration barrier in summer. See detailed discussion in Section 4.2.2.

Columbia River runs of Chinook tend to slow migration rate when temperatures increase because of observed CWR use in that system. These fish derive a benefit from CWR use because unfavorable main stem temperatures ahead of them will cool (toward the fall and winter months) while they are holding in CWR.

The conditions in the Willamette Basin do not match the Columbia. The unique early run timing of UWR spring Chinook means they begin migrating in early spring while main stem temperatures are warming. UWR spring Chinook appear to increase their migration rate as main stem temperatures warm. UWR spring Chinook are less likely to benefit from CWR use because the main stem temperatures would continue to warm from spring to summer while they were holding in CWR. Fish that move quickly through the main stem are likely to benefit by entering much cooler water in the upstream tributaries.

5.7.1.2 Higher risk of acute temperature exposure

Migration delay potentially increases exposure to high main stem temperatures and increases overall ATU accumulation. A study on summer run Chinook salmon from the Puntledge River, British Columbia, found that migration delay increased exposure rates to high main stem river temperatures (>21°C) because it delayed entry to cooler waters closer to spawning locations (Hasler et al. 2012).

In the Willamette River, fish encounter cooler waters when leaving the main stem upriver of the migration corridor (see Chapter 2 and 4). UWR Chinook passing Willamette Falls dam in June-August have the highest probability of experiencing temperatures >18°C on average but the lowest total ATU accumulation because they migrate faster (Figure 4-234-23). Average August water temperatures in the high-elevation tributaries are 4°-10°C cooler than the main stem and migration corridor (Figure 3-7). Increased residence time in the Willamette River main stem delays entry to these cooler waters (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015, 2019).

5.7.1.3 Higher overall thermal exposure

The duration of migration also leads to higher overall thermal unit (ATU) accumulation in the lower Willamette migration corridor (Figure 4-234-23). Cumulative ATU levels can serve as a proxy for thermally-induced stresses and may predict higher risk of disease expression, reproductive failure, and pre-spawn mortality risk (Flett et al. 1996, Wagner et al. 2005b, Mathes et al. 2010, Keefer et al. 2015). Total migration thermal exposure ranges from 500-2,000 ATU for migrating UWR Chinook, depending on date of migration start and duration to arrival in tributaries (Jepson et al. 2015, Keefer et al. 2015). Definite ATU thresholds have not been established for UWR Chinook. A hypothetical and conservative threshold of at least 1,600 ATU is considered detrimental to spawning success and survival (Keefer et al. 2019).

5.7.1.4 Predation and harvest

Physical injuries to fish acquired during migration, whether from handling, angling, dam passage, or predation, may be greater contributors to overall mortality than thermal stress within the main stem (Keefer et al. 2017). Increased residence time in the lower river, especially at or below Willamette Falls may increase predation risk from non-native fish and sea lions (Mesa et al. 2002, Lawrence et al. 2014, Wargo Rub et al. 2019). No currently available studies have measured direct links between water temperature, cold-water refuge use, and sea lion predation in the Willamette River. There is potential for increased predation by sea lions if fish congregate and hold in CWR for long periods. Research from the Columbia river shows that high fishing pressure in cold-water refuges reduces survival in steelhead that use the refuge (Keefer et al. 2009).

5.7.1.5 Legacy Pollution

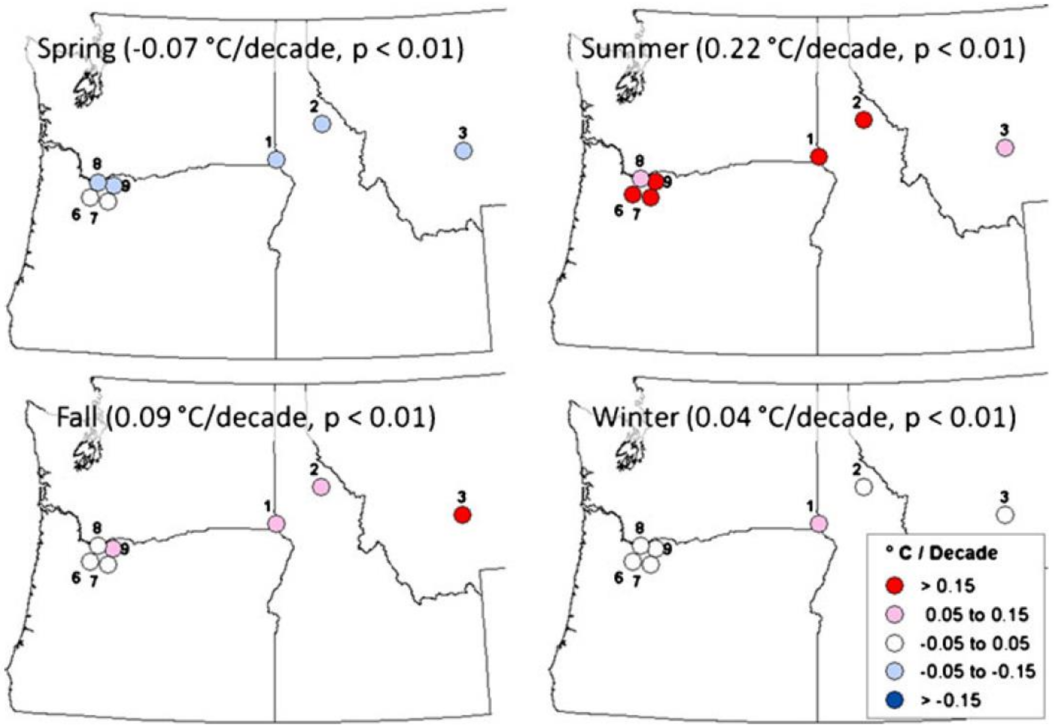
The first 25 miles of the migration corridor flows through Oregon’s largest metropolitan area. Due to the geology and hydrography of the lower river, the majority of cold-water tributaries and gravel features occur downstream of Willamette Falls in this urbanized reach. Many of these features are small cold-water habitats that are too small for adults but may be suitable for juveniles. Historical pollution between Portland and the Willamette Falls potentially extirpated a native run of fall Chinook by the mid-20th century (Dimick and Merryfield 1945, Ward et al. 1994, Myers et al. 2006). Legacy contamination of DDT and PCB along the west-bank reach of the Willamette River at Portland Harbor may be affecting survival in current juvenile runs. Coincidentally, this bank is where most of the small cold inflows occur in this reach of the migration corridor. Mortality for out-migrating juvenile Chinook salmon along the west bank of Portland Harbor is elevated compared to the east bank (Lundin et al. 2019). Therefore, juvenile salmon and steelhead attracted to this cool water may have increased risk from contaminant exposure. See additional discussion on juveniles in Chapter 7.

5.7.1.6 Climate Change

Water temperature response

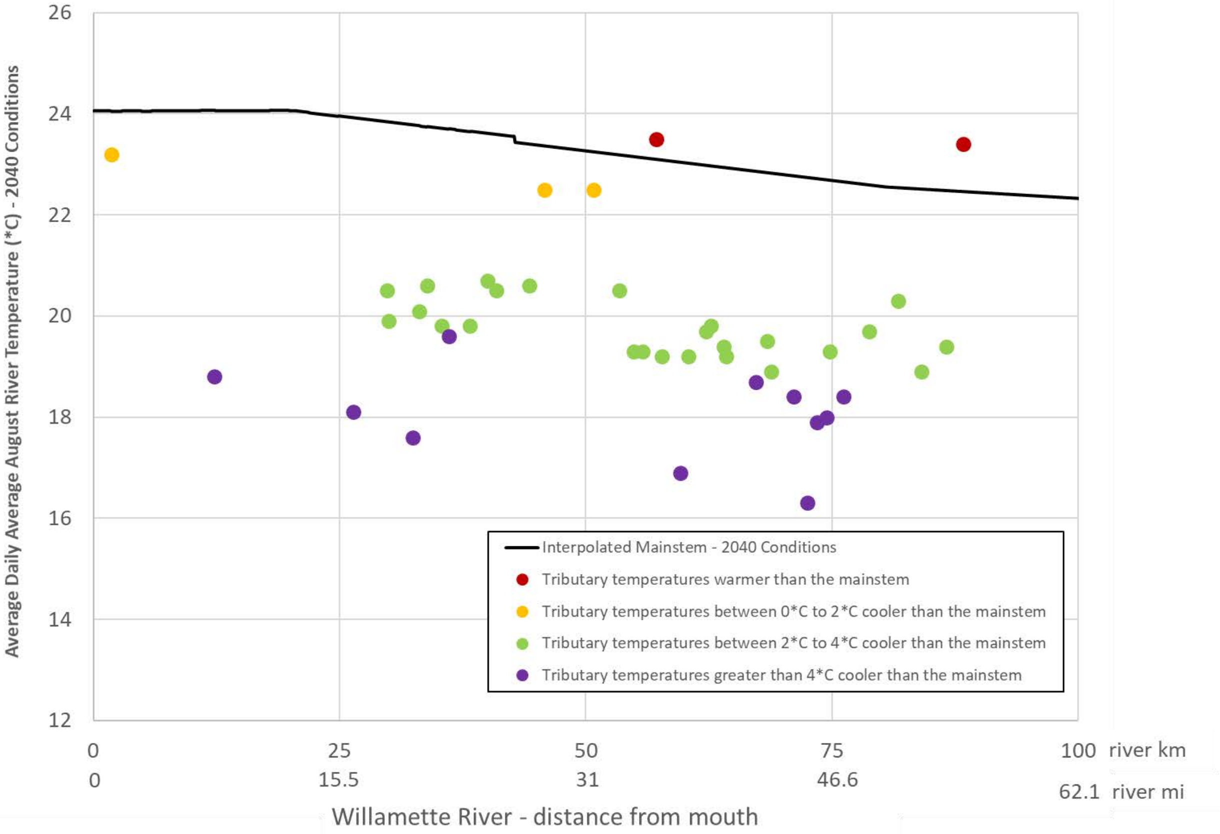
Climate change in the Pacific Northwest is trending to warm river systems off all types in the summer (Dalton et al. 2017). Temperature increases will primarily affect valley bottom streams, such as the migration corridor (Luce et al. 2014). Already realized climatic warming is estimated as greater than 0.15°C per decade in the summer (Isaak et al. 2012). Realized water temperature changes have been more minimal in winter, spring, and fall (Figure 5-5). While warming in upstream tributaries will occur, climate forcing is expected to cause water temperature increases just below the 18°C threshold for many of the holding and spawning tributaries in the Cascade Range (Dalton et al. 2017, Chang et al. 2018).

Figure 5-5 Realized seasonal temperature trends in Pacific Northwest rivers due to climate change since 1980. Data source: (Isaak et al. 2012)



Within the migration corridor, climate change is most likely to increase maximum August temperatures, reduce flows, and shift the onset of temperature criterion exceedances to begin earlier in the summer. Mean August temperatures in the Willamette main stem and surrounding tributaries are projected to warm by 2-3°C by 2040 (Leinenbach 2017). The number of tributaries that meet the framework for CWR (2°C cooler or more) are projected to remain the same by 2040. However, their quality as CWR will go down because their absolute temperatures will still increase even though their temperature relative to the main stem remains cooler (Figure 5-6). The NorWeST model projects only five of the 39 potential cold tributaries of all sizes to have daily average water temperatures in August of less than 18°C by 2040.

Figure 5-6 NorWeST climate change projection of August average daily river tempertures by the year 2040. Black line shows main stem water temperature. Colored dots show temperature difference (0->4°C) for modeled tributaries. (Leinenbach 2017)



Migration behavioral adaptation

The general behavioral response of adult UWR spring Chinook to warmer temperatures is a shift to earlier migration timing and faster migration rates (Keefer et al. 2019). Because winter and spring temperature changes have so far been relatively neutral under climate change (Isaak et al. 2012), it is possible the current behavioral strategy to migrate early and move quickly to avoid or minimize exposure to peak summer temperatures could remain adaptive. More information is needed to evaluate future risks. While thermal risks to the proportion of the run exposed to higher temperatures will likely increase with average summer temperatures due to climate change, it is uncertain whether the proportion of the run exposed to higher temperatures will also increase relative to current conditions. T

The behavioral response of adult UWR steelhead to stressful temperatures in the migration corridor is unknown. Effects from climate change may not be as severe so long as average daily temperatures do not regularly exceed 18°C in the main stem by the end of May. Best available projections for the Pacific Northwest suggest stable or slower temperature increase during fall, winter, and spring months when the native adult steelhead populations migrate (Isaak et al. 2012, 2018, Chang et al. 2018).

5.8 Conclusions for adult CWR use risks

Given the relationship between migration delay and increased thermal unit accumulation in migrating UWR Chinook, DEQ concludes that:

- The available information, summarized above, indicates that a faster migration rate and lower residence time in the lower Willamette migration corridor may be the preferred behavioral strategy for UWR Chinook.
- Cold-water refuge use may have a short-term, but so far not quantifiable, benefit in avoiding immediate acute exposure and mortality from high temperatures in the migration corridor.
- Cold-water refuge use may also have long-term risks from increased long-term thermal accumulation (ATU) that could ultimately reduce survival or spawning success. More information is needed to quantify these risks.
- **Under conditions where the 20°C migration corridor criterion is attained**, cold-water refuge seeking behavior in UWR Chinook and steelhead does not appear to be triggered. There is high uncertainty whether the current distribution or additional CWR imparts any particular benefits under these conditions.
- **Under conditions when the 20°C migration corridor criterion is exceeded,** there is not enough information to evaluate the relative risks or benefits of providing additional CWR for UWR salmon or steelhead at this time. It is uncertain whether CWR use would provide either net benefit or additional risk for negative impacts in migrating adult UWR Chinook salmon.
- Due to climate change, there are predicted increases in summertime water temperatures and a concurrent reduction in CWR quality. CWR use during extreme heat events is likely to increase in future decades.

6. Sufficiency of current CWR in the lower Willamette River for migrating adult salmon and steelhead

6.1 Chapter description

6.1.1 Objective:

The objective of this chapter is to evaluate whether the spatial and temporal extent of cold-water refuge is sufficient to meet the cold-water refuge narrative criterion, given all the information provided in earlier chapters. If there is not sufficient refuge, another objective is to estimate the additional extent of cold-water refuge needed.

DEQ evaluates CWR sufficiency for migrating adult under two sets of conditions:

12. CWR sufficiency at times when water temperatures attain the 20°C migration corridor criterion.

This addresses the core of the RPA to interpret the CWR narrative during main stem water temperatures up to and including the 20°C criterion, were it attained.

13. CWR sufficiency under conditions when water temperatures exceed the 20°C migration corridor criterion.

This addresses the ability of CWR to offset risks from conditions when the waterbody is warmer than the numeric criterion. In the lower Willamette River, current and expected natural condition temperatures exceed 20°C for a portion of most summers.

6.1.2 Approach:

1. DEQ Primarily relied on the expertise of biologists who study the Willamette River. As well, on fish tag and tracker data when available, and data on fish migration timing in relation to river temperature.
2. Complement information for the Willamette with the scientific literature and data from other NW rivers.
3. Identify the level of certainty or uncertainty of any findings or conclusions.

6.1.3 Assumptions and limitations:

- Direct evidence of refuge use, specifically for the Lower Willamette River, is limited.
- There are no available metrics for CWR carrying capacity at this time.
- Credible assumptions will be need to be made using the best available data and professional expertise where data are not available.

- Information obtained from the Columbia and other western rivers and in the general literature is relevant and should be informative.

6.1.4 Definitions:

“CWR Sufficiency” refers to whether the amount and distribution of cold-water refuges allows salmon and steelhead to avoid or mitigate detrimental impacts of warm river temperatures during their migration.

6.1.5 Tasks:

1. Identify measureable outcomes and criteria metrics, if any, that describe whether the amount and distribution of CWR in the lower Willamette River is sufficient.
2. Evaluate if the quality, quantity and distribution or frequency of CWR is sufficient to provide migratory conditions for adult salmon and steelhead in the lower Willamette River main stem when maximum river temperatures are above 20°C, but within the range of natural temperature conditions.
3. Identify by species, what data would help fill knowledge gaps.

6.2 Evaluating adult CWR sufficiency

The sufficiency of cold-water refuge can be assessed using measureable physiological or demographic outcomes at specific geographic endpoints. These may include survival or spawning success at the end of the migration corridor, or in spawning tributaries. The sufficiency of refuges available to migrating adult salmon and steelhead within the lower Willamette River corridor could be defined by increased probability of survival or success at reaching spawning grounds. Refuge sufficiency is influenced by the capacities and physical characteristics of each individual refuge, the spatial and temporal extent of the refuges, and the baseline temperature conditions of the river. It is important to recognize that sufficiency is relative and context-dependent.

It is also important to recognize that the standard for the migration corridor when adopted was 20°C or the natural condition. The complementary cold-water refuge narrative was intended to protect refuges that may help fish to navigate a river when main stem temperatures under natural condition exceeded 18-20°C. DEQ did not intend for the standard to imply that cold-water refuges could prevent or mitigate main stem temperatures that greatly exceed 18-20°C due to anthropogenic warming.

6.3 Findings on adult CWR sufficiency

The available evidence suggests that the majority of migrating adult UWR spring Chinook, adult UWR winter steelhead, and adult LCR winter steelhead are not exposed to water temperatures above the 20°C criterion and would not be expected to use cool water habitat as CWR under our current framework.

For purposes of evaluating the CWR narrative, when water temperatures are attaining the 20°C migration corridor criterion, the available evidence indicates that the proportion of the UWR and LCR Chinook run that is exposed to temperatures of 18-20°C is not delaying to hold in the currently available CWR in the migration corridor. See data and discussion in Section 4.5.2.

For purposes of evaluating the CWR narrative when water temperatures exceed the 20°C criterion, there are limited observations of incidental use by a small percentage of UWR Chinook in the Clackamas

River/Meldrum Bar area, Johnson Creek, and Tryon Creek. There is not sufficient observation of Chinook behavior and habitat use when temperatures exceed 20°C to make strong conclusions about sufficiency or insufficiency of the current distribution and volume of CWR at this time.

The favored migration strategy for adult UWR spring Chinook appears to be to shift migration timing earlier and increase migration rate when temperatures are warm. There is a strong historical and genetic basis for this behavioral strategy for spring Chinook in the lower Willamette due to the influence of Willamette Falls. The falls historically formed a natural barrier to migration when river flows dropped in the summer. In addition, migration delay in the lower river, resulting from cold-water refuge use or migration blockage, could compound pre-spawn mortality risk by increasing the cumulative thermal exposure during the migration period. Delayed migration likely increases risk of exposure to high water temperatures later in the migration in upstream portions of the main stem and this is more strongly linked to en route and pre-spawn mortality.

The USGS, City of Portland, and others identified multiple sites that could provide CWR. These sites are distributed throughout the lower Willamette migration corridor (see Figure 3-38). However, few of the total number of potential CWR sites are of significant flow and may not be large enough to be detected or used by adult salmon. The total volume of cold water that is available from sites of significant flow is unknown. Multiple CWR of varying size are available within a median day's travel time for both UWR Chinook and UWR steelhead (see Section 3.5.2) and there is no indication that the population saturates these CWR. Cold water refuge density from the falls to Newberg (RM26.7 – 50.8) is slightly lower than the mouth to Willamette Falls (RM 0 – 26.7). There is a gap of 21 km (13 mi) between available CWR from Willamette Falls to Coffee Lake Creek (RM 26.7 – 39.0). Fish seeking refuge would need to travel at least the median migration speed observed for Chinook and steelhead upstream of Willamette Falls in order to access refuge within a day's travel time.

The major cold-water refuge source by volume in the migration corridor is the Clackamas River. Secondary refuge is provided by Johnson Creek, Kellogg Creek, and Tryon Creek. A small number of UWR Chinook salmon individuals have been observed temporarily entering tributaries at the Clackamas River (RM 26) and Tryon Creek (RM 20.1) during migration. The SLICES and Silver et al surveys have observed both adults and juveniles congregating in these areas. Fish frequent these habitats at times when the main stem temperature is both above and below the criterion of 20°C.

Small numbers of adult Chinook were observed seeking refuge in Johnson Creek during extreme temperature conditions in June 2015 when average temperatures in the Willamette River were above 22°C. These high temperatures coincided with the peak of Chinook migration. However, surveys in Tryon creek during the same event in May and June of 2015 showed that Chinook left the CWR as temperatures in the main stem approached these extremes, at precisely the time it was most likely to serve as CWR. There are no data on what proportion of the Chinook run used refuge in the corridor or the mortality rate within the corridor due to temperature in 2015. See discussion in Section 4.5.2.

6.4 Summary of conclusions on adult CWR sufficiency

6.4.1 Adult UWR and LCR steelhead

6.4.1.1 Below and above Willamette Falls (RM 0 – 50.8)

1. Evidence presented in this report suggests that current run timing of migrating adult UWR and LCR winter steelhead does not expose these populations to temperatures that exceed the migration corridor criterion or would be expected to trigger CWR use under current conditions.
    - UWR winter steelhead complete passage at Willamette Falls dam before temperatures exceed 18°C as a daily average and 20°C as a 7-day average of daily maximums under current conditions (See Figure 4-6, Figure 4-20).
    - LCR winter steelhead passage of North Fork Dam on the Clackamas River is complete before the period when Willamette River temperatures at Portland exceed 18°C as a daily average and 20°C as a 7-day average of daily maximums under current conditions (See Figure 4-8).
2. Given current lack of critical temperature exposure for migrating adult UWR and LCR winter steelhead, there is not currently a need for CWR to support upstream migration through the corridor for these populations.
3. Therefore, DEQ can conclude that for upstream migrating adult UWR and LCR steelhead the CWR narrative is attained, so long as mainstem temperatures continue to stay below the 20°C criterion during these runs, which occur November through May.

6.4.2 Adult UWR spring Chinook salmon

6.4.2.1 Above Willamette Falls (RM 26.7 – 50.8)

1. **During water temperatures up to and including the 20°C criterion** available evidence indicates the current distribution of CWR above Willamette Falls (RM 26.7 – 50.8) is sufficient.
    - Short residence time and lack of observed CWR use in numerous examples of fish implanted with thermal loggers fish shows holding in CWR does not occur above Willamette Falls. See Section 4.5.2.1, Figure 4-34, (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015)
2. **Under conditions when the 20°C criterion is exceeded** DEQ cannot conclude whether the current distribution of CWR is sufficient or insufficient to support migration for the minority portion of annual runs exposed to these conditions.
    - There is high uncertainty about UWR Chinook behavior and CWR use when water temperatures exceed 18-20°C due to a low number of studies in hot years or during high temperatures and limitations in fish sampling protocols during warm conditions. See Section 4.5; Figure 4-28, 4-31, 4-34, 4-35; (Schreck et al. 1994, Jepson et al. 2015, Keefer et al. 2015)

6.4.2.2 Below Willamette Falls (RM 0 – 26.7)

1. **During water temperatures up to and including the 20°C criterion,** available evidence indicates the current distribution of CWR is sufficient.
    - Current observations and evidence indicate low or infrequent CWR use levels by adult LCR or UWR Chinook when water temperatures attain the criterion. See Section 4.5.2; Figure 4-31, 4-32, 4-34.
2. **Under conditions when the 20°C criterion is exceeded** DEQ cannot conclude from the available information whether CWR is sufficient or insufficient to support migration for the minority of annual runs exposed to these conditions.

- There are significant knowledge gaps on UWR and LCR Chinook behavior, habitat use, and mortality for RM 0-26.7.
- It is uncertain whether the limited observations of CWR use benefitted the fish to continue their migration successfully. See Figure 4-33, 5-2, 5-3.

- There is strong evidence that in response to seasonal warming, the behavioral response of UWR Chinook is to pass through the migration corridor earlier and faster. This has the effect of reducing the length of exposure of individuals to elevated temperatures. See Figures 4-17, 4-19, 4-23 (Schreck 1994, Jepson et al. 2015, Keefer et al. 2015, 2019).

6.4.3 Adult LCR spring/fall Chinook salmon

6.4.3.1 Below Willamette Falls (RM 0 – 26.7)

1. **During water temperatures up to and including the 20°C criterion** DEQ cannot conclude from the available information whether the current availability of CWR is sufficient or insufficient to support migration of LCR Chinook.
    - Current observations show low CWR use levels by any population of Chinook and additional uncertainty due to lack of specific data on run timing and abundance of LCR Chinook for RM 0 – 26.7. See Section 4.2, 4.5.2; Figure 4-31, 4-32, 4-34.
    - Once entering the Clackamas River, LCR Chinook do not experience water temperatures that exceed daily maximums of 20°C under current conditions. See Section 4.3.2.1; Figure 4-8
2. **Under conditions when the 20°C criterion is exceeded** DEQ cannot conclude from the available information whether CWR is sufficient or insufficient to support migration for the proportion of the annual run exposed to these conditions.
    - There are significant knowledge gaps on LCR Chinook behavior, habitat use, and mortality for RM 0 – 26.7.
    - No tagging studies have targeted LCR Chinook and the extent to which they are included in observations and surveys of Chinook downstream of Willamette Falls is unknown. See Section 4.5; (NMFS 2000, Jepson et al. 2015)

Table 6-1 Summary of interpretation of the narrative CWR criterion for migrating adults

	Population	Conditions up to 20°C	Conditions exceeding 20°C
Below Willamette Falls (RM 0 –26.7)	UWR Chinook	Attained	Insufficient data
	UWR steelhead	Attained	N/A
	LCR Chinook	Insufficient data	Insufficient data
	LCR steelhead	Attained	N/A
Above Willamette Falls (RM 26.7–50.8)	UWR Chinook	Attained	Insufficient data
	UWR steelhead	Attained	Insufficient data

6.5 Knowledge gaps and research needs on CWR sufficiency

1. There is limited data for the lower Willamette or other any river systems, which determine the capacity of a specific volume of cold-water refuge; that is, how many migrating adults are supported per unit volume.
2. Studies to identify a range of optimal density and distance requirements for CWR would greatly assist future conservation and restoration planning.
3. Additional research of mortality and/or spawning success outcomes following CWR use in the lower Willamette is required to determine whether restoration of additional CWR would present additional risk or benefit to migrating adult UWR Chinook.
4. More data needed for cold-water refuge use and its effect on mortality for UWR Chinook, especially during high temperature events exceeding the 20°C criterion, to establish sufficiency of current CWR availability and future distribution under expected climate change scenarios.

7. Juvenile salmon and steelhead presence and use of CWR in the lower Willamette migration corridor

7.1 Chapter outline

7.1.1 Objective:

The main objective of this study is to interpret Oregon's cold-water refuge narrative criterion in protecting migrating adult salmon and steelhead in the Lower Willamette migration corridor. However, the corridor also serves as an out-migration route for juveniles of the listed Chinook populations, and for juveniles and adult kelts of the listed steelhead populations in the Willamette basin. In this Chapter, we review the information on the presence, potential exposure, habitat use, and risks and benefits of cold-water refuge use by juveniles.

7.1.2 Approach:

1. Use available data, published studies, and the expertise of biologists who study the Willamette River.
2. Identify the level of certainty or uncertainty of any findings or conclusions.

Key Metrics: Migration timing, habitat use, abundance, from fish habitat surveys, and radio-tag studies.

7.1.3 Tasks:

1. Gather and summarize existing research on juvenile salmon and steelhead migration timing, abundance, and habitat use, and survival within the lower Willamette migration corridor.
2. Connect juvenile migration, habitat use, and mortality to water temperature conditions within the migration corridor through existing literature where possible.
3. Prioritize studies conducted in the Willamette Basin, with a nexus to temperatures and conditions in the lower Willamette migration corridor. Inference can be drawn from studies conducted in the Columbia River and other basins in the Northwest.
4. Identify, by species, what data would help fill knowledge gaps.

7.1.4 Assumptions and limitations:

- Data on juvenile salmon and steelhead use of cold water refuge, passage timing, and coincident mortality due to temperature, are limited.
- Credible assumptions will be need to be made using the best available data and professional expertise where data are not available.

- Information obtained from the Columbia and other western rivers and in the general literature is relevant and should be informative.

7.2 Biological effects and thresholds of temperature on juveniles

Juvenile salmon and steelhead optimal growth rates occur over a wider range of temperatures than optimal temperature ranges for migrating adults. Optimal growth can occur in temperatures as high as constant temperatures of 20°C. This overlaps with the range of increased disease risk and may represent a tradeoff between faster growth and reduced disease risk. Juveniles require cool temperatures for smoltification, and exposure to high temperatures can delay or reverse this process (Wedemeyer et al. 1980). Juvenile cold-water refuge use has been observed in steelhead but was not triggered until temperatures were 22-25°C (Brewitt and Danner 2014).

Table 7-1 Biological effects of constant temperature on juvenile salmon and steelhead (McCullough 1999, EPA 2003, Richter and Kolmes 2005b)

Constant Temperature Range	Exposure Timeframe	Effects
13-20°C	Months	• Optimal growth range
>14°C	Weeks	• Impaired smoltification
18-20°C	Days to Weeks	• High disease risk
23-26°C	Hours to Days	• Incipient lethal limit • Acute metabolic stress and mortality • Migration blockage
32°C	Instant	• Instantaneous mortality lethal limit

7.3 Identification of CWR suitable for juveniles

Juvenile salmon and steelhead are likely able to utilize the same cold-water refuge available to adult salmon and steelhead identified in Chapter 3. In addition, they may take advantage of smaller-scale cold-water refuges created by small channel features, inflows, and tributaries with average August flows of less than 1 cfs. As a result, the number and distribution of identified cold-water refuge locations is greater for juveniles than for migrating adults (Figure 2-1).

We identified 47 sources of cold water that were measured to be at least 2°C cooler than the main stem temperature using the data compiled in Section 3.1.4 (Figure 7-1 and Table 7-2). There is a large amount of thermal habitat heterogeneity in the reach of the corridor above Willamette Falls, and downstream of the falls to Johnson Creek. There is a gap in available cold-water refuge sites in the heavily urbanized reach between Ross Island and Portland Harbor. There are also several, but small, cold-water refuges in the main stem near Portland Harbor, the Northwest Industrial area, and the confluence with Multnomah Channel.

Figure 7-1 Map of cold-water inflows suitable for juvenile salmon and steelhead. Light grey shaded areas show urban boundaries.

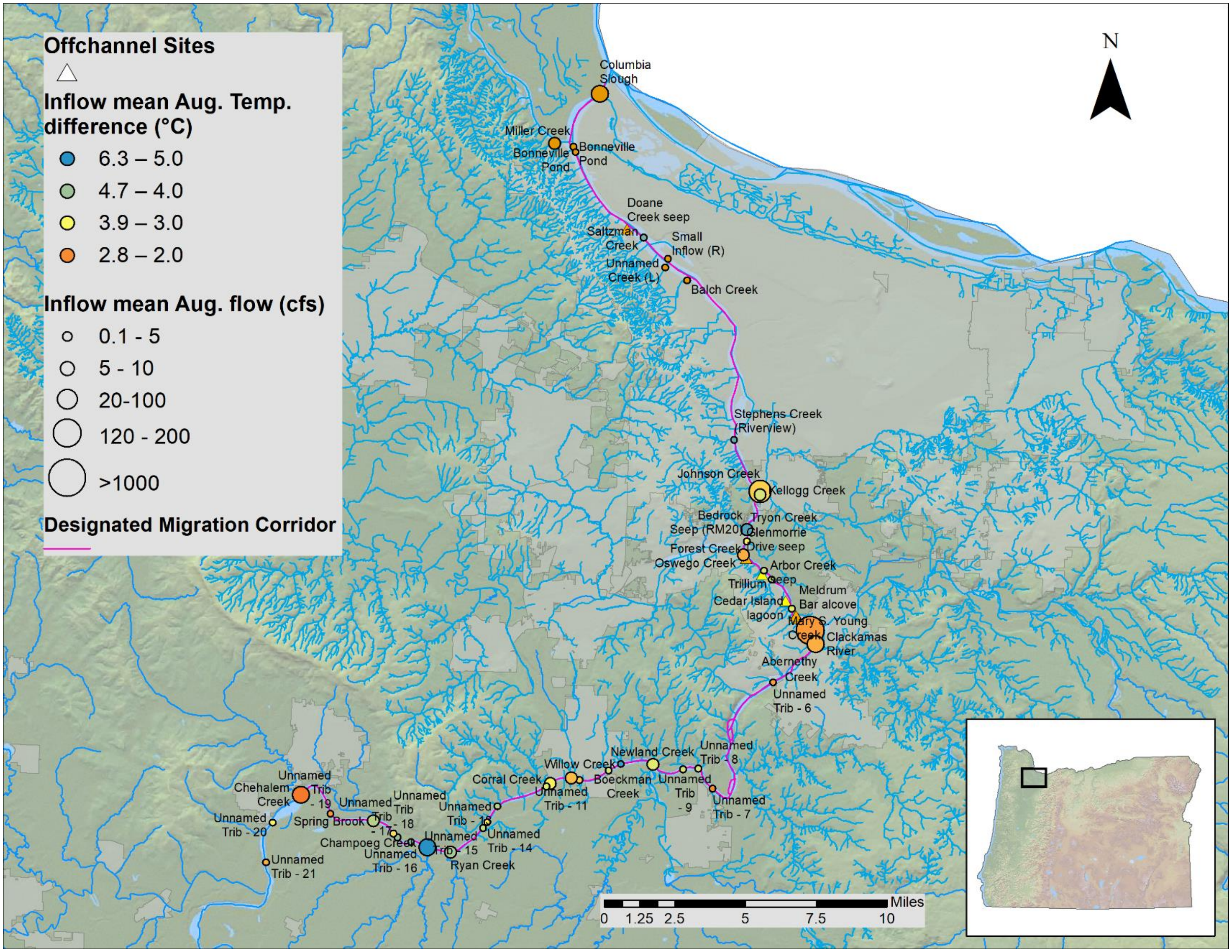


Table 7-2 List of cold-water inflows suitable for juvenile salmon and steelhead use and summary of identifying data sources.

X = refuge observed	Supporting Data Sources
O = refuge not indicated	
— = not sampled	

Tributary Name	Type[9]	Class	Main stem River Mi.	NorWeST	PDX	USGS	FLIR	Other data
Columbia Slough	CWR	Tributary	1.1	O	X	X	O	X
Miller Creek	CWR	Tributary	3.5	—	X	—	X	
Unnamed Inflow (R) Bonneville Pond	Cold inflow	Seep	4.5	—	X	—	O	
Unnamed Inflow (R) Bonneville Pond	Cold inflow	Seep	4.6	—	X	—	O	
Doane Seep	CWR	Seep	7	—	X	X	X	
Saltzman Creek	Cold inflow	Tributary	7.6	X	X	—	O	
Unnamed Creek (L)	Cold inflow	Tributary	8.8	—	X	—	O	
Very Small Inflow (R)	Cold inflow	Tributary	8.9	—	X	—	O	
Balch Creek	Cold inflow	Tributary	9.8	—	X	—	O	X
Unnamed Inflow (L)	Cold inflow	Tributary	9.6	—	X	—	O	
Ross Island	CWR	Morphologic	14.9	—	—	—	O	X
Stephen's Creek	Cold inflow	Tributary	16.4	X	X	—	O	

---

[9] See definitions in Section 3.1.2

Tributary Name	Type[9]	Class	Main stem River Mi.	NorWeST	PDX	USGS	FLIR	Other data
Johnson Creek	High quality CWR	Tributary	18.5	X	X	X	X	O
Kellogg Creek	CWR	Tributary	18.6	X	X	X	X	
Tryon Creek	High quality CWR	Tributary	20.1	X	X	X	X	
Forest Creek	Cold inflow	Tributary	20.6	X	—	—	—	
Oswego Creek	CWR	Tributary	21.1	X	O	—	O	
Glenmorrie Seep	CWR	Morphologic	21.2	—	—	X	X	
Arbor Creek	CWR	Tributary	22.0	X	—	X	—	
Trillium Creek	Cold inflow	Tributary	22.4	X	—	—	—	
Cedar Island Lagoon	CWR	Morphologic	23.4	—	—	X	O	
Mary S. Young Creek	Cold inflow	Tributary	23.7	X	—	—	—	
Meldrum Bar	High quality CWR	Morphologic	24.1	—	—	X	O	
Clackamas River	High quality CWR	Tributary	24.9	X	X	X	X	
Abernethy Creek	CWR	Tributary	25.4	X	X	X	X	
Tanner Creek	Cold inflow	Tributary	27.5	X	—	—	—	
Willow Creek	Cold inflow	Tributary	33.2	X	—	—	—	
Unnamed Tributary	Cold inflow	Tributary	34.1	X	—	—	—	
Hidden Creek	Cold inflow	Tributary	34.7	X	—	—	—	
Newland Creek	Cold inflow	Tributary	35.9	X	—	—	—	
Willow Creek	Cold inflow	Tributary	37.0	X	—	—	—	
Boeckman Creek	Cold inflow	Tributary	37.5	X	—	—	—	

Tributary Name	Type[9]	Class	Main stem River Mi.	NorWeST	PDX	USGS	FLIR	Other data
Miley Creek (Unnamed at RM38.7)	Cold inflow	Tributary	38.6	X	—	—	—	
Coffee Lake Creek	CWR	Tributary	39.0	X	—	X	—	
Corral Creek	CWR	Tributary	39.8	X	—	X	—	
Murray's Creek	Cold inflow	Tributary	40.0	X	—	—	—	
Unnamed Tributary	Cold inflow	Tributary	41.8	X	—	—	—	
Jim Tappman Creek	Cold inflow	Tributary	42.5	X	—	—	—	
Joseph Rogers Creek	Cold inflow	Tributary	42.8	X	—	—	—	
Ryan Creek	High quality CWR	Tributary	44.2	X	—	—	—	
Champoeg Creek	High quality CWR	Tributary	45.0	X	—	—	—	
Kramien Creek	Cold inflow	Tributary	45.7	X	—	—	—	
Unnamed Tributary	Cold inflow	Tributary	46.3	X	—	—	—	
Lesley Creek	Cold inflow	Tributary	46.5	X	—	—	—	
Skookum Creek	Cold inflow	Tributary	49.0	X	—	—	—	
Spring Brook Creek	Cold inflow	Tributary	47.3	X	—	X	—	
Chehalem Creek	CWR	Tributary	50.8	X	—	—	—	
Unnamed Tributary	Cold inflow	Tributary	52.3	X	—	—	—	
Hess Creek	Cold inflow	Tributary	53.8	X	—	—	—	

7.4 Juvenile presence and migration timing

There are no data currently available on the number of juveniles that enter the migration corridor from upriver or mortality within the migration corridor before fish enter the Columbia River. Juvenile salmon and steelhead, especially Chinook salmon, show some level of limited rearing habitat use year round

(Friesen et al. 2007). The presence of juvenile fish increases in late autumn and peak abundance persists into the following spring for out-migration (Friesen 2005, Schroeder et al. 2016).

Table 7-3 Juvenile Chinook and steelhead migration and rearing timing in the lower Willamette migration corridor. Brackets and dashes show period of peak migration use for each population. Data source: ODFW. Accessed Aug. 8, 2019.

Life Stage/Activity/Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Juvenile Out-Migration and Rearing - Mouth to Falls												
UWR Winter steelhead		■	■ [- -	■ - -	■ - -	■ - -	■ - -	■]	■	▨	▨	
UWR Spring Chinook salmon	▨	▨■	■ [	■ - -	■ -]	■	■	■	■	▨	▨	▨
LCR Winter steelhead (Clackamas R.)	░	░	░	░	░	░	░	░	░	░	░	░
LCR Chinook salmon (Clackamas R.)	▨	▨■	■	■	■	■	■	■	■	▨	▨	▨
Juvenile Out-Migration and Rearing- Falls to Newberg												
UWR Winter steelhead	░	░■ [	■ - -	■ - -	■ - -	■ - -	■ - -	■░]	░	░	░	░
UWR Spring Chinook salmon	■ - -	■ - -	■ - -	■ - -	■ - -	■ - -	■▨]	■	■	■ [-	■ - -	■ - -
Juvenile Out-Migration and Rearing- Newberg to Yamhill												
UWR Winter steelhead	░	░	■ [-	■ - -	■ - -	■ - -	■ - -	■░]	░	░	░	░
UWR Spring Chinook salmon	■ - -	■ - -	■ - -	■ - -	■ - -	■ - -	■▨]	▨	▨	■ [-	■ - -	■ - -

■ Represents periods of peak use based on professional opinion.

▨ Represents lesser level of use based on professional opinion.

░ Represents periods of presence, either with no level of use OR uniformly distributed level of use indicated.

Based on professional opinion, 90% of the life-stage activity occurs during the time frame shown as the peak use period.

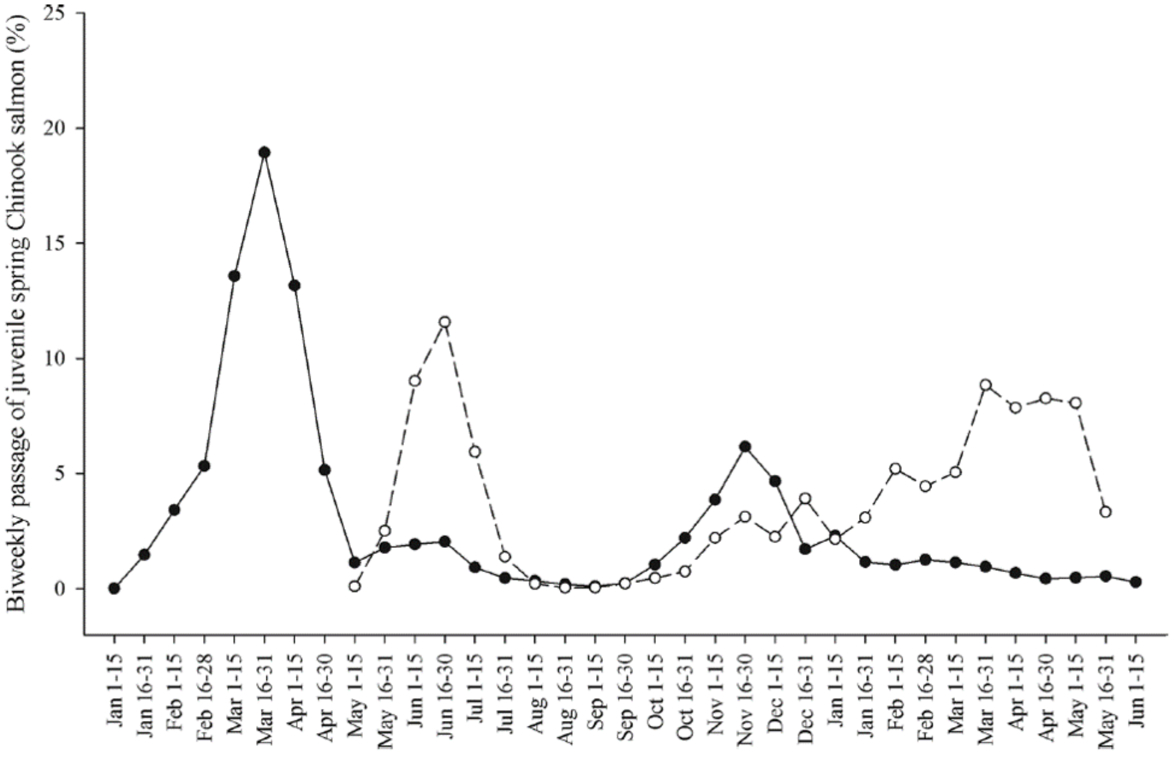
Based on professional opinion, 10% of the life-stage activity occurs during the time frame shown as the lesser use period.

7.4.1 Chinook Salmon

Juvenile Chinook salmon present in the lower migration corridor downstream of Willamette Falls may represent either Upper Willamette River or Lower Columbia River ESU populations. Juvenile Chinook appear to cue migration from ATU accumulation rather than a specific temperature threshold (Sykes et al. 2009, Sykes and Shrimpton 2010). Peak timing for Chinook out-migration in this reach occurs from March 15 – May 30 and smaller numbers are present in the migration corridor into July (Friesen 2005). Warmer temperatures in the spawning and rearing tributaries usually result in earlier migration timing. Out-migration drops off rapidly at Willamette Falls by the time daily average temperatures exceed 19°C in July and remains low until November (Figure 7-2). Out-migrating juvenile Chinook can potentially avoid temperatures greater than 19°C average and 20°C maximum under current average conditions if they continue from the falls to the Columbia River estuary without delay (see Figure 3-1). However, the residence time for out-migrating juveniles downstream of Willamette Falls is currently unknown. In years with unseasonable early warming, such as 2015, exposure to elevated temperatures during June is likely, regardless of residence time (Figure 3-2).

Density of juvenile Chinook rearing in the migration corridor is low from mid-July-November. However, small numbers of Chinook can be found year-round (Friesen 2005). A low level of presence or rearing in the main stem also occurs year-round for UWR Chinook above Willamette Falls. Most small Chinook salmon in the lower Willamette River are thought to be spring-run fish that out-migrate through the corridor as sub-yearlings, rather than long-term residents (Friesen 2005).

Figure 7-2 Average out-migration timing of juvenile Chinook salmon at the Leaburg Dam (solid circles) and Willamette Falls (open circles, dashed line) 2004–2013. Source: (Schroeder et al. 2016)



7.4.2 Steelhead

Juvenile steelhead present below Willamette Falls may represent either the Upper Willamette River or Lower Columbia River ESU populations. Steelhead are less likely to rear in the lower Willamette migration corridor and are mainly present during peak out-migration periods in winter and spring (Friesen 2005). Steelhead out-migration occurs from February to mid-August. Exposure to average temperatures greater than 19°C is likely for out-migrating steelhead in July and August under current average conditions. The residence time for out-migrating steelhead downstream of Willamette Falls is currently unknown.

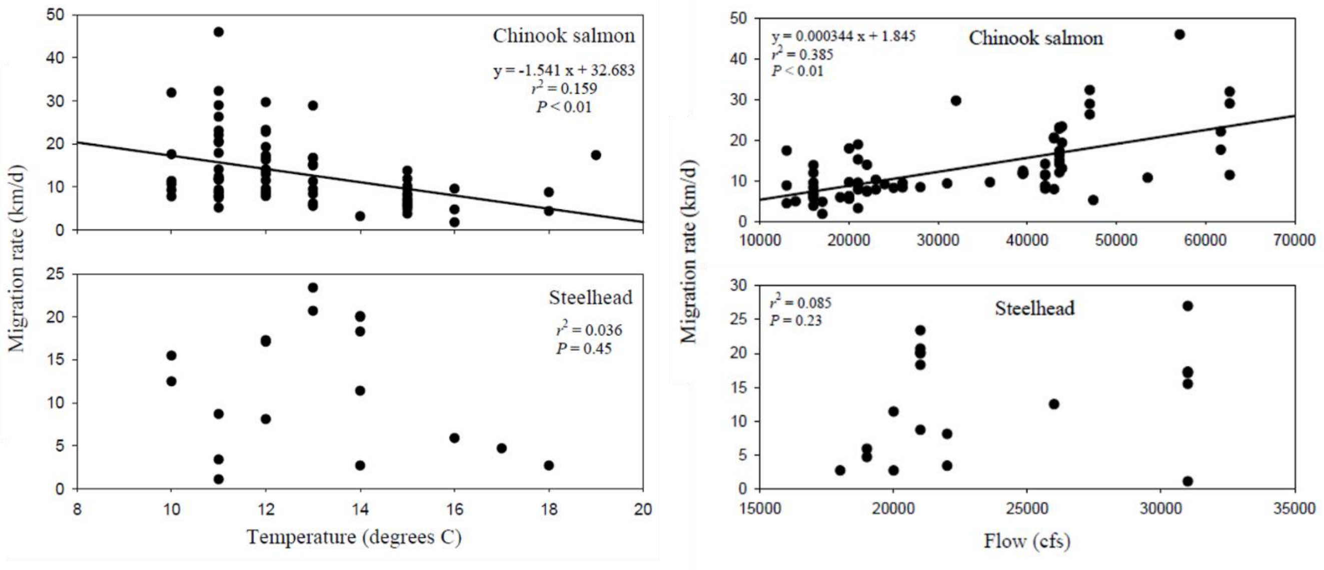
7.5 Juvenile out-migration rates

Out-migration of juveniles through the lower Willamette is relatively quick compared to adult up-migration, although small numbers of fish can be found in the corridor essentially year round (Friesen 2005, Friesen et al. 2007). Chinook salmon migrate an average of 11.3 km/day in the Willamette main stem (Friesen 2005). Migration rates for radio-tagged Chinook accelerate below Willamette Falls. The rate from Willamette Falls to the estuary was 25.2 km/day, over twice as fast as that from release sites to the falls (Schroeder et al. 2016). Total duration was an average of 5–6 days to travel 131 km from the falls to the Columbia River estuary.

Steelhead migrated more evenly at rates of about 12.5 km/d (Friesen 2005). Median residence times below Willamette Falls for radio-tagged migrants were 3.4 days for Chinook salmon and 2.5 days for steelhead (Friesen 2005).

Migration rates for Chinook salmon were negatively correlated with water temperature and positively correlated with flow rate (Figure 7-3). Flow variability appeared to explain more variation in migration rate than temperature, and there is co-variance between low flows and high temperatures so it is hard to isolate the effects of both factors. Migration rates for steelhead were not correlated with either water temperature or flow.

Figure 7-3 Juvenile UWR Chinook and steelhead migration rates versus temperature and flow. Data source: (Friesen 2005)



7.6 Juvenile habitat use and behavior

The migration corridor use was so designated because adult migration was expected to be the primary salmonid use of this reach and the most sensitive to temperature exposure. Since Oregon's temperature standard was adopted in 2003, there is increased appreciation for the importance of the secondary function of juvenile rearing and growth the lower Willamette migration corridor and major tributaries (Friesen 2005). Winter and spring are the periods of greatest juvenile salmon and steelhead abundance in the lower Willamette main stem and migration corridor (Friesen 2005, Whitman et al. 2017).

Juvenile Chinook salmon feed and grow during their outmigration and are the most commonly found juvenile species in the migration corridor. Steelhead rear primarily in their natal streams and larger upriver tributaries. Steelhead may outmigrate more quickly through the migration corridor (Friesen 2005). Most juveniles captured during surveys in the migration corridor are Chinook salmon (87%), and few are steelhead (3%) (Friesen 2005).

7.6.1 Distribution in habitat types

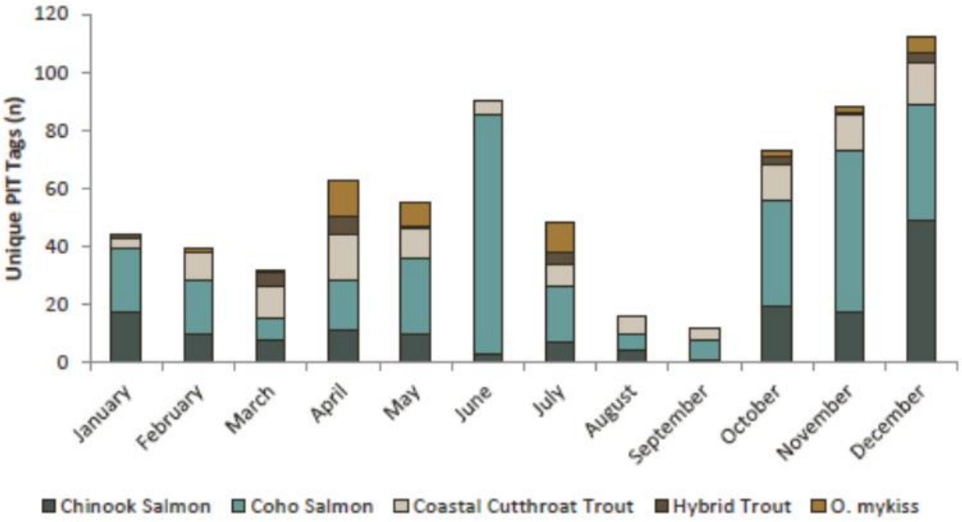
A number of surveys of juvenile presence and habitat use in the lower Willamette migration corridor have been published since 2003. Juvenile salmon and steelhead use a variety of habitats in this reach, including tributary streams, nearshore bank habitats, and the main stem itself.

7.6.1.1 Tributaries

Juvenile salmon and steelhead access some tributaries within the migration corridor that provide cold-water refuge or can serve as rearing habitat. In surveys conducted for the City of Portland by ODFW, juvenile chinook salmon are present in the lowest reaches of Crystal Springs, Johnson, Miller, Stephens, and Tryon creeks (Tinus et al. 2003b). The Tinus study not correlate abundance of juvenile presence with temperature or flow. However, they noted juvenile Chinook were most abundant in winter months. Juvenile rainbow/steelhead trout are observed in very low numbers in accessible portions of Tryon Creek and throughout the Johnson Creek watershed. Juvenile trout were most likely to be detected in the spring months (Tinus et al. 2003b). The tributaries downstream of the Clackamas River are not expected to function as major spawning habitat for Chinook or steelhead at this time.

Tryon Creek is heavily used by juvenile Chinook (Figure 7-4). The number of juvenile detections is highest from October through April. The number of Chinook salmon detections is low in June, July, August, and September. Steelhead are present in small numbers with peak detections in April, May, and July. Total detections at the Tryon Creek site are lowest during these months when main stem temperatures would be most likely to exceed the migration corridor criterion. The authors of this study concluded that juveniles may be using Tryon Creek for relief from high flows in the Willamette main stem (Silver et al. 2017a).

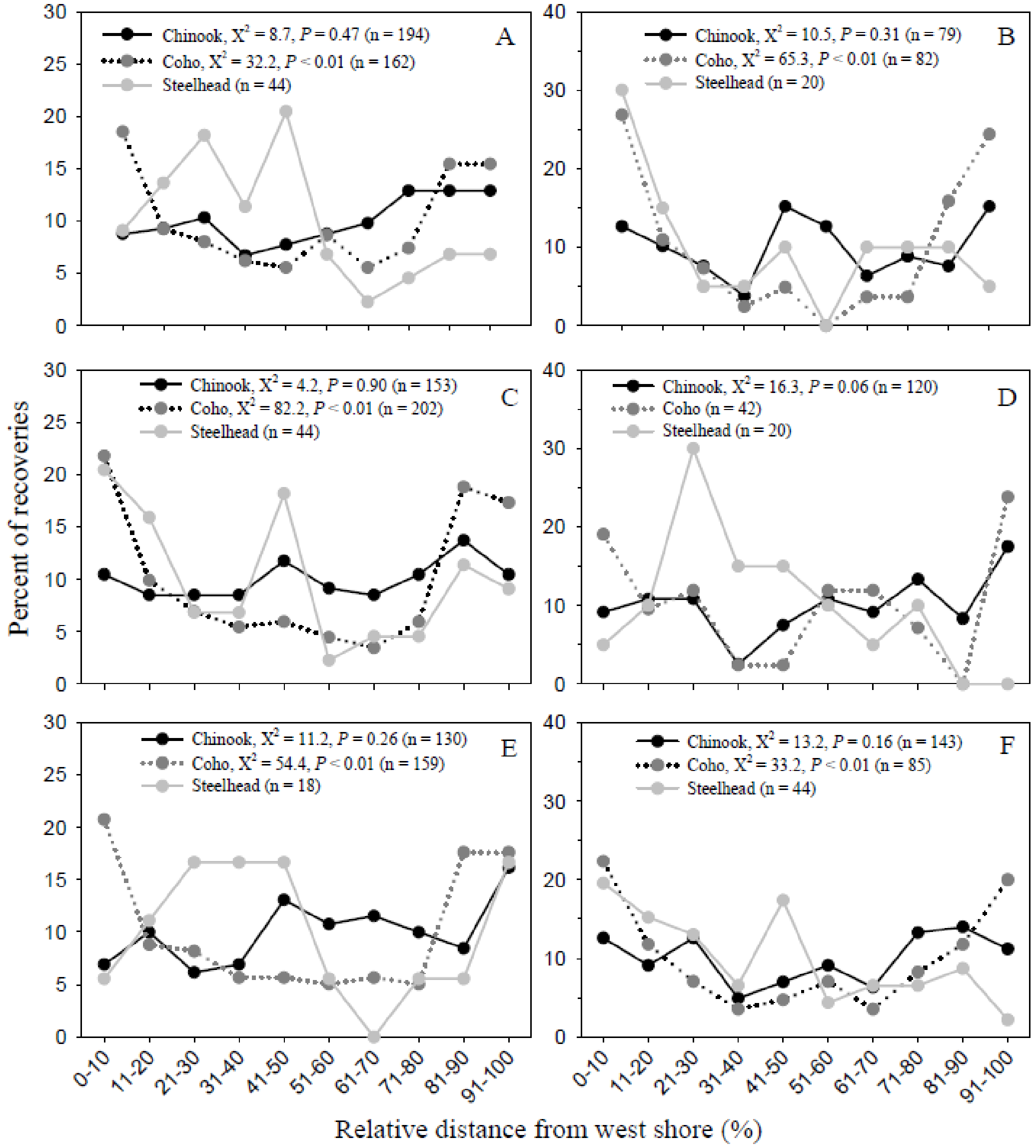
Figure 7-4 Average number of unique PIT tag detections of juvenile anadromous salmon and steelhead at the mouth of Tryon Creek, by month, 2012-2016. Chinook salmon shown as dark gray-bottom of bar stacks. Steelhead/rainbow trout shown as light brown – top of bar stacks. (Silver et al. 2017a)



7.6.1.1 Main channel habitat

Migrating Chinook and steelhead use a variety of channel habitats in the lower Willamette migration corridor. Surveys find ~75% of recoveries of radio-tagged juvenile Chinook and steelhead occur offshore in the main channel and not in nearshore habitats (Friesen 2005). Radio-tagged juvenile Chinook have a mostly uniform distribution across the river channel regardless of year, time of day, or hatchery origin (Figure 7-5) (Friesen et al. 2007). Separated by age class, yearling spring Chinook salmon and steelhead are abundant in mid channel areas, while smaller fish (age-0 Chinook salmon) are most abundant in near shore habitats (Friesen et al. 2007).

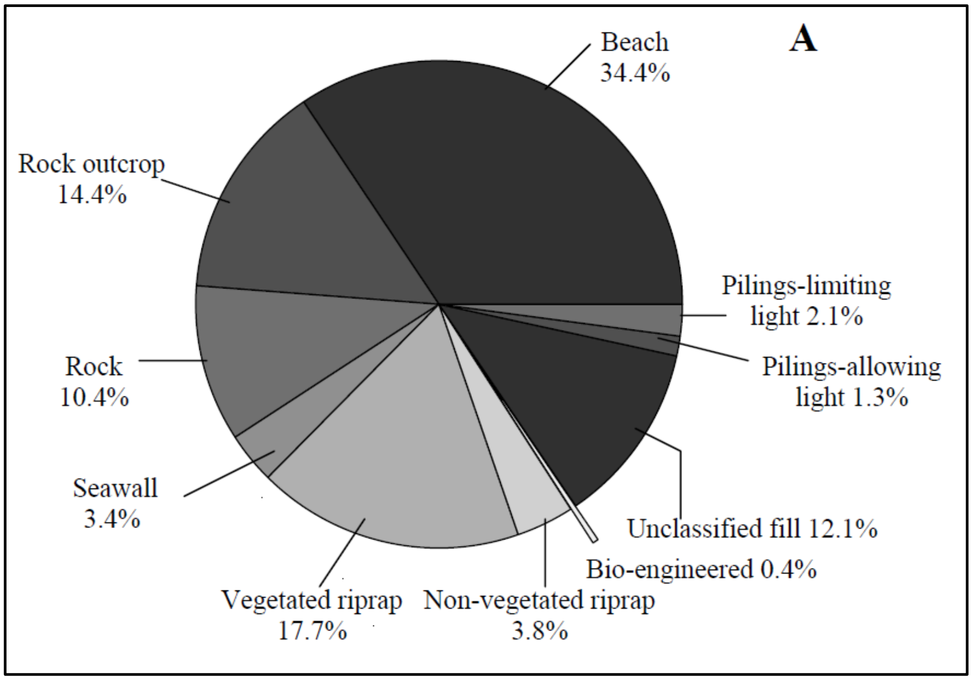
Figure 7-5 Juvenile UWR Chinook and steelhead channel utilization during different conditions. A = daytime, B= nighttime, C= River km 22.6-42.6, D = River km 0-22.5, E=unmarked fish, F = hatchery fish Source: (Friesen 2005)



7.6.1.2 Nearshore habitats

Surveys of juvenile salmon and steelhead habitat in the lower Willamette have identified 12 nearshore habitat types available to fish in addition to tributaries and the main channel (Figure 7-6). Juvenile Chinook from natural production most commonly appeared in beach seines near undeveloped beaches. Chinook were present near the beaches most of the year (November to July). Friesen and others hypothesized that beaches are particularly important habitats for naturally spawned Chinook (Friesen 2005). Friesen also found little evidence to suggest that current condition of nearshore habitat in the lower Willamette are a critical threat for juvenile salmon and steelhead survival. Development of nearshore habitat in the migration corridor below Willamette Falls dam does not appear to significantly increase juvenile Chinook mortality from predation (Ward et al. 1994, Friesen et al. 2003, Friesen 2005, Whitman et al. 2017). However, loss of flood plain, shallow water habitat, velocity refuge during winter in the Willamette Basin, and exposure to legacy pollution in remaining habitats is an ongoing concern for UWR spring-run Chinook salmon (Friesen et al. 2003, NMFS 2016).

Figure 7-6 Nearshore habitat types in the lower Willamette migration corridor (Willamette Falls to Columbia River). Source: (Friesen 2005).



7.6.2 Conclusions for juvenile cold water refuge use

None of the juvenile surveys we reviewed specifically identified or observed juvenile use of cold-water refuges. Few of the available studies measured or correlated habitat use with water temperature. The relatively even distribution of juvenile Chinook and steelhead in main-channel and near-shore habitats during spring and summer surveys does not suggest that juveniles cluster near sources of cold water.

7.7 Risks and benefits of juvenile CWR use

7.7.1 Potential benefits of juvenile CWR use

The potential benefits of cold-water refuge use to juvenile salmon and steelhead are similar to the potential benefits to migrating adults:

- Thermal habitat heterogeneity provides for behavioral thermoregulation, growth, and maturation.
- Reduction of acute thermal stress.

There is very limited data to directly evaluate juvenile use of cold-water refuge in the lower Willamette migration corridor. Juvenile Chinook salmon in the Santiam river were less likely to migrate from natal tributaries during August when their local water temperatures approach or exceed 20°C (Kock et al. 2015). This suggest benefits to maintaining cold-water refuge in these upstream areas.

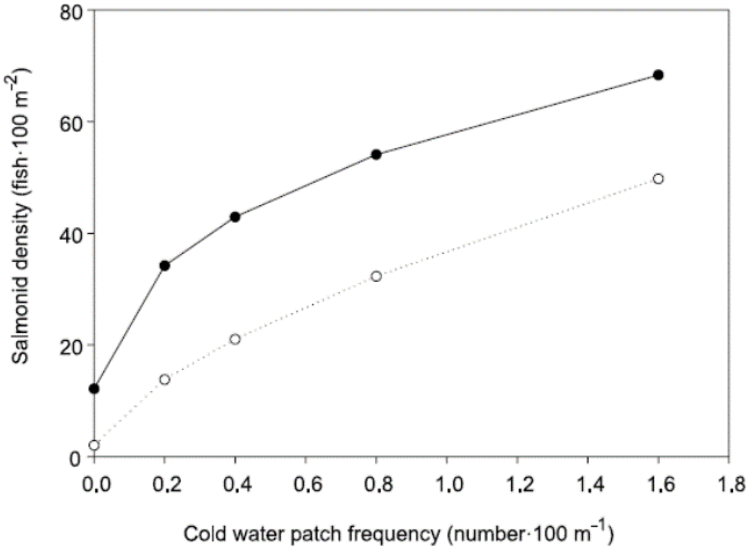
Juvenile steelhead pass quickly through lower Willamette and are in low abundance by mid-June until November. This migration strategy suggests that steelhead mostly avoid migrating through the migration corridor during warmer conditions when they would benefit from refuge use in the corridor. However, juvenile steelhead are also more likely to encounter warm temperatures in the migration corridor because their migration timing extends into the summer months of July and August. UWR steelhead adult kelt mortality is hypothesized to occur when fish with limited metabolic reserves encounter warm water temperatures in the lower Willamette River (Jepson et al. 2015).

There are no data currently available that measures juvenile mortality within the migration corridor before fish enter the Columbia River. Adult returns in 2017 were from the cohort exposed to extreme water temperatures during out-migration in June-August 2015. Chinook returns in 2017 were actually up 8% from the previous year (ODFW and WDFW 2018). However, steelhead returns in 2017 were the lowest on record. There are several possible factors that could have contributed to reduced steelhead returns in 2017:

1. Poor spawning success of adults that migrated upstream during 2015 would reduce the size of the cohort.
2. High mortality of out-migrating juvenile steelhead in 2015.
3. Poor ocean conditions from 2015-2017 could reduce growth and survival to adult stage of returning adults.

Examples of juvenile refuge use from other river systems are mixed. In an experimental heating study of streams in British Columbia, rapid heating of habitat to 19-23°C did not appear to cause refuge-seeking behavior in juvenile spring Chinook, but did cause physiological stress (Quigley and Hinch 2006). In the Klamath basin, juvenile steelhead were observed to seek cold-water refuge when temperatures exceeded 22°C-25°C (Brewitt and Danner 2014). A field study in the Grande Ronde Basin of Oregon showed that fine-scale cold-water patch frequency has a positive relationship to juvenile steelhead and Chinook salmon density, along with other habitat factors including riparian canopy coverage and pool availability (Figure 7-7 The relationship between juvenile salmonid density and cold water patch frequency in streams of the Grand Ronde Basin, Oregon. Solid circles are for Rainbow trout (resident), open circles are for Chinook salmon (migratory). (Ebersole et al. 2003).Figure 7-7) (Ebersole et al. 2003). This shows that with a greater abundance and diversity of thermal habitat, headwater streams can support more steelhead and Chinook. However, the benefits of cold-water patches in natal headwater streams could be quite different from those in the lower main stem. The lower Willamette main stem is not a natal stream, and is primarily used by fish that will ultimately outmigrate through the reach.

Figure 7-7 The relationship between juvenile salmonid density and cold water patch frequency in streams of the Grand Ronde Basin, Oregon. Solid circles are for Rainbow trout (resident), open circles are for Chinook salmon (migratory). (Ebersole et al. 2003).**Figure 7-7 The relationship between juvenile salmonid density and cold water patch frequency in streams of the Grand Ronde Basin, Oregon. Solid circles are for Rainbow trout (resident), open circles are for Chinook salmon (migratory). (Ebersole et al. 2003).**



7.7.2 Potential risks of juvenile CWR use

Juvenile use of cold-water refuge could present a number of risks to survival. These are mainly migration delay, predation risk, and exposure to pollution.

7.7.2.1 Out-migration delay

Rapid travel through degraded habitats presumably improves survival for migrating juveniles in the Willamette migration corridor. Juvenile salmon and steelhead spend less time exposed to sub-optimal habitat, predation, poor water conditions, and toxins if they do not delay (Friesen 2005). Delay caused by CWR use potentially increases risk from these causes in the migration corridor.

7.7.2.2 Predators

Researchers don't expect increased predation risk for juvenile Chinook and steelhead a when using CWR in small inflows and seeps in the migration corridor. Radio-tagged predatory fish were shown to favor near shore habitat associated with conversion to pilings and rocky banks in the migration corridor (Friesen 2005). This is not habitat favored by juvenile Chinook or steelhead. Densities of large predator fishes in the migration corridor are low and are expected to have negligible effects on juvenile mortality (Ward et al. 1994, Friesen 2005). Thermal stress has not been strongly linked to increased predation risk in the Willamette River (Mesa et al. 2002) and temperature X predator interactions are not shown to increase short-term mortality in juvenile spring chinook in other river systems (Kuehne et al. 2012).

7.7.2.3 Legacy Pollution

Most of the potential cold-water habitat downstream from Ross Island occurs in the Portland Harbor – Northwest Industrial area of Portland. Exposure to toxins and other poor water conditions during habitat use in this area is a concern. In one study, juvenile Chinook that migrated along the west bank of the

Portland Harbor area saw an estimated 20% increase in mortality compared to migrants that followed the east bank (Lundin et al. 2019).

7.7.2.4 Climate change

Juvenile Chinook potentially avoid high temperatures in the lower Willamette at the population level by a tendency to migrate out by mid-July (Schroeder et al. 2016, Silver et al. 2017a). However, an unknown portion of the population may be present in the lower Willamette migration corridor further into the summer. Summer maximum water temperatures will see the greatest increase from already realized and future climate change (Isaak et al. 2012, Chang et al. 2018). These increases may affect juvenile Chinook and steelhead more acutely than migrating adults in the Willamette migration corridor. In addition to temperature increases, projected changes to flow in April and June related to climate change may reduce shallow beach habitat favored by juvenile Chinook in the lower Willamette (Jorgensen et al. 2013).

7.8 Juvenile refuge sufficiency

7.8.1 Juvenile outmigration and rearing

Due to limitations in study design and sampling protocols, there is limited data on passage timing, behavior, abundance, and mortality for rearing and migrating juvenile salmon and steelhead in the migration corridor. Data is especially limited from times when main stem temperatures exceed 20°C. There are no direct studies of juvenile CWR use or other habitat use during elevated temperatures in the migration corridor. Other researchers have concluded that current conditions appear to adequately support juvenile fish populations and that the lower Willamette migration corridor has value as rearing habitat (Friesen 2005). Given these constraints, DEQ is unable to conclude whether CWR is sufficient or insufficient for the needs of juveniles of listed populations of UWR and LCR Chinook or UWR and LCR steelhead at this time.

Studies and data from others that DEQ identified in this report shows a number of large and small CWR exist that contribute to thermal habitat diversity along the entire migration corridor. Maintaining access to spatial and temporal heterogeneity of these habitats in the Willamette basin is likely to have multiple benefits for juvenile Chinook and steelhead (Schroeder et al. 2016).

7.9 Knowledge gaps on juvenile CWR use

1. There are only a small number of studies that investigate the origin, abundance, habitat use, residence time, and survival of sub-yearling Chinook salmon and steelhead in the lower Willamette River.
2. Existing studies and surveys have limited temporal resolution.
3. Due to limitations in study design and fish sampling protocols, there are no data from direct observations of juvenile habitat use under conditions when temperatures exceed the migration corridor criterion.
4. Data on migration timing, mortality, and thermal exposure for out-migrating adult steelhead kelts is extremely limited.
5. While this study identifies cold-water sources in the migration corridor suitable to support juvenile salmon and steelhead, further research is needed to monitor and evaluate these refuges for carrying capacity and use by juvenile salmon and steelhead.

8. Actions to protect and enhance CWR in the lower Willamette migration corridor

Because the apparent level of use of the existing CWR is low based on available data, and because of the knowledge gaps and lack of data around fish behavior and CWR habitat use during conditions when the migration corridor criterion is exceeded. Therefore, DEQ cannot make specific recommendations for the need, location, and size of additional CWR habitat in the lower Willamette River at this time. Until these knowledge gaps are addressed, DEQ recommends that the currently identified CWR habitat be protected for the reasons discussed below. Designated Management Agencies (DMAs) are required to consider impacts to CWR under the TMDLs in effect for the Willamette Basin. DMAs may also initiate projects that will address these knowledge gaps. The NPDES permitting program is are required to consider thermal plume impacts to CWR when issuing new permits.

This study identifies multiple CWR locations in the Lower Willamette and evaluates their current level of use, quality, and availability using the best available information. The results of the study can be used to implement the CWR narrative and inform actions in future TMDLs, implementation actions by DMAs, and NPDES permits to protect the existing CWRs that have been identified.

8.1 Actions to protect CWR for migrating adult salmon and steelhead

1. The existing thermal heterogeneity in the lower Willamette mainstem identified in this study (Table 3-6) should be maintained and protected in order to support potential use by migrating adult and juvenile salmon and steelhead.
2. Maintaining access and cool temperatures in the Clackamas River - Meldrum Bar area (RM 24-25) is important as this is the largest CWR area by volume at a key junction within the lower Willamette migration corridor. This area is particularly important for fish that may pause in this area as they prepare to ascend Willamette Falls, just upstream.
3. Maintaining cool temperatures in the Clackamas River is also important for LCR Chinook and LCR steelhead populations that spawn and rear in the Clackamas River basin.
4. DEQ did not find sufficient evidence to recommend the creation of additional CWR in the migration corridor at this time. However, significant knowledge gaps about use of existing CWR by adult Chinook for river mile 0–25 exist. These knowledge gaps should be addressed to inform setting specific habitat conservation and restoration priorities for CWR habitat. See detailed discussion of research needs in Section 4.10.
5. The USGS and others are doing complementary work to identify CWR distribution in the greater Willamette Basin upriver of the migration corridor. The USGS work may also answer questions whether and where it is possible to create new CWR habitat in this reach of the river, or any constraints on restoration caused by hydrology and geomorphology limitations in the lower river.

8.2 Actions to protect CWR and rearing habitat for juvenile salmon and steelhead

1. Protect existing thermal habitat heterogeneity to support juvenile salmonid rearing and migration and potential use by other native species (Table 7-2). In addition, the protection of this habitat heterogeneity is important for multiple habitat functions by other native salmonid and non-salmonid resident aquatic species in addition to thermal relief.
2. Protect and enhance access to existing cold off-channel sites of all sizes– alcoves, seeps, small tributaries, and other cold inflows. See work by others– such as City of Portland and U.S. Army Corps of Engineers restoration of off-channel habitat at Oaks Bottom.
3. There are significant knowledge gaps about the need for, and level of use, of cold-water habitat by juvenile Chinook and steelhead, out-migrating steelhead kelts, and other native aquatic species in Willamette river mile 0–27. These knowledge gaps should be addressed before investing in specific habitat restoration and enhancement projects. See a discussion of the knowledge gaps and research priorities in Chapter 7.

8.3 Mechanisms for implementation

1. DEQ's Clean Water Act Programs and Designated Management Agencies will continue to implement existing temperature TMDLs to achieve temperature reductions in the main stem and cold-water tributaries. These TMDLs will maintain and enhance the large-scale CWRs identified in this report. For example, implementing the Clackamas Basin TMDL will increase and protect the quality of cold-water refuge provided by the Clackamas River confluence.

   To date, DEQ has TMDLs for the following major tributaries in the migration corridor:

   - Main stem Willamette River TMDL
   - Clackamas Sub-Basin TMDL
   - Johnson Creek Watershed (Lower Willamette Sub-Basin TMDL)
   - Columbia Slough Watershed (Lower Willamette Sub-Basin TMDL)
   - Tryon Creek Watershed (Lower Willamette Sub-Basin TMDL)
   - Tualatin River Sub-Basin TMDL
   - Molla-Pudding Sub-Basin TMDL

2. Designated management agencies (DMAs) along the mainstem Willamette River are required to address Cold Water Refugia (CWR) according to the 5-year Willamette Basin TMDL Implementation Plans. The Implementation Plans require DMAs to evaluate impacts to existing CWR, now identified in this study, identify additional CWR if applicable, and provide options for protecting or enhancing such areas.
3. NPDES permits for discharges are required to evaluate and prohibit thermal impacts to CWR under the authority of OAR 340-041-0053 (d). When permits are issued for discharges within the migration corridor, potential for impacts to the CWR identified in this report, or any additional CWR identified by DMAs, can now be evaluated and thermal plume limitations applied as necessary.

9. Literature cited & bibliography

Anderson, J. J., and W. N. Beer. 2009. Anderson and Beer 2009, Oceanic, riverine, and genetic influences on spring chinook salmon migration timing..pdf. Ecological Applications 19:1989–2003.

Arrigoni, A., S., G. Poole C., L. Mertes A. K., S. O'Daniel J., W. Woessner W., and S. Thomas A. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. Water Resources Research 44.

Baigún, C. R. M. 2003. Characteristics of Deep Pools Used by Adult Summer Steelhead in Steamboat Creek, Oregon. North American Journal of Fisheries Management 23:1167–1174.

Baigun, C. R., J. Sedell, and G. Reeves. 2000. Influence of water temperature in use of deep pools by summer steelhead in Steamboat Creek, Oregon (USA). Journal of Freshwater Ecology 15:269–279.

Beer, W. N., and J. J. Anderson. 2013. Sensitivity of salmonid freshwater life history in western US streams to future climate conditions. Global Change Biology 19:2547–56.

Benda, S. E., G. P. Naughton, C. C. Caudill, M. L. Kent, and C. B. Schreck. 2015. Cool, Pathogen-Free Refuge Lowers Pathogen-Associated Prespawn Mortality of Willamette River Chinook Salmon. Transactions of the American Fisheries Society 144:1159–1172.

Bowerman, T., A. Roumasset, M. L. Keefer, C. S. Sharpe, and C. C. Caudill. 2018. Prespawn Mortality of Female Chinook Salmon Increases with Water Temperature and Percent Hatchery Origin. Transactions of the American Fisheries Society.

Brewitt, K. S., and E. M. Danner. 2014. Spatio-temporal temperature variation influences juvenile steelhead (Oncorhynchus mykiss) use of thermal refuges. Ecosphere 5.

Burkholder, B. K., G. E. Grant, R. Haggerty, T. Khangaonkar, and P. J. Wampler. 2008. Influence of hyporheic flow and geomorphology on temperature of a large, gravel-bed river, Clackamas River, Oregon, USA. Hydrological Processes 22:941–953.

Chang, H., E. Watson, and A. Strecker. 2018. Climate Change and Stream Temperature in the Willamette River Basin: Implications for Fish Habitat. Pages 119–132 Bridging Science and Policy Implication for Managing Climate Extremes.

Cooke, S. J., S. G. Hinch, A. P. Farrell, M. F. Lapointe, S. R. M. Jones, J. S. Macdonald, D. A. Patterson, M. C. Healey, and G. Van Der Kraak. 2004. Abnormal Migration Timing and High en route Mortality of Sockeye Salmon in the Fraser River, British Columbia. Fisheries 29:22–33.

Coutant, C. C. 1987. Thermal preference: when does an asset become a liability? Environmental Biology of Fishes 18:167–172.

Coutant, C. C. 1999. Perspectives on Temperature in the Pacific Northwest's Fresh Water.

Crossin, G. T., S. G. Hinch, S. J. Cooke, D. W. Welch, D. A. Patterson, S. R. M. Jones, A. G. Lotto, R. A. Leggatt, M. T. Mathes, J. M. Shrimpton, G. Van Der Kraak, and A. P. Farrell. 2008. Exposure to high temperature influences the behaviour, physiology, and survival of sockeye salmon during spawning migration. Canadian Journal of Zoology 86:127–140.

Dalton, M. M., K. D. Dello, P. W. Mote, and D. E. Rupp. 2017. The Third Oregon Climate Assessment Report. Oregon Climate Change Research Institute, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR.

Dimick, R. E., and F. Merryfield. 1945. The Fishes of the Willamette River System in Relation to Pollution. Engineering Experiment Station, Oregon State College, Corvallis, Oregon.

Donaldson, M. R., S. J. Cooke, D. A. Patterson, S. G. Hinch, D. Robichaud, K. C. Hanson, I. Olsson, G. T. Crossin, K. K. English, and A. P. Farrell. 2009. Limited behavioural thermoregulation by adult upriver-migrating sockeye salmon (Oncorhynchus nerka) in the Lower Fraser River, British Columbia. Canadian Journal of Zoology 87:480–490.

Dugdale, S. J., N. E. Bergeron, and A. St-Hilaire. 2013. Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. Remote Sensing of Environment 136:358–373.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2001. Relationship between stream temperature, thermal refugia and rainbow trout Oncorhynchus mykiss abundance in arid-land streams in the northwestern United States. Ecology of Freshwater Fish 10:1–10.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2003a. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 60:1266–1280.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2003b. Cold water patches in warm streams: Physicochemical characteristics and the influence of shading. Journal of the American Water Resources Association 39:355–368.

Ebersole, J. L., P. J. Wigington, J. P. Baker, M. A. Cairns, M. R. Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, and S. G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transactions of the American Fisheries Society 135:1681–1697.

Ebersole, J. L., P. J. Wigington, S. G. Leibowitz, R. L. Comeleo, and J. V. Sickle. 2015. Predicting the occurrence of cold-water patches at intermittent and ephemeral tributary confluences with warm rivers. Freshwater Science 0.

Eliason, E. J., T. D. Clark, M. J. Hague, L. M. Hanson, Z. S. Gallagher, K. M. Jeffries, M. K. Gale, D. A. Patterson, S. G. Hinch, and A. P. Farrell. 2011. Differences in Thermal Tolerance Among Sockeye Salmon Populations. Science 332:109–112.

EPA, E. P. A. 2003. EPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards. Page pages. U.S. EPA, pp. 49, EPA 910-B-03-002.

Evans, E. C., and G. E. Petts. 1997. Hyporheic temperature patterns within riffles. Hydrological Sciences Journal 42:199–213.

Farrell, A. P., S. G. Hinch, S. J. Cooke, D. A. Patterson, G. T. Crossin, M. Lapointe, and M. T. Mathes. 2008. Pacific salmon in hot water: applying aerobic scope models and biotelemetry to predict the success of spawning migrations. Physiol Biochem Zool 81:697–708.

Fernald, A. G., D. H. Landers, and P. J. Wigington. 2006. Water quality changes in hyporheic flow paths between a large gravel bed river and off-channel alcoves in Oregon, USA. River Research and Applications 22:1111–1124.

Flett, P. A., G. V. D. Kraak, and J. F. Leatherland. 1996. Overripening as the cause of low survival to hatch in Lake Erie coho salmon (Oncorhynchus kisutch) embryos. Canadian Journal of Zoology 74:851–857.

Friesen, T. A. 2005. Biology, Behavior and Resources of Resident and Anadromous Fish in the Lower Willamette River. ODFW Information Report.

Friesen, T. A., H. K. Takata, J. S. Vile, J. C. Graham, R. A. Farr, M. J. Reesman, and B. S. Cunningham. 2003. Relationships between bank treatment / nearshore development and anadramous / resident fish in the lower Willamette River. Annual Progress Report to the City of Portland Bureau of Environmental Services, Oregon Department of Fish and Wildlife, Columbia River Investigations Program, Clackamas, OR.

Friesen, T. A., J. S. Vile, and A. L. Pribyl. 2007. Outmigration of juvenile Chinook salmon in the lower Willamette River, Oregon. Northwest Science 81:173–190.

Fulton, L. A. 1968. Spawning areas and abundcance of Chinook salmon, Oncorhynchus tshawytscha, in the Columbia River Basin – past and present. U.S. Fish and Wildlife Service.

Gariglio, F. P., D. Tonina, and C. H. Luce. 2013. Spatiotemporal variability of hyporheic exchange through a pool-riffle-pool sequence. Water Resources Research 49:7185–7204.

Gombert. 2018. Gombert, 2018-MS Thesis-Characterization of Thermal Regimes of Side Channels, Alcoves, and Ponds on the Willamette River, OR.pdf.

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L. C. Stuehrenberg. 2006. Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures. Transactions of the American Fisheries Society 135:408–419.

Gregory, S. V. 2008. Historical channel modification and floodplain forest decline: implications for conservation and restoration of a large floodplain river – Willamette River, Oregon. Pages 763–777 Developments in Earth Surface Processes. Elsevier.

Hannah, D. M., I. A. Malcolm, and C. Bradley. 2009. Seasonal hyporheic temperature dynamics over riffle bedforms. Hydrological Processes 23:2178–2194.

Hasler, C. T., S. J. Cooke, S. G. Hinch, E. Guimond, M. R. Donaldson, B. Mossop, and D. A. Patterson. 2012. Thermal biology and bioenergetics of different upriver migration strategies in a stock of summer-run Chinook salmon. Journal of Thermal Biology 37:265–272.

Hester, E. T., and M. N. Gooseff. 2010. Moving Beyond the Banks: Hyporheic Restoration Is Fundamental to Restoring Ecological Services and Functions of Streams. Environmental Science & Technology 44:1521–1525.

Hester, E. T., G. C. Poole, and M. W. Doyle. 2007. Effects of In-Stream Geomorphic Structures on Stream Temperatures and Streambed Heat Flux Through Induced Hyporheic Exchange. American Geophysical Union 13:1538.

High, B., C. A. Peery, and D. H. Bennett. 2006. Temporary Staging of Columbia River Summer Steelhead in Coolwater Areas and Its Effect on Migration Rates. Transactions of the American Fisheries Society 135:519–528.

Hodgson, S., and T. P. Quinn. 2002. The timing of adult sockeye salmon migration into fresh water: adaptations by populations to prevailing thermal regimes. Canadian Journal of Zoology-Revue Canadienne De Zoologie 80:542–555.

Hodgson, S., T. P. Quinn, R. Hilborn, R. C. Francis, and D. E. Rogers. 2006. Marine and freshwater climatic factors affecting interannual variation in the timing of return migration to fresh water of sockeye salmon (Oncorhynchus nerka). Fisheries Oceanography 15:2–24.

Howell, P. J., J. B. Dunham, and P. M. Sankovich. 2010. Relationships between water temperatures and upstream migration, cold water refuge use, and spawning of adult bull trout from the Lostine River, Oregon, USA. Ecology of Freshwater Fish 19:96–106.

Hughes, R. M., and J. R. Gammon. 1987. Longitudinal Changes in Fish Assemblages and Water Quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116:196–209.

Hulse, D., A. Branscomb, C. Enright, S. V. Gregory, and R. Wildman. 2007. Linking cold-water refuges into a biologically effective network in the Willamette River floodplain. 208-8006-5780, Oregon Water Resources Enhancement Board.

Hulse, D., A. Branscomb, C. Enright, S. V. Gregory, and R. Wildman. 2010. Linking cold-water refuges into a biologically effective network in the Willamette River floodplain : final report on OWEB research grant, 208-8006-5780. Oregon Water Resources Enhancement Board.

Hulse, D., S. V. Gregory, and J. Baker, editors. 2002. Willamete River Basin Planning Atlas: Trajectories of Environmental and Ecological Change. First Edition. Oregon State University Press.

Hyatt, K. D., M. M. Stockwell, and D. P. Rankin. 2003. Impact and Adaptation Responses of Okanagan River Sockeye Salmon (Oncorhynchus nerka) to Climate Variation and Change Effects During Freshwater Migration: Stock Restoration and Fisheries Management Implications. Canadian Water Resources Journal / Revue canadienne des ressources hydriques 28:689–713.

Isaak, D. J., C. H. Luce, D. L. Horan, G. L. Chandler, S. P. Wollrab, and D. E. Nagel. 2018. Global Warming of Salmon and Trout Rivers in the Northwestern U.S.: Road to Ruin or Path Through Purgatory? Transactions of the American Fisheries Society 147:566–587.

Isaak, D. J., S. J. Wenger, E. E. Peterson, J. M. Ver Hoef, D. E. Nagel, C. H. Luce, S. W. Hostetler, J. B. Dunham, B. B. Roper, S. P. Wollrab, G. L. Chandler, D. L. Horan, and S. Parkes-Payne. 2017. The NorWeST Summer Stream Temperature Model and Scenarios for the Western U.S.: A Crowd-Sourced Database and New Geospatial Tools Foster a User Community and Predict Broad Climate Warming of Rivers and Streams. Water Resources Research 53:9181–9205.

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climatic Change 113:499–524.

Jay, S., and D. Talke. 2015. How extreme were 2015 water temperatures in the lower Columbia and Willamette Rivers?

Jepson, M. A., T. S. Clabough, M. L. Keefer, and C. C. Caudill. 2011. Migratory Behavior, Run Timing, and Distribution of Radio-tagged Adult Spring Chinook Salmon in the Willamette River - 2011. Technical Report.

Jepson, M. A., M. L. Keefer, C. C. Caudill, and T. S. Clabough. 2014. Migratory Behavior, Run Timing, and Distribution Of Radio-Tagged Adult Winter Steelhead, Summer Steelhead, and Spring Chinook Salmon in the Willamette River – 2013. Page 114. Technical Report.

Jepson, M. A., M. L. Keefer, C. C. Caudill, T. S. Clabough, C. S. Erdman, and T. Blubaugh. 2015. Migratory Behavior, Run Timing, and Distribution of Radio- Tagged Adult Winter Steelhead, Summer Steelhead, Spring Chinook Salmon, and Coho Salmon in the Willamette River: 2011-2014. Technical Report.

Jepson, M. A., M. L. Keefer, T. S. Clabough, and C. C. Caudill. 2012. Migratory Behavior, Run Timing, and Distribution Of Radio-Tagged Adult Winter Steelhead, Summer Steelhead, and Spring Chinook Salmon in the Willamette River – 2012. TECHNICAL REPORT.

Jones, K. 2017. Cold Water Refuges in the Lower Willamette River and Tributaries.

Jorgensen, J. C., M. M. Mcclure, M. B. Sheer, and N. L. Munn. 2013. Combined Effects of Climate Change and Bank Stabilization on Shallow Water Habitats of Chinook Salmon. Conservation Biology 27:1201–1211.

Keefer, M., and C. C. Caudill. 2010. A review of adult salmon and steelhead life history and behavior in the Willamette River basin: Identification of knowledge gaps and research needs. United States Army Corps of Engineers, Portland District, Portland, Oregon.

Keefer, M. L., and C. C. Caudill. 2016. Estimating thermal exposure of adult summer steelhead and fall Chinook salmon migrating in a warm impounded river. Ecology of Freshwater Fish 25:599–611.

Keefer, M. L., Christopher A. Peery, and Heinrich, Matthew J. 2008a. Temperature-mediated en route migration mortality and travel rates of endangered Snake River sockeye salmon. Ecology of Freshwater Fish 17:136–145.

Keefer, M. L., T. S. Clabough, M. A. Jepson, T. Blubaugh, G. P. Naughton, and C. C. Caudill. 2019. Potential Effects of Changes to Temperature Targets in the North Santiam River on Adult Chinook Salmon Behavior and Survival. U.S. Army Corps of Engineers, Portland District.

Keefer, M. L., T. S. Clabough, M. A. Jepson, E. L. Johnson, C. A. Peery, and C. C. Caudill. 2018. Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. PLOS ONE 13.

Keefer, M. L., T. S. Clabough, M. A. Jepson, G. P. Naughton, T. J. Blubaugh, D. C. Joosten, and C. C. Caudill. 2015. Thermal exposure of adult Chinook salmon in the Willamette River basin. Journal of Thermal Biology.

Keefer, M. L., M. A. Jepson, G. P. Naughton, T. J. Blubaugh, T. S. Clabough, and C. C. Caudill. 2017. Condition-Dependent En Route Migration Mortality of Adult Chinook Salmon in the Willamette River Main Stem. North American Journal of Fisheries Management 37:370–379.

Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. 2004. Hydrosystem, Dam, and Reservoir Passage Rates of Adult Chinook Salmon and Steelhead in the Columbia and Snake Rivers. Transactions of the American Fisheries Society 133:1413–1439.

Keefer, M. L., C. A. Peery, and C. C. Caudill. 2008b. Migration Timing of Columbia River Spring Chinook Salmon: Effects of Temperature, River Discharge, and Ocean Environment. Transactions of the American Fisheries Society 137:1120–1133.

Keefer, M. L., C. A. Peery, and B. High. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (Oncorhynchus mykiss): variability among sympatric populations. Canadian Journal of Fisheries and Aquatic Sciences 66:1734–1747.

Keefer, M. L., G. A. Taylor, D. F. Garletts, G. A. Gauthier, T. M. Pierce, and C. C. Caudill. 2010. Prespawn mortality in adult spring Chinook salmon outplanted above barrier dams: Chinook salmon prespawn mortality. Ecology of Freshwater Fish 19:361–372.

Kock, T. J., J. W. Beeman, A. C. Hansen, H. C. Hansel, G. S. Hansen, T. W. Hatton, E. E. Kofoot, M. D. Sholtis, and J. M. Sprando. 2015. Open-File Report. U.S. Geological Survey. Prepared in cooperation with the U.S. Army Corps of Engineers., Reston, Virginia.

Kuehne, L. M., J. D. Olden, and J. J. Duda. 2012. Costs of living for juvenile Chinook salmon (Oncorhynchus tshawytscha) in an increasingly warming and invaded world. Canadian Journal of Fisheries and Aquatic Sciences 69.

Lawrence, D. J., B. Stewart-Koster, J. D. Olden, A. S. Ruesch, C. E. Torgersen, J. J. Lawler, D. P. Butcher, and J. K. Crown. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24:895–912.

Leinenbach, P. 2017. Evaluation of the potential CWR by tributaries in the Willamette based on NorWeST modeling.

Lestelle, L. C., W. E. McConnaha, G. Blair, and B. Watson. 2005. Chinook Salmon Use of Floodplain, Secondary Channel, and Non-Natal Tributary Habitats in Rivers of Western North America. Mid-Willamette Valley Council of Governments, U.S. Army Corps of Engineers, and Oregon Department of Fish and Wildlife.

Loheide, S. P., and S. M. Gorelick. 2006. Quantifying Stream−Aquifer Interactions through the Analysis of Remotely Sensed Thermographic Profiles and In Situ Temperature Histories. Environmental Science & Technology 40:3336–3341.

Luce, C., B. Staab, M. Kramer, S. Wenger, D. Isaak, and C. McConnell. 2014. Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. Water Resources Research 50:3428–3443.

Lundin, J. I., J. A. Spromberg, J. C. Jorgensen, J. M. Myers, P. M. Chittaro, R. W. Zabel, L. L. Johnson, R. M. Neely, and N. L. Scholz. 2019. Legacy habitat contamination as a limiting factor for Chinook salmon recovery in the Willamette Basin, Oregon, USA. PLOS ONE 14.

Madej, M. A., C. Currens, V. Ozaki, J. Yee, and D. G. Anderson. 2006. Assessing possible thermal rearing restrictions for juvenile coho salmon (Oncorhynchus kisutch) through thermal infrared imaging and in-stream monitoring, Redwood Creek, California. Canadian Journal of Fisheries and Aquatic Sciences 63:1384–1396.

Malcolm, I. A., D. M. Hannah, M. J. Donaghy, C. Soulsby, and A. F. Youngson. 2004. The influence of riparian woodland on the spatial and temporal variability of stream water temperatures in an upland salmon stream. Hydrology and Earth System Sciences 8:449–459.

Mangano, J. F., N. L. Buccola, D. R. Piatt, C. D. Smith, and J. S. White. 2017. Point measurements of temperature and water quality in main-channel and off-channel features of the Willamette River, 2015–16: U.S. Geological Survey data release. data release, U.S. Geological Survey.

Mangano, J. F., D. R. Piatt, K. L. Jones, and S. A. Rounds. 2018. Water Temperature in Tributaries, Off-Channel Features, and Main Channel of the Lower Willamette River, Northwestern Oregon, Summers 2016 and 2017. Open-File Report, U.S. Geological Survey.

Mangano, J., K. Jones, N. Buccola, T. Friesen, S. Gregory, D. Hulse, S. Rounds, R. Wallick, C. Smith, and L. Whitman. 2016. Synthesizing the State of the Science for Coldwater Refuges in the Willamette River Basin.

Mathes, M. T., S. J. Cooke, G. T. Crossin, A. P. Farrell, S. G. Hinch, A. G. Lotto, and D. A. Patterson. 2010. Effect of water temperature, timing, physiological condition, and lake thermal refugia on migrating adult Weaver Creek sockeye salmon (Oncorhynchus nerka). Canadian Journal of Fisheries and Aquatic Sciences 67:70+.

Mattson, C. R. 1948. Spawning ground studies of Willamette River spring Chinook salmon. Pages 21–32. Fish Commission of Oregon, Portland, Oregon.

McCullough, D. A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Page 291. Seattle.

McElhany, P., M. Chilcote, J. Myers, and R. Beamesderfer. 2007a. Viability Status of Oregon Salmon and Steelhead Populations in the Willamette and Lower Columbia Basins Part 6: Upper Willamette Chinook. Page 54. Oregon Department of Fish and Wildlife (ODFW) and the National Marine Fisheries Service (NMFS) Northwest Region.

McElhany, P., M. Chilcote, J. Myers, and R. Beamesderfer. 2007b. Viability Status of Oregon Salmon and Steelhead Populations in the Willamette and Lower Columbia Basins Part 6: Upper

Willamette Chinook. Oregon Department of Fish and Wildlife and National Marine Fisheries Service.

Mesa, M. G., L. K. Weiland, and P. Wagner. 2002. Effects of acute thermal stress on the survival, predator avoidance, and physiology of juvenile fall chinook salmon. Northwest Science 76:118–128.

Meyers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum.

Monk, W. A., N. M. Wilbur, R. Allen Curry, R. Gagnon, and R. N. Faux. 2013. Linking landscape variables to cold water refugia in rivers. Journal of Environmental Management 118:170–176.

Myers, J., Craig Busack, Dan Rawding, Anne Marshall, David Teel, Donald M. Van Doornik, and Michael T. Maher. 2006. NOAA Technical Memorandum NMFS-NWFSC-73, Historical Population Structure of Pacific Salmonids in the Willamette River and Lower Columbia River Basins.

Naughton, G. P., C. C. Caudill, M. L. Keefer, T. C. Bjornn, L. C. Stuehrenberg, and C. A. Peery. 2005. Late-season mortality during migration of radio-tagged adult sockeye salmon (Oncorhynchus nerka) in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 62:30–47.

NMFS. 2000. Guidelines for Electrofishing Waters Containing Salmonids Listed Under the Endangered Species Act. National Oceanographic and Atmospheric Administration, National Marine Fisheries Service.

NMFS. 2008. Consultation on the “Willamette River Basin Flood Control Project.” National Marine Fisheries Service.

NMFS. 2015. Endangered Species Act Biological Opinion on the Environmental Protection Agency’s Proposed Approval of Certain Oregon Water Quality Standards Including Temperature and Intergravel Dissolved Oxygen. Biological Opinion, United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

NMFS. 2016. 2016 5-Year Review : Summary Evaluation of Upper Willamette River Steelhead and Upper Willamette River Chinook. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

NMFS. 2018. Consultation on effects of the 2018-2027 U.S. v. Oregon Management Agreement. NMFS Consultation, National Oceanic and Atmospheric Administration National Marine Fisheries Service, U.S. Fish and Wildlife Service, Bureau of Indian Affairs, National Marine Fisheries Service, West Coast Region.

ODFW. 2013. Wild fish passage timing at Willamette Falls. Memorandum, Oregon Departmetn of Fish and Wildlife.

ODFW. 2015, June 18. Higher water temperatures primary cause of early spring Chinook mortality. Press Release. Clackamas, OR.

ODFW, and NMFS. 2011. Upper Willamette River Conservation and Recovery Plan for Chinook Salmon and Steelhead. Oregon Department of Fish and Wildlife (ODFW) and the National Marine Fisheries Service (NMFS) Northwest Region.

ODFW, and WDFW. 2016. 2016 Joint Staff Report: Stock status and fisheries for Spring Chinook, Summer Chinook, Sockeye, Steelhead and other species. Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife.

ODFW, and WDFW. 2018. 2018 Joint Staff Report: Stock status and fisheries for Spring Chinook, Summer Chinook, Sockeye, Steelhead and other species. Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife.

Oetter, D. R., L. R. Ashkenas, S. V. Gregory, and P. J. Minear. 2004. GIS methodology for characterizing historical conditions of the Willamette River flood plain, Oregon. Transactions in GIS 8:367–383.

Peterson, W. T., J. L. Fisher, C. A. Morgan, B. J. Burke, and K. C. Jacobson. 2017. Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. Page 94. NOAA Fisheries.

Piatt, D. R., C. D. Smith, G. W. Gordon, and J. F. Mangano. 2018. Point measurements of temperature and water quality in the main channel and off-channel features of the lower reaches of the Willamette River, Clackamas River, Molalla River, and Johnson Creek, 2017. data release, U.S. Geological Survey.

Poole, G. C., and C. H. Berman. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management 27:787–802.

Portland BES. 2011. Airborne Thermal Infrared Remote Sensing Columbia & Willamette Rivers Oregon. City of Portland Bureau of Environmental Services.

Quigley, J. T., and S. G. Hinch. 2006. Effects of rapid experimental temperature increases on acute physiological stress and behavior of stream dwelling juvenile chinook salmon. Journal of Thermal Biology 31:429–441.

Rand, P. S., S. G. Hinch, J. Morrison, M. G. G. Foreman, M. J. MacNutt, J. S. Macdonald, M. C. Healey, A. P. Farrell, and D. A. Higgs. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon. Transactions of the American Fisheries Society 135:655–667.

Richter, A., and S. Kolmes. 2005a. Appendix L. Maximum Temperature Limits for Salmonids in the Willamette and Lower Columbia Rivers.

Richter, A., and S. A. Kolmes. 2005b. Maximum temperature limits for Chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13:23–49.

Rounds, S. 2007. Temperature effects of point sources, riparian shading, and dam operations on the Willamette River. Scientific Investigations Report, U.S. Geological Survey.

Rounds, S. A. 2010. Thermal Effects of Dams in the Willamette River Basin, Oregon. Scientific Investigations Report, U.S. Geological Survey.

Salinger, D. H., and J. J. Anderson. 2006. Effects of Water Temperature and Flow on Adult Salmon Migration Swim Speed and Delay. Transactions of the American Fisheries Society 135:188–199.

Sawyer, A. H., M. Bayani Cardenas, and J. Buttles. 2012. Hyporheic temperature dynamics and heat exchange near channel-spanning logs. Water Resources Research 48.

Sawyer, A. H., and M. B. Cardenas. 2012. Effect of experimental wood addition on hyporheic exchange and thermal dynamics in a losing meadow stream. Water Resources Research 48:n/a-n/a.

Schreck, C. B., J. C. Snelling, R. D. Ewing, C. S. Bradford, L. E. Davis, and C. H. Slater. 1994. Migratory Behavior of Adult Spring Chinook Salmon in the Willamette River and its Tributaries: Completion report.

Schroeder, R. K., K. R. Kenaston, and L. K. McLaughlin. 2007. Spring Chinook Salmon in the Willamette and Sandy Rivers. Progress Report 2005-2007, Oregon Department of Fish and Wildlife, Salem, Oregon.

Schroeder, R. K., L. D. Whitman, B. Cannon, and P. Olmsted. 2016. Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River basin, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 73:921–934.

Sedell, J. R., and J. L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U. S. A., from its floodplain by snagging and streamside forest removal. SIL Proceedings, 1922-2010 22:1828–1834.

Silver, B., M. Hudson, and T. A. Whitesel. 2017a. Tryon Creek Restoration Monitoring Project. U.S. Fish and Wildlife Service, Columbia River Fiash and Wildlife Conservation Office, Vancouver, WA.

Silver, B. P., J. M. Hudson, and T. A. Whitesel. 2017b. Tryon Creek Restoration Monitoring Monitoring Project. City of Portland FY 2016 Progress Report. Page 39. U.S. Fish and Wildlife Service, Columbia River Fish and Wildlife Conservation Office, Vancouver, WA.

Strange, J. S. 2010. Upper Thermal Limits to Migration in Adult Chinook Salmon: Evidence from the Klamath River Basin. Transactions of the American Fisheries Society 139:1091–1108.

Strange, J. S. 2012. Migration Strategies of Adult Chinook Salmon Runs in Response to Diverse Environmental Conditions in the Klamath River Basin. Transactions of the American Fisheries Society 141:1622–1636.

Sutton, R. J., M. L. Deas, S. K. Tanaka, T. Soto, and R. A. Corum. 2007. Salmonid observations at a Klamath River thermal refuge under various hydrological and meteorological conditions. River Research and Applications 23:775–785.

Sykes, G. E., C. J. Johnson, and J. M. Shrimpton. 2009. Temperature and Flow Effects on Migration Timing of Chinook Salmon Smolts. Transactions of the American Fisheries Society 138:1252–1265.

Sykes, G. E., and J. M. Shrimpton. 2010. Effect of temperature and current manipulation on smolting in Chinook salmon (Oncorhynchus tshawytscha): the relationship between migratory behaviour and physiological development. Canadian Journal of Fisheries and Aquatic Sciences 67:191+.

Tate, K. W., D. L. Lancaster, and D. F. Lile. 2007. Assessment of thermal stratification within stream pools as a mechanism to provide refugia for native trout in hot, arid rangelands. Environmental Monitoring and Assessment 124:289–300.

Taylor, B. 1999. Salmon and steelhead runs and related events of the Clackamas River basin – a historical perspective. Portland General Electric, Portland, Oregon.

Tinus, E. S., J. A. Koloszar, and D. L. Ward. 2003a. Abundance and distribution of fish in City of Portland Streams Final Report 2001-2003. Volume I - Final Report of Research. Page 86. Oregon Department of Fish and Wildlife, Clackamas, OR.

Tinus, E. S., J. A. Koloszar, and D. L. Ward. 2003b. Abundance and Distribution of Fish in City of Portland Streams. Final Report 2001-03 Prepared for: City of Portland Bureau of Environmental Services. Oregon Department of Fish and Wildlife.

Torgersen, C. E., J. L. Ebersole, and D. M. Keenan. 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. US Environmental Protection Agency Report.

Torgersen, C. E., D. M. Price, H. W. Li, and B. A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of chinook salmon in northeastern Oregon. Ecological Applications 9:301–319.

USACE. 2013. Adult Salmon Thermal Refugia in the Lower Columbia and Lower Snake Rivers. Federal Columbia River Power System. Amendment 1 of the Supplemental FCRPS BiOp. Northwestern Division, U.S. Army Corps of Engineers.

Wagner, G. N., S. G. Hinch, L. J. Kuchel, A. Lotto, S. R. Jones, D. A. Patterson, J. S. Macdonald, G. V. D. Kraak, M. Shrimpton, K. K. English, S. Larsson, S. J. Cooke, M. C. Healey, and A. P. Farrell. 2005a. Metabolic rates and swimming performance of adult Fraser River sockeye salmon (*Oncorhynchus nerka*) after a controlled infection with *Parvicapsula minibicornis*. Canadian Journal of Fisheries and Aquatic Sciences 62:2124–2133.

Wagner, G. N., Larsson, S., Kuchel, L.J., Lotto, A., Jones, S.R.M., D. A. Patterson, Macdonald,J.S., Kraak, G.V.D., Shrimpton, M., English, K.K., Larsson, S., Cooke, S.J., and Healey, M.C. 2005b. Metabolic rates and swimming performance of adult Fraser River sockeye salmon (Oncorhynchus nerka) after a controlled infection with Parvicapsula minibicornis. Canadian Journal of Fisheries and Aquatic Sciences 62:2124–2133.

Waples, R. S., D. J. Teel, J. M. Myers, and A. R. Marshall. 2004. Life-history divergence in Chinook salmon: historic contingency and parallel evolution. Evolution; International Journal of Organic Evolution 58:386–403.

Ward, D. L., A. A. Nigro, R. A. Farr, and C. J. Knutsen. 1994. Influence of waterway development on migrational characteristics of juvenile salmonids in the lower willamette river, oregon. North American Journal of Fisheries Management 14:362–371.

Wargo Rub, A. M., N. A. Som, M. J. Henderson, B. P. Sandford, D. M. Van Doornik, D. J. Teel, M. J. Tennis, O. P. Langness, B. K. van der Leeuw, and D. D. Huff. 2019. Changes in adult Chinook salmon (Oncorhynchus tshawytscha) survival within the lower Columbia River amid increasing pinniped abundance. Canadian Journal of Fisheries and Aquatic Sciences:1–12.

Wargo-Rub, A. M., L. G. Gilbreath, R. L. McComas, B. P. Sandford, D. J. Teel, and J. W. Ferguson. 2011. Survival of adult spring/summer Chinook salmon from the mouth of the Columbia River to Bonneville Dam, 2011.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental Factors Affecting Smoltification and Early Marine Survival of Anadromous Salmonids. Marine Fisheries Review 42:1–14.

Whitman, L. D., R. K. Schroeder, and T. A. Friesen. 2017. Evaluating migration timing and habitat for juvenile chinook salmon and winter steelhead in the mainstem willamette river and major spawning tributaries. Oregon Department of Fish and Wildlife, Willamette Research, Monitoring, and Evaluation Program, Corvallis, Oregon.