Effects of Riparian Revegetation on Stream Temperature in the Walla Walla Basin

by

Evan T. Romasco-Kelly

A thesis submitted in partial fulfillment of the requirements
for graduation with Honors in Geology-Environmental Studies.

Whitman College
2018

Certificate of Approval

This is to certify that the accompanying thesis by Evan T. Romasco-Kelly has been accepted in partial fulfillment of the requirements for graduation with Honors in Geology-Environmental Studies.

Nick E. Bader

Whitman College
May 9, 2018

Table of Contents

Acknowledgements

I would like to thank Kooskooskie Commons and Tri-State Steelheaders for carrying out the stream temperature monitoring and collecting the data which made my thesis possible. Specifically I would like to thank Judith Johnson: the work you do for the people and landscapes of the Walla Walla basin is inspiring and I deeply appreciate the time I have spent working you.

I would also like to thank Professor Nick Bader for all of his patience, support, and expertise during the thesis process. I do not think I would have finished a thesis without you as my advisor, and I am very grateful for your guidance. My gratitude also goes to Professor Amy Molitor for her help with technical aspects of my thesis and for her patience with the seniors in her Methods class.

Thank you to the Whitman College Student Engagement Center and the Community Fellowship program for providing me the opportunity to work for Kooskooskie Commons and helping to make this research possible.

Lastly, I would like to thank my parents, Mike and Lisa, for their support throughout my life (including in the final stages of thesis writing) and for providing me with an incredible education.

Abstract

Habitat degradation across the Pacific Northwest has resulted in the decline of stocks of salmonids such as bull trout, steelhead trout, and Chinook salmon. High stream temperatures play a significant part of this degradation by causing behavioral and physiological changes or causing direct mortality to salmonids. In the Walla Walla basin of southeastern Washington there are numerous streams which have been designated as polluted by high temperatures under the Clean Water Act during the summer months of June through September. In response local nonprofit organizations have implemented riparian restoration projects which seek to lower heat inputs into streams by removing non-native vegetation along stream banks and replacing it with native foliage which provides shade and other cooling functions. I used data from in-stream dataloggers to analyze temperature trends in the years following the installation of revegetation projects. Data from loggers near the sources and mouths of Garrison Creek and Caldwell Creek were compared to determine trends in downstream temperature change over time. In Garrison Creek there was a trend towards increased downstream heating in August and September between 2013 and 2017. In Caldwell Creek there has been a slight trend towards increased downstream cooling in June and August between 2015 and 2017. Despite the riparian restoration projects, temperatures in both creeks still regularly rise high enough to maintain their classification as polluted under the Clean Water Act (CWA).

List of Figures

List of Acronyms and Abbreviations

CURB	Creating Urban Riparian Buffers program
CWA	Clean Water Act
ESA	Endangered Species Act
Ma	million years ago
NMFS	National Marine Fisheries Service
ODEQ	Oregon Department of Environmental Quality
TMDL	Total Maximum Daily Load
USFWS	U.S. Fish and Wildlife Service
WDOE	Washington State Department of Ecology
WSDOT	Washington State Department of Transportation
WWBWC	Walla Walla Basin Watershed Council
WWCCD	Walla Walla County Conservation District

Introduction

Pacific salmon stocks have declined by more than 90% over the previous century due to habitat degradation (Gregory and Bisson, 1997). The restoration of depleted salmonid populations is important in the Pacific Northwest region and in the Walla Walla Basin in particular. Streams in the Walla Walla watershed are important migration pathways for Chinook salmon, steelhead trout, and bull trout (Baldwin and Stohr, 2007; U.S. Fish and Wildlife Service, 2015; National Marine Fisheries Service, 2016). The Washington Department of Ecology (WDOE) and the Oregon Department of Environmental Quality (ODEQ) have officially categorized 23 creeks and rivers in the Walla Walla watershed as significantly polluted due to high stream temperatures (ODEQ, 2012; WDOE, 2016). Elevated water temperatures can be lethal to salmonids or lead to behavioral and physiological changes which result in decreased population sizes (Poole et al., 2001). In response to this issue, state and local agencies, nonprofits, and private landowners have worked together to create riparian buffers along streams in the Walla Walla watershed. A primary goal of these buffers is to provide shade to the stream in order to reduce water temperatures.

Previous research has established the connection between riparian vegetation cover and water temperature as well as the potential for revegetation projects to keep streams cooler (Brazier and Brown, 1973; Adam and Sullivan, 1989; Bartholow, 2000; Garner et al., 2017). Other studies have focused specifically on watersheds Oregon and Washington, showing how riparian and channel restoration can result in lower stream temperature, benefiting salmonids (Bond et al., 2015; Justice et al., 2017). These studies often focus on using computer models parameterized with field observations to predict the effects of various climatic and riparian vegetation scenarios on stream temperatures (Bond et al., 2015; Garner et al., 2017; Justice et al., 2017). Only one study, conducted by the Tri-State Steelheaders (a local salmon enhancement nonprofit), has investigated the effects of riparian restoration projects in the Walla Walla watershed. This study examined Yellowhawk Creek and found a slight decrease in the temperature (-0.8°C) in years following riparian revegetation as compared to an earlier reference year (Paris and Sheedy, 2014). There has been a lack of research on the effects of recent riparian restoration projects across other streams in the Walla Walla watershed.

While most research has either focused on a particular stream reach (Paris and Sheedy, 2014; Bond et al., 2015) or employed predictive computer modeling (Garner et al., 2017; Justice et al., 2017) few studies have examined how multiple streams in a watershed have actually responded to riparian restoration treatments. I hypothesize that stream heating (i.e. the increase in temperature from an upstream point to a downstream point) in the summer months will be decreased for streams treated with riparian restoration projects, and that the magnitude of this effect will increase with time as riparian plantings become mature and produce more shade.

Background

Geography

The Walla Walla watershed is located in southeast Washington and part of northeast Oregon (Fig. 1). It covers roughly 1,760 square miles ranging from the Columbia River in the west to the Blue Mountains in the east (Baldwin and Stohr, 2007). The focus of this study is the area in and around the City of Walla Walla and the adjacent City of College Place, located just north of the Oregon state line at the base of the Blue Mountains. In addition to the Walla Walla River, several creeks originating in the mountains flow through the city, including Mill Creek, Cottonwood Creek, and Russell Creek. Several other streams emerge in the city from springs which are fed by the shallow alluvial aquifer (described below). These spring-fed creeks include Caldwell Creek, College Creek, Butcher Creek, Stone Creek, Whitney Spring Creek, and Lincoln Creek.

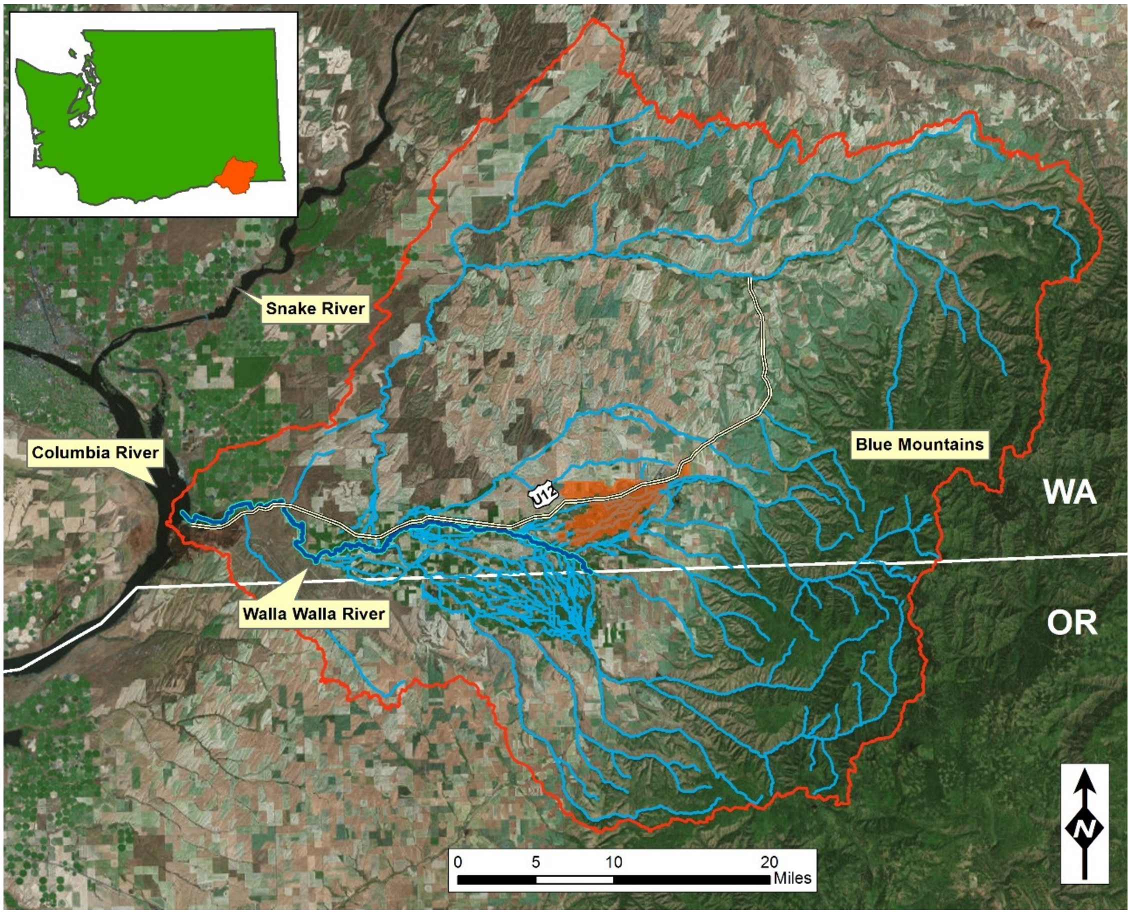

Fig. 1: Walla Walla Basin watershed (red boundary) and stream network in Washington and Oregon. Most streams originate in the Blue Mountains in the east; the Walla Walla River empties into the Columbia river to the west. Note numerous distributary streams and spring creeks in the center of the basin near Walla Walla and Milton-Freewater. The city limits of Walla Walla and College Place are shaded orange in the center of the map. GIS data from WWBWC, WSDOT, WWCCD (2014), and ESRI.

Geology

The geology of the Walla Walla Valley is similar to much of the Columbia Plateau: Quaternary sedimentary deposits overlying Tertiary flood basalts of the Columbia River Basalt Group (Newcomb, 1965; Carson and Pogue, 1996). After the last of the flood basalts were erupted by about 6 Ma,, faulting allowed the Walla Walla Valley to drop as much as 800 feet in elevation (Carson and Pogue, 1996; Henry et al., 2013), providing a basin for sedimentary deposition. Streams originating in the Blue Mountains formed alluvial fans in the late Miocene and Pliocene which deposited gravel, silts, and clay up to 800 feet thick (Newcomb, 1965). Above this, alluvium is interspersed with deposits from the Pleistocene Missoula Floods and loess, derived from upwind Missoula Flood deposits (Busacca and McDonald, 1994). Together these Quaternary sediments host the shallow alluvial aquifer that lies under the surface of the Walla Walla basin. This shallow alluvial aquifer is in hydraulic connectivity with the surface waters of the Walla Walla Valley and serves as the source for the numerous spring creeks described above (Newcomb, 1965; Henry et al., 2013).

Legal Framework

Streams in the Walla Walla valley fall under the purview of several regulatory bodies. First, many of the streams and spring creeks in Walla Walla are classified as polluted by high temperatures under Section 303(d) of the CWA (WDOE, 2016). This has resulted in the development of a Total Maximum Daily Load (TMDL) for the Walla Walla basin watershed by WDOE which specifies thresholds for different types of streams. For the streams analyzed in this study the daily maximum temperature must not exceed 18°C (Baldwin and Stohr, 2007). Waterways in the Walla Walla basin are also subject to the provisions of the Endangered Species Act (ESA) due to the presence of endangered spring-run Chinook salmon and threatened bull trout and steelhead trout (Baldwin and Stohr, 2007; USFWS, 2015; NMFS, 2016).

Riparian Buffers

Fluctuations in stream temperature naturally result from the transfer of heat energy in the form of solar radiation, wind convection, and inputs of water from tributaries or from hyporheic exchange (Adam and Sullivan, 1989; Baldwin and Stohr, 2007). Riparian corridors can play a large role in controlling these fluctuations. First, shrubs and trees on and near the banks of streams provide shade to the river, reducing the solar energy flux into a stream (Brazier and Brown, 1973; Steinblums et al., 1984; Adam and Sullivan, 1989). Many studies have shown that removal of riparian vegetation results in higher stream temperatures during the day (especially during the summer months) and cooler temperatures at night (Brazier and Brown, 1973; Holtby, 1988; Brosofske et al., 1997; Bartholow, 2000). Second, riparian vegetation can create a microclimate around streams with generally cooler air temperatures, lower wind speeds, and higher relative humidity (Brosofske et al., 1997; Bartholow, 2000).

The temperature TMDL for the Walla Walla basin includes as an implementation action "install, enhance, and protect riparian buffers" in order to achieve the goal of cooler stream temperatures (Baldwin and Stohr, 2007). Many of the creeks running through the City of Walla Walla have had large portions of their riparian corridors removed or altered by human development (Johnson, 2009). In response, the nonprofit organizations Kooskooskie Commons and Tri-State Steelheaders received a grant from WDOE administered by the Walla Walla County Conservation District in 2007 and again in 2012 to install riparian buffers along streams in the city and educate landowners and other citizens about stream conservation (WWCCD, 2014). This project, called Creating Urban Riparian Buffers (CURB) installed 69 riparian buffers were on eight streams between 2008 and 2014. These projects consisted of the removal of non-native plants and replanting of native riparian trees and shrubs (willows, conifers, etc.). The average buffer length was 290 feet, and the average width was 21 feet (WWCCD, 2014).

Methods

Description of Available Data

Temperature data for streams in the Walla Walla Basin is available from several sources. Kooskooskie Commons and Tri-State Steelheaders, two nonprofit organizations who implemented the CURB restoration projects along with the Walla Walla Conservation District, have maintained a network of in-stream temperature dataloggers with data collection starting in 2008 and continuing to the present. Temperature was measured with in-stream Onset HOBO U22-001 temperature loggers or U26-001 temperature and dissolved oxygen loggers, collecting measurements at hourly or half-hourly intervals. Although many of these dataloggers have been moved over the past eight years, five streams in the basin have continuous data from July 2013 through the present (representing almost 5 years of data). The data are currently unpublished; however, Kooskooskie Commons is in the process of adding the data to WDOE's Environmental Information Management System (EIM).

Kooskooskie Commons also has records of the CURB restoration projects which includes their location, size, number of riparian plants installed, and other information. Garrison Creek had 36 restoration projects installed between 2008 and 2014, for a total of 9,856 linear feet and 221,820 square feet of stream bank restored. Caldwell Creek has had two restoration projects installed: one in February 2013 and the other in May 2014. Together they comprise 515 linear feet and 28,025 square feet of stream bank restored (Fig. 2) (WWCCD, 2014).

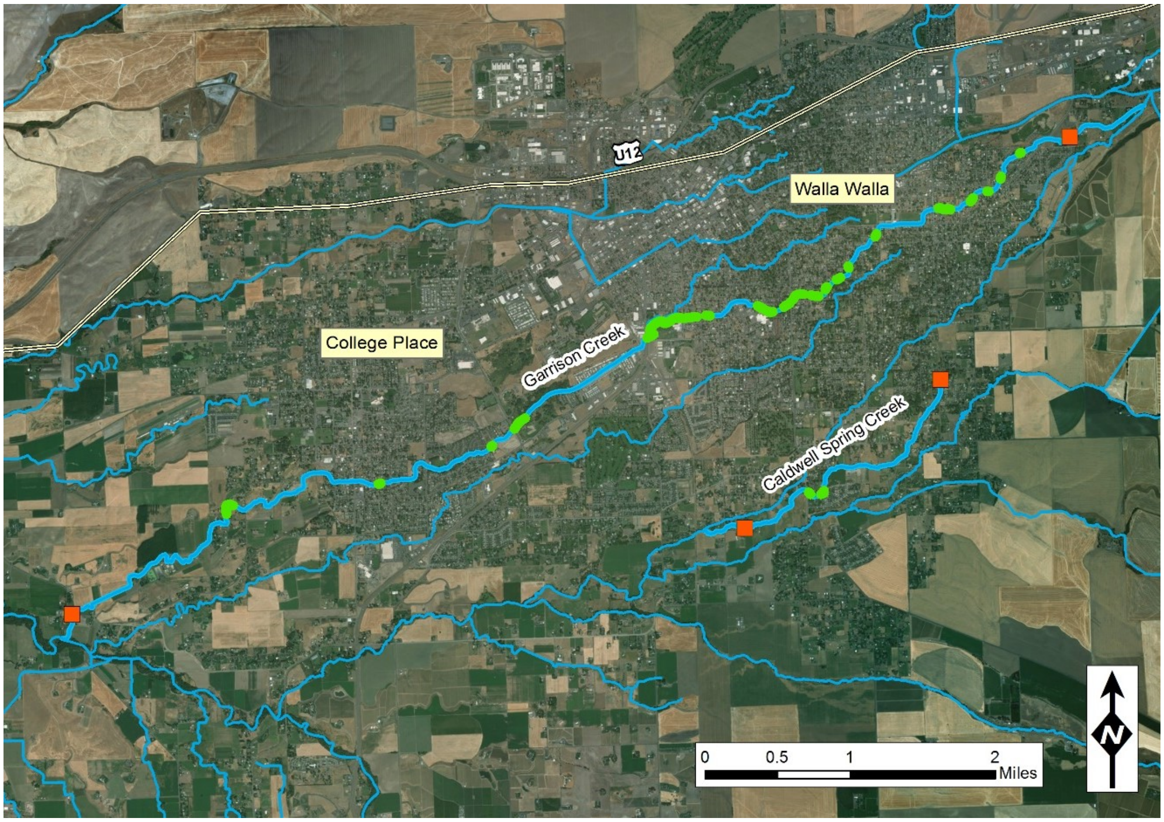

Fig. 2: Locations of Garrison Creek and Caldwell Creek. Restoration projects are denoted as bright green lines, and datalogger monitoring locations are denoted as orange squares. GIS data from WWBWC, WWCCD (2014), and ESRI.

Experimental Design

In this analysis, I test whether two streams in the Walla Walla Basin with riparian restoration projects exhibit differences over time in stream heating between points upstream and downstream of the treatments. These streams, Garrison Creek and Caldwell Creek, were chosen because they represent the largest time span of data available from loggers at both the mouth and the source as well as the largest number of restoration projects. The focus of this study is specifically on maximum stream temperatures in the summer months, June through September, when temperatures exceed Clean Water Act standards (herein referred to as the 'summer months') (Baldwin and Stohr, 2007).

Dataloggers at specific monitoring locations were grouped into analysis pairs based on the location of restoration projects such that one datalogger was located upstream and the other downstream of a stream reach with riparian restoration projects. Temperature data from the upstream-downstream pairs were selected from the date range during which both members of the pair were collecting data. Hourly or half-hourly data were then summarized by the maximum daily, and then data from the summer months were further summarized by the mean daily maximum temperature for a given month. Standard error of the mean was then calculated for these values in order to determine uncertainty of the mean value. Downstream temperature change was determined by subtracting the daily maximum temperature at the upstream point from the daily maximum temperature at the downstream point.

Results

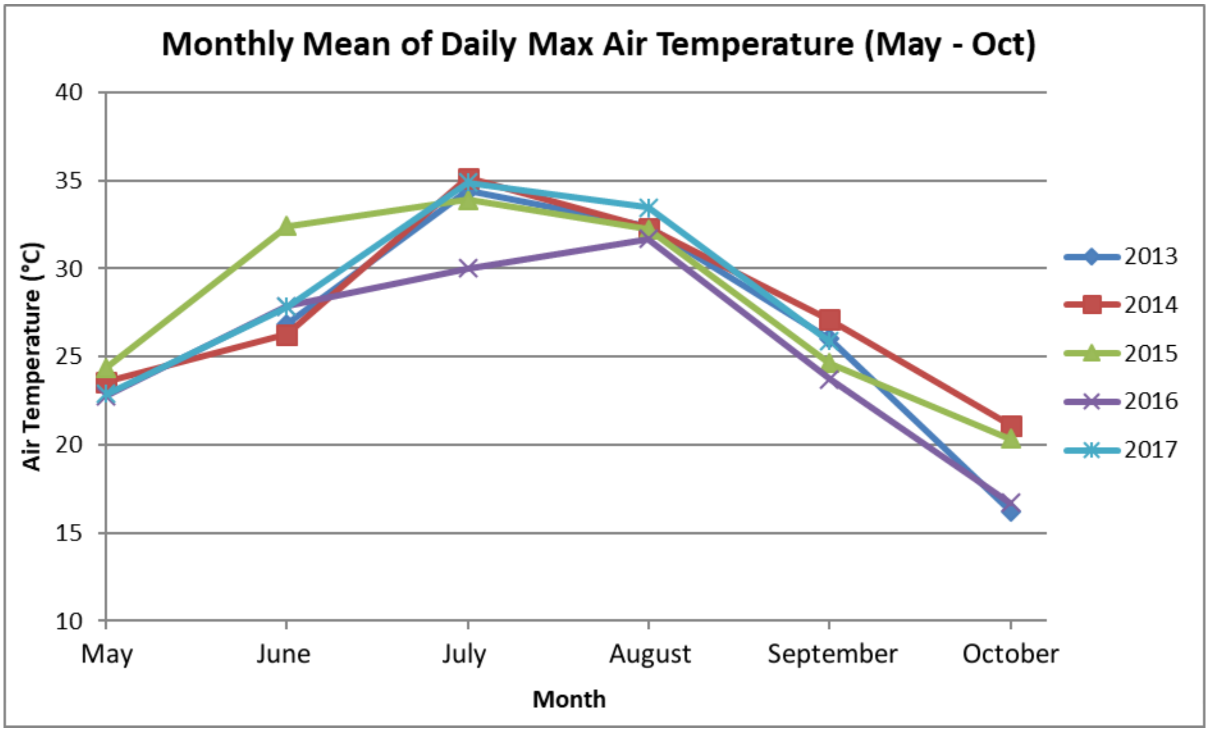

Fig. 3: Monthly means of maximum daily air temperature collected by the National Weather Service at Walla Walla Regional Airport (KALW). Note that temperatures generally increase from June to July and decrease from July to September.

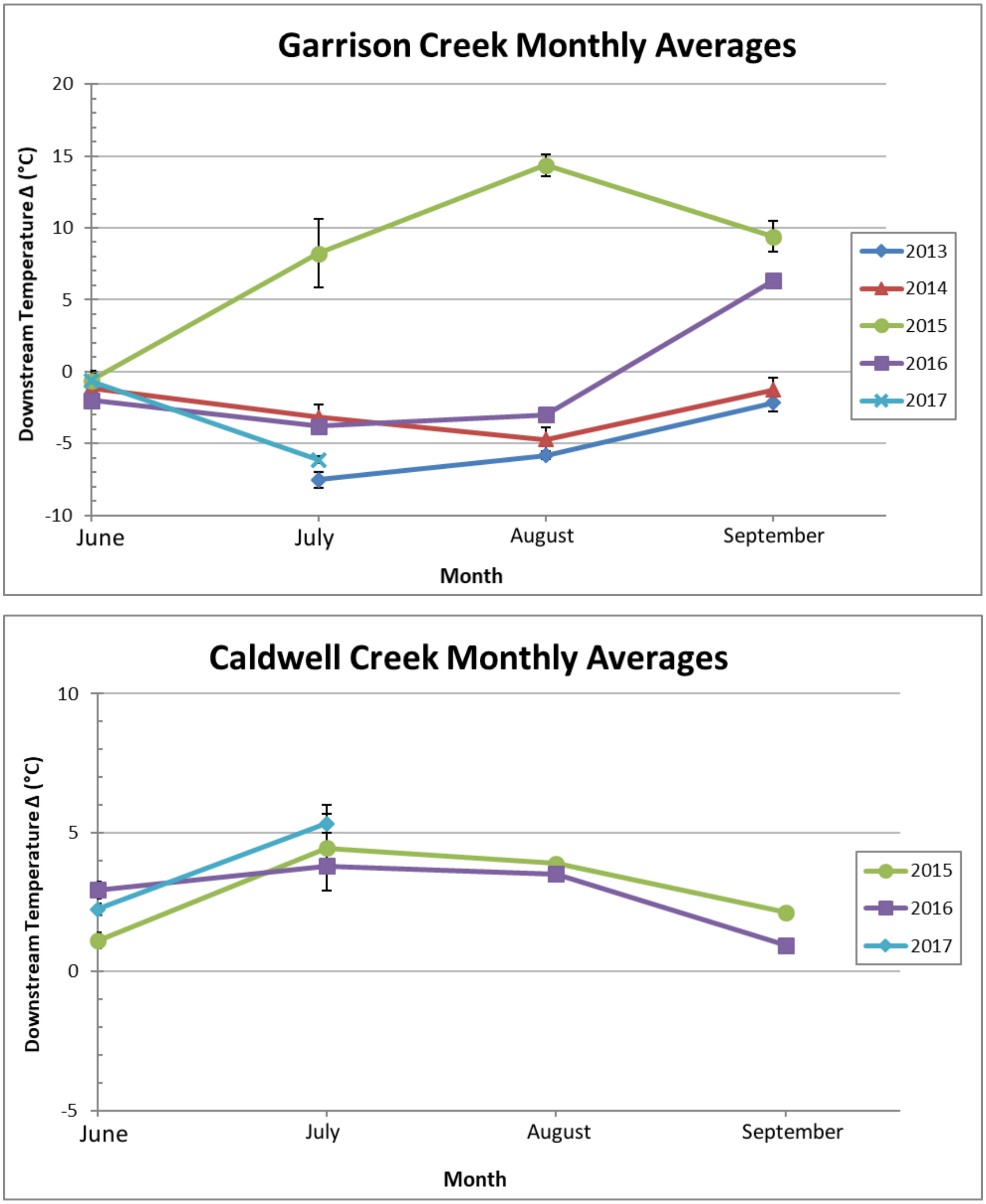

Fig 4: Monthly averages of daily maximum stream temperature for Garrison Creek and Caldwell Creek by year. Error bars show standard error of the mean.

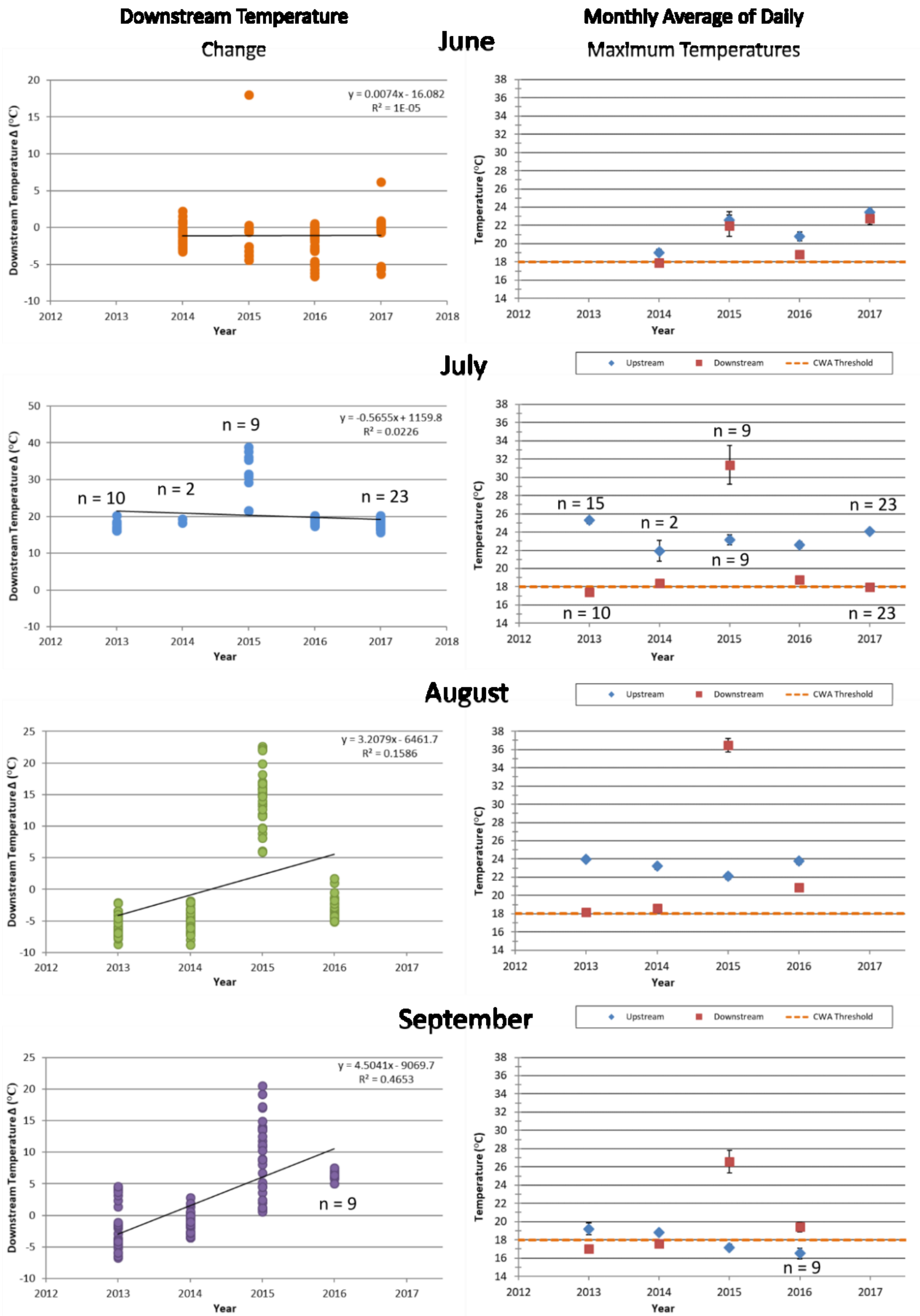

Fig. 5: Temperature analysis results for Garrison Creek. Graphs on the left show downstream heating and graphs on the right show monthly averages of daily maximum temperature for both the upstream and downstream location. Months or samples where less than 25 days of data exist are marked with an "n =" label. Error bars show standard error of the mean. The orange dashed lines show the CWA threshold of 18°C for Caldwell Creek (classified in Baldwin and Stohr (2007) as a Class A stream).

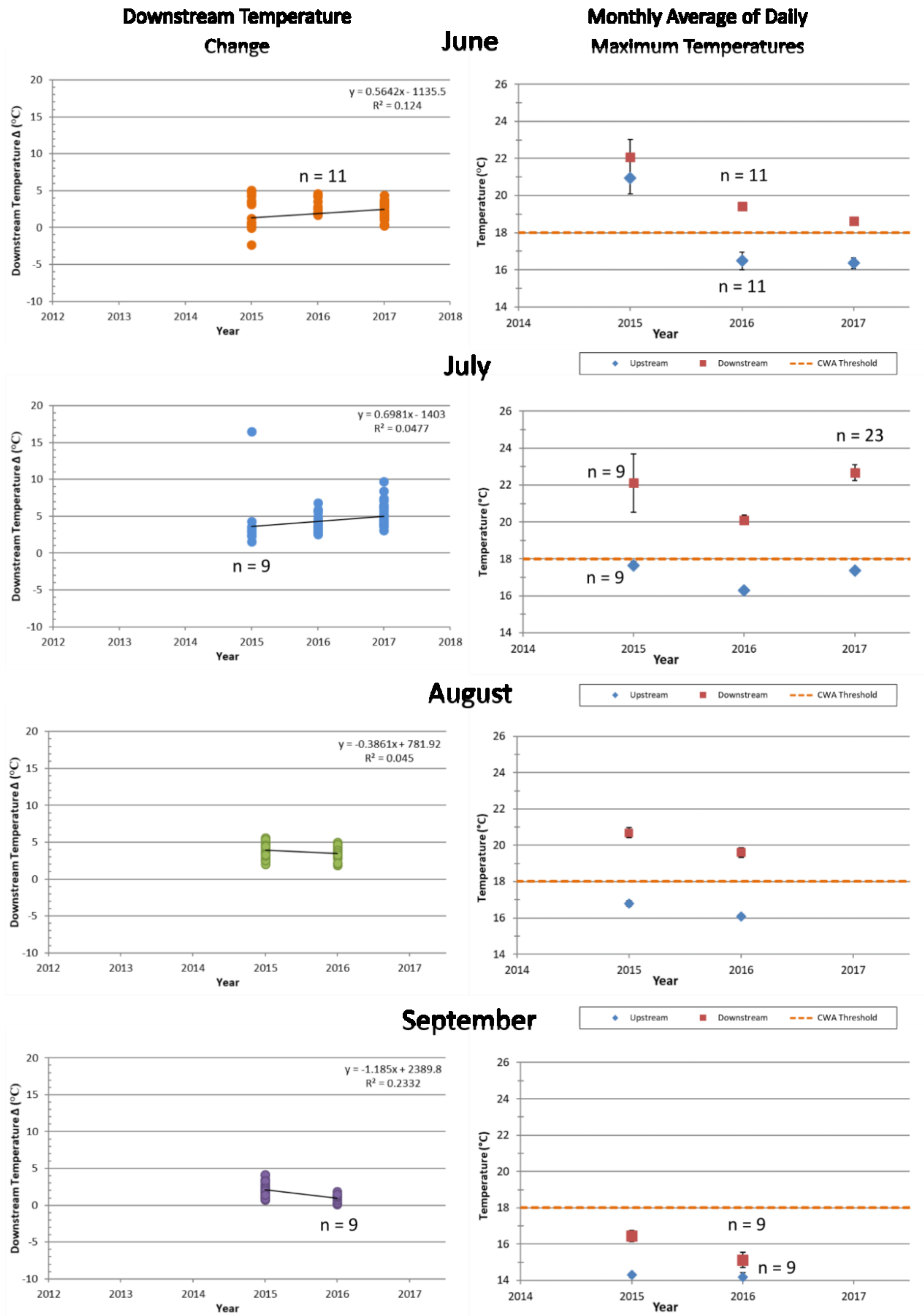

Fig. 6: Temperature analysis results for Caldwell Creek. Graphs on the left show downstream heating and graphs on the right show monthly averages of daily maximum temperature for both the upstream and downstream location. Months or samples where less than 25 days of data exist are marked with an "n =" label. Error bars show standard error of the mean. The orange dashed lines show the CWA threshold of 18°C for Caldwell Creek (classified in Baldwin and Stohr (2007) as a Class A stream).

Temperature Conditions

Stream temperature on both Garrison and Caldwell Creeks followed a similar pattern, increasing from June to July where they reached their peak, then decreasing into August and September (the coolest summer month). This tracks with the air temperatures recorded by the National Weather Service at the Walla Walla Airport (Fig. 3) Downstream heating followed this pattern on Caldwell Creek (Fig. 4), however on Garrison Creek downstream cooling increased from June to July, stayed relatively stable between July and August, and then decreased between August and September (Fig. 4). Temperature data did not follow this pattern during the summer of 2015, instead downstream heating increased between June and August and then decreased from August to September.

Stream temperatures on Garrison Creek at its source (i.e. its point of diversion point on Mill Creek) were between 1 and 7°C above the 18°C Clean Water Act threshold. Temperatures were almost always lower at the mouth of Garrison Creek, ranging between 2°C above and below the CWA threshold (Fig. 5). This trend of downstream cooling was only broken between July and September 2015, when the creek experienced a large degree of heating.

Caldwell Creek exhibits the opposite trend: temperatures at the source were always lower than those at the mouth (Fig. 6). At the source, temperatures were 1-2°C below the 18°C CWA threshold except for June 2015 when it was 3°C above the threshold. Conversely, temperatures at the mouth ranged approximately between <1 and 5°C above the threshold. September 2015 and 2016 were exceptions to this trend with stream temperatures remaining below 18°C at the source and mouth for both months.

Trends Following CURB Projects

Trends in the years following the installment of riparian restoration projects were different for the two creeks. For Garrison Creek the magnitude of downstream cooling has decreased and even shifted towards downstream heating in some months for the four or five years for which there is data (Fig. 5). For June the degree of downstream cooling has remained relatively stable with a simple linear regression showing a very slight decrease in cooling from 2014 to 2017. July exhibits a slight increase in downstream cooling between 2013 and 2017. In both August and September, the trend changes towards a pronounced decrease over time in downstream cooling (i.e. increased downstream heating).

Downstream heating in Caldwell Creek increased slightly for some months, however there are fewer data for Caldwell Creek than for Garrison Creek: June and July have three years of data whereas August and September have two years. In both June and July downstream heating increased between 2015 and 2017 (Fig. 6). In August and September, however, downstream heating decreased slightly between 2015 and 2016.

Discussion

Temperature Conditions

The data show that temperatures on both Garrison Creek and Yellowhawk Creek regularly exceed the 18°C threshold set forth in the Walla Walla TMDL. This supports listing these streams on the Washington 303(d) list for temperature pollution as Category 4A polluted waters with an approved TMDL (Baldwin and Stohr, 2007; WDOE, 2016).

Paris and Sheedy (2014) found that Yellowhawk Creek, which is diverted from Mill Creek at the same location as Garrison Creek, experienced about 2°C of cooling between the source and the mouth which they speculated was due to inputs from spring-fed creeks and groundwater. These inputs may be the cause of the cooling observed in Garrison Creek as well. Data on hyporheic exchange is needed in order to better understand the causes of cooling and stream reaches where it occurs.

Caldwell Creek exhibits the opposite trend (i.e. downstream heating) because its source is the shallow alluvial aquifer which keeps water cool until it reaches the surface. This interpretation is supported by the consistently low temperatures observed at the source of Caldwell Creek (Fig. 6). Exposure to solar radiation and other heat inputs cause the increased temperatures observed at the mouth.

Trends Following CURB Projects

Riparian restoration projects function by reducing heat energy inputs into streams, not by removing heat energy from streams, so any stream cooling that occurs between the upstream and downstream logger cannot be attributed to riparian restoration. Instead, changes in the magnitude of downstream cooling can indicate the function of restoration projects. The observed trend of increased downstream heating on Garrison Creek in August and September and Caldwell Creek in June and July seems to contradict my hypothesis.

I speculate that this heating may be caused by hydrologic factors (reduced discharge and/or reduced groundwater inputs). I also speculate that this heating may partially result from implementation of the CURB restoration projects. Implementation involved removing nonnative vegetation within the creek and buffer zone and replacing it with native riparian vegetation. It is possible that the pre-CURB vegetation was providing shade which was not immediately replaced when the CURB projects were installed. If so, we might expect to see downstream heating decrease in future years as the CURB vegetation matures.

There are several potential sources of error and uncertainty for this analysis. First, this dataset is limited, covering only five years at its longest extent and two years at its shortest. Second, data for some months in the study have large gaps in coverage. For example, on Garrison Creek there are only ten days of data for July 2013, two days for July 2014, and nine days for July 2015. The lack of data for the majority of the days in those months affects the trends shown by the simple linear regression.

Conclusion

The Creating Urban Riparian Buffers program installed 36 riparian restoration projects on Garrison Creek between 2008 and 2014 and 2 projects on Caldwell Creek between 2013 and 104. The goal of these projects was to reduce heat energy inputs into these streams and help to bring summer stream temperatures below the Clean Water Act threshold of 18 °C set forth in the Walla Walla temperature TMDL. Temperature data from the years since these projects were implemented show that temperatures in both Garrison Creek and Caldwell Creek routinely rise above that threshold.

Garrison Creek largely experiences downstream cooling, but over the last five years there has been a trend towards stream heating in the months of August and September. Caldwell Creek experiences downstream heating and the degree of that heating appears to have increased slightly over the last three years in June and July. These results contradict my hypothesis, however the dataset they are based on is limited in terms of timespan and coverage of the summer months. It is likely too early to see what effects the CURB projects have had on downstream temperature change for these two creeks.

I recommend that temperature data collection continue on these creeks and others in the basin in order to provide more years of information over which trends can become clear. Future research may also include characterizing the impact of groundwater on downstream temperature change. Data could be collected on hyporheic exchange in these streams in order to better isolate the effects of riparian restorations.

References

Adam, T.N., and Sullivan, K., 1989, The Physics of Forest Stream Heating: A Simple Model: Washington Department of Natural Resources TFW-WQ3-90-007, http://www.dnr.wa.gov/sites/default/files/publications/fp_tfw_wq3_90_007.pdf?8zejoi.

Baldwin, K., and Stohr, A., 2007, Walla Walla Watershed Temperature Total Maximum Daily Load - Water Quality Improvement Report: Washington Department of Ecology 07-10–030, 167 p.

Bartholow, J.M., 2000, Estimating cumulative effects of clearcutting on stream temperatures: Rivers, v. 7, p. 284–297.

Bond, R.M., Stubblefield, A.P., and Van Kirk, R.W., 2015, Sensitivity of summer stream temperatures to climate variability and riparian reforestation strategies: Journal of Hydrology: Regional Studies, v. 4, p. 267–279, doi: 10.1016/j.ejrh.2015.07.002.

Brazier, J.R., and Brown, G.W., 1973, Buffer Strips for Stream Temperature Control: Forest Research Laboratory, Oregon State University Research Paper Paper 865.

Brosofske, K.D., Chen, J., Naiman, R.J., and Franklin, J.F., 1997, Harvesting Effects on Microclimatic Gradients from Small Streams to Uplands in Western Washington: Ecological Applications, v. 7, p. 1188, doi: 10.2307/2641207.

Busacca, A.J., and McDonald, E.V., 1994, Regional Sedimentation of Late Quaternary Loess on the Columbia plateau: Sediment Source Areas and Loess Distribution Patterns, *in* Lasmanis, R. and Cheney, E.S. eds., Regional geology of Washingron State: Washington Division of Geology and Earth Resources Bulletin 80, p. 181–190.

Carson, R.J., and Pogue, K.R., 1996, Flood Basalts and Glacier Floods: Roadside Geology of Parts of Walla Walla, Franklin, and Columbia Counties: Olympia, WA, Washington State Department of Natural Resources, Division of Geology and Earth Resources Information Circular 90.

Garner, G., Malcolm, I.A., Sadler, J.P., and Hannah, D.M., 2017, The role of riparian vegetation density, channel orientation and water velocity in determining river temperature dynamics: Journal of Hydrology, v. 553, p. 471–485, doi: 10.1016/j.jhydrol.2017.03.024.

Gregory, S.V., and Bisson, P.A., 1997, Degradation and Loss of Anadromous Salmonid Habitat in the Pacific Northwest, *in* Stouder, D.J., Bisson, P.A., and Naiman, R.J. eds., Pacific Salmon & their Ecosystems, Boston, MA, Springer.

Henry, R., Lindsey, K., Wolcott, B., Patten, S., and Baker, T., 2013, Walla Walla Basin Aquifer Recharge Strategic Plan: Walla Walla Basin Watershed Council Strategic Plan.

Holtby, L.B., 1988, Effects of Logging on Stream Temperatures in Carnation Creek British Columbia, and Associated Impacts on the Coho Salmon (*Oncorhynchus kisutch*): Canadian Journal of Fisheries and Aquatic Sciences, v. 45, p. 502–515, doi: 10.1139/f88-060.

Johnson, J.S., 2009, Small Order Stream and Spring Monitoring Network 2009 Report Historic Springs Report: Walla Walla Basin Watershed Council Watershed Management Initiative Monitoring Program Phase II Final Report.

Justice, C., White, S.M., McCullough, D.A., Graves, D.S., and Blanchard, M.R., 2017, Can stream and riparian restoration offset climate change impacts to salmon populations? Journal of Environmental Management, v. 188, p. 212–227, doi: 10.1016/j.jenvman.2016.12.005.

Newcomb, R.C., 1965, Geology and Ground-Water Resources of the Walla Walla River Basin Washington - Oregon: Washington State Division of Water Resources Water Supply Bulletin 21, 162 p.

NMFS, 2016, 2016 5-Year Review: Summary & Evaluation of Middle Columbia River Steelhead: National Marine Fisheries Service, http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/2016/2016_middle-columbia.pdf.

ODEQ, 2012, Water Quality Assessment - Oregon's 2012 Integrated Report Assessment Database and 303(d) List: Oregon Department of Environmental Quality, http://www.deq.state.or.us/wq/assessment/rpt2012/search.asp.

Paris, B., and Sheedy, D., 2014, Yellowhawk Stream Temperature Analysis: 2010-2013 versus 2001: Tri-State Steelheaders.

Poole, G., Dunham, J., Hicks, M., Keenan, D., Lockwood, J., Materna, E., McCullough, D., Mebane, C., Risley, J., Sauter, S., Spalding, S., and Sturdevant, D., 2001, Technical Synthesis Scientific Issues Relating to Temperature Criteria for Salmon, Trout, and Char Native to the Pacific Northwest: Environmental Protection Agency Summary Report EPA 910-R-01-007, 24 p.

Steinblums, I.J., Froelich, H.A., and Lyons, J.K., 1984, Designing stable buffer strips for stream protection: Journal of Forestry, v. 821, p. 49–52.

USFWS, 2015, Mid-Columbia Recover Unit Implementation Plan for Bull Trout: U.S. Fish and Wildlife Service, https://www.fws.gov/pacific/bulltrout/pdf/Final_Mid_Columbia_RUIP_092915.pdf (accessed May 2018).

WDOE, 2016, Water Quality Assessment 303(d) list: Washington Department of Ecology, https://fortress.wa.gov/ecy/approvedwqa/ApprovedSearch.aspx.

WWCCD, 2014, Creating Urban Riparian Buffers (CURB) Program Project Completion Report: Walla Walla County Conservation District G1300052.