

Stream Temperature Monitoring in Forested Tributaries of the Skagit River Basin: 15-Year Update and Analysis



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October 25, 2023

Acknowledgements

We would like to acknowledge the hard work of former Forest & Fish Ecologist Nora Kammer, former Forest & Fish Program Scientist Anna Mostovetsky and former Watershed Scientist Jeff Phillips for the great work they did developing and sustaining this long-term temperature monitoring program; this report builds upon the foundations they established. Additional recognition and gratitude to Mike Olis and Scott Morris who helped sustain this project through the years. We would like to thank the reviewers Gus Seixas and Catherine Austin (Skagit River System Cooperative) for their thoughtful comments and suggestions for this paper, as well as Sarah Schooler for her invaluable help regarding statistical analysis and R-code support. We would like to express our appreciation to the Sauk-Suiattle Indian Tribe for providing some of the data included in this report.

We also thank the following landowners for providing access to monitoring sites: Goodyear Nelson Hardwood and Lumber Company; Grandy Lake Forest Associates; Hampton Lumber; and Sierra Pacific Industries.

Cover: Rocky Creek/Day Creek confluence, Susannah Maher

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This report is available online at: <http://skagitcoop.org/documents/>

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Abstract

Maximal summer stream temperatures are an important factor affecting juvenile salmon survival. In 2008, the Skagit River System Cooperative began collecting stream temperature data each summer season in lands managed for timber throughout the Skagit River basin. Using 15 years of data, our objectives for this report are to 1) investigate the effects of the extreme heatwave that occurred in 2021 on stream temperature maxima 2) determine if there is a trend present at the basin and/or site scale, and 3) explore the year-round data at four stations that have received multi-season monitoring since 2018. We used a combination of general linear models and univariate linear regression but did not identify a trend at the basin scale, though two sites (Hobbit and Savage Creeks) have significantly increasing maxima. A review of yearly maximum stream temperature shows that there was not an extreme impact on water temperature during the 2021 heatwave. Most sites' highest recorded temperatures occurred in years other than 2021, suggesting the important role of snowpack and discharge in determining the impact of extreme heat events on aquatic habitats. We found that winter temperatures at four sites are within the optimum threshold for salmonid incubation and emergence using peer-reviewed optimal temperature ranges and calculations of Accumulated Thermal Units. This report provides data that will help identify summer-rearing stream habitat that would benefit most from protection and/or restoration. We emphasize the need to continue collecting temperature data and expand the spatial network to increase our understanding of temperature regimes throughout the basin.

1. Background

1.1. Introduction

Summertime stream temperature regimes can impact the growth and survival of cold-water fish, such as salmon and trout (Beschta et al. 1987, Richter and Kolmes, 2005). Temperatures are also a widely used indicator of cumulative human impacts, ranging from local riparian alteration to global climate drivers (MacDonald, et al. 1991, Poole, et al. 2001). For these reasons, the Skagit River System Cooperative has monitored summer stream temperatures in Skagit River tributaries from 2008 to the present. This is an open-ended ‘trend monitoring’ project (MacDonald et al., 1991), in which every additional year of data allows continued refinement of spatial and temporal patterns. Every 4-5 years, SRSC produces a progress report that addresses a range of sub-topics including water quality implications and the influence of numerous watershed attributes (Table 1).

Table 1. Reports documenting SRSC tributary temperature monitoring program

Report authors and year	Years of data	Number of Sites ¹	New Topics Addressed
Phillips et al., 2011	2	22	Spatial variation, water quality exceedance, longitudinal trends, basin land use
Mostovetsky et al., 2015	6	18	Channel and basin attributes, interannual patterns, diurnal ranges
Kammer et al., 2020	11	30	Seasonal snowpack and precipitation, preliminary trend analysis.
This report	15	23	2021 Heatwave response, expanded trend analysis, year around temperatures patterns
1. Number of SRSC-operated stations, though reports include stations monitored by other organizations as well			

Since the latest report (Kammer et al. 2020), we have acquired four more years of temperature data that allow us to address new topics. First, subsequent temperature measurements have documented local stream response to the record-breaking heatwave of late June 2021. Second, the 15-year record allows expanded analysis of temporal trends at the site and aggregated level. And thirdly, with five years of year-round data, we can evaluate temperature patterns during critical incubation and overwintering life stages of salmon. These new investigations address timely climate concerns that motivated this updated report.

We address these new topics by directly analyzing temperature data and exploring correlations with various potential temperature drivers, both temporal and physical. This is not a comprehensive or final document, but rather an extension beyond the findings of previous reports generated from this project. Previous reports contain important analyses and findings which likely remain valid though are not revisited in this report.

1.2. Project Purpose and Report Objectives

From inception, the SRSC temperature monitoring project has focused on Skagit tributaries that contain anadromous salmonid fish and are dominated by forestry land use. It is designed to track status and trends of stream temperatures and identify particularly warm and thermally sensitive stream reaches. This is not an ‘effectiveness monitoring’ project (MacDonald et al 1991) designed to quantify the effects of forest buffers and other upstream conditions that may influence water quality. Riparian management practices are known to affect temperature regimes (Moore & Wondzell, 2005) and were implemented in monitored

watersheds during the project, resulting in dynamic shade conditions upstream from each monitoring station.

Objectives of this report are to document:

1. Summer stream temperature maxima from 2019 through 2022.
2. Stream temperature response to the record-breaking heatwave of June 2021.
3. Trends in stream temperature maxima (if any) within the 15-year temperature record.
4. Results of year-round sites and comparison to temperatures documented as suitable for salmonid life stages outside the summer season.

2. Study Area and Methods

2.1. Study Area Hydrology, Vegetation, and Land use

The Skagit River is located in the northwestern Cascade Range in Washington state (Fig. 1). The climate is temperate with mild, dry summers and cool, wet winters and abundant precipitation, the majority of which falls as rain at low and mid elevations. Elevations above ~1,000 m experience heavy winter snowpacks and glaciers are common in alpine headwaters.

The Skagit River basin (Fig. 1) includes the mainstem Skagit River (including tributaries, sloughs, and estuaries) and numerous secondary basins, the largest being the Sauk River watershed. These waters provide essential freshwater habitat for anadromous salmonids, including several species that are listed as threatened under the Endangered Species Act (Lawrence, 2008). Five species of salmon (Chinook, coho, pink, chum, and sockeye) are present as well as two char species (Dolly Varden and bull trout), rainbow/steelhead and cutthroat trout (trout species include migratory and non-migratory life histories) (Beamer et al., 2005).

Land use in the Skagit is a mix of agriculture, urban, suburban, rural, forestry, and conservation lands (federal wilderness areas). The forested portions of the Skagit basin where this study is located have been managed for timber harvest since the late 19th century. Historical timber harvest practices involved a variety of techniques, including extensive timber harvest in riparian areas. However, beginning in the 1970's and increasing in the 1990's, many riparian areas and potentially unstable terrain have been left with un-harvested mature forest buffers to mitigate erosion and maintain riparian functions including shade. The lowlands of the basin, where most of the anadromous habitat is located, are dominated by small farms and rural residential development that often have less riparian protection (Hyatt 2022). Many of the water bodies in the lowlands have been historically modified by draining, diking or channelization (Beechie et al., 2008). This project did not monitor these non-forest reaches, though the [Skagit County Water Quality Program](#) has done so during this period.

Lower elevation forests where monitoring sites are located are in the Western Hemlock Climax Zone (Franklin & Dyrness, 1973). Western redcedar, Douglas-fir, and western hemlock are the dominant conifer species and red alder, black cottonwood, and bigleaf maple are common deciduous species. Riparian stands at monitoring sites are almost entirely less than 100 years old due to historic logging and/or channel disturbance. Riparian forests have regrown rapidly, and second growth forests are over 30 m tall at most monitoring sites.

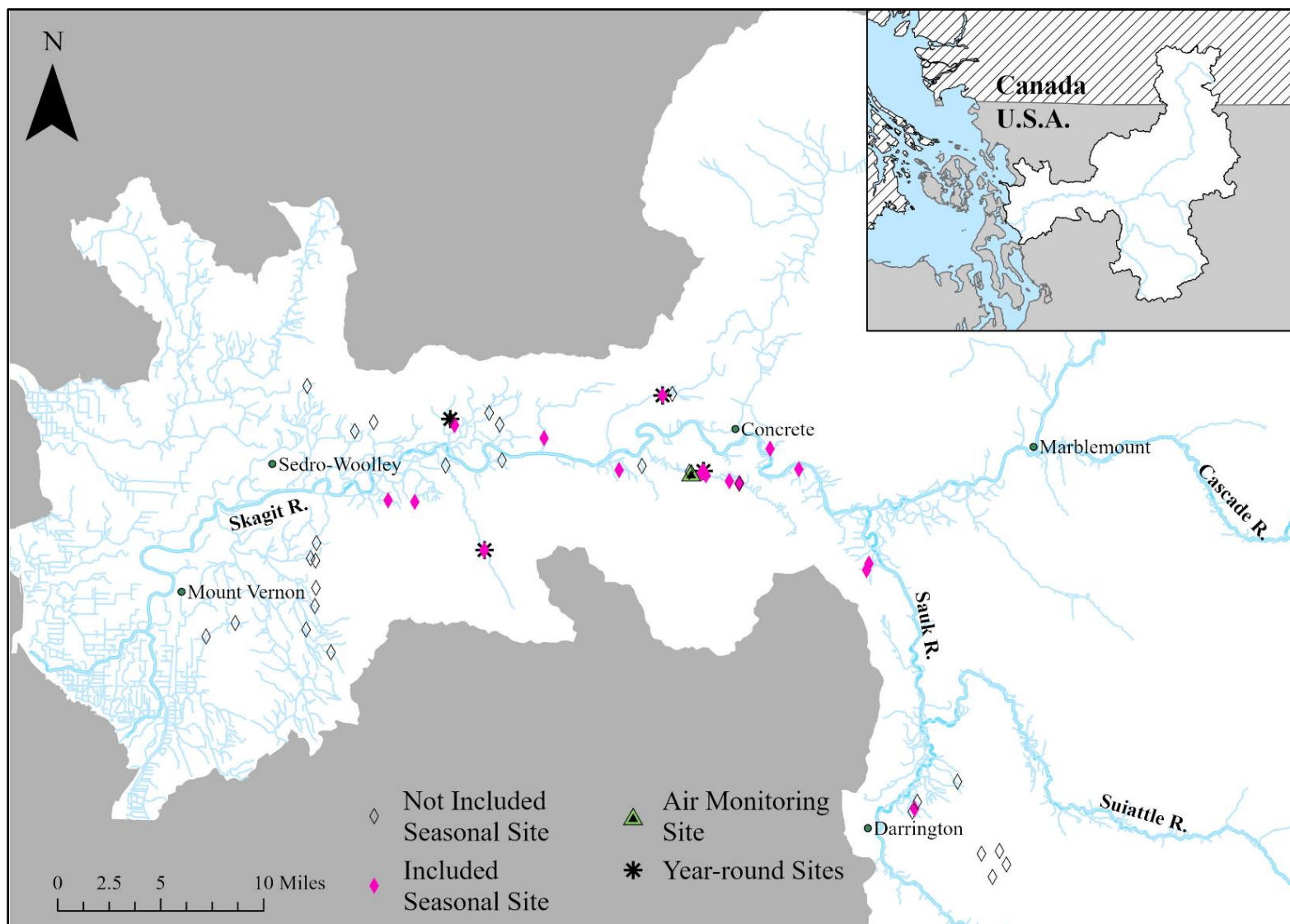


Figure 1. Skagit watershed study area map showing location of stream temperature monitoring sites on various tributaries. Sites with 10 or more years of seasonal data (pink diamonds) are included in the inter-annual analysis described in this report.

2.2 Sampling Locations

Stream temperature data were collected over fifteen summers (2008-2022) at thirty-eight monitoring sites located throughout the central and lower Skagit and Sauk River basins (Fig. 1). Some stations have been added or dropped to improve overall reliability and data relevance. Occasionally, a station is moved immediately up or downstream to the adjacent pool due to the original pool filling in, the thalweg shifting, or to avoid equipment tampering. The tributary basin areas for monitored locations range in catchment area from 0.2 to 116 km². The hydrology of the basins is primarily rain-dominated or rain-snow mix, although upper elevations receive snow during winter months in most years. Unlike the mainstem rivers, none of the monitored sites receive any glacial meltwater.

This report focuses on data collected by SRSC, supplemented by similar stations operated by the Sauk-Suiattle Indian Tribe that have not been publicly reported elsewhere. Monitoring stations are in land managed for timber harvest to complement monitoring being done by other organizations (e.g., Skagit County, US Forest Service, Seattle City Light).

2.3. Data Collection and Quality Protocols

Data collection methods are explained in detail in Kammer et al. (2020, Sections 2.2 – 2.5).

Key points:

- Seasonal data is collected hourly by automated probes that are deployed between mid-June and mid-September.
- Four annual stations were in place year-round, and data were downloaded twice a year.
- Calibration and installation methods follow standard Department of Ecology protocols (Nelson & Dugger, 2022).
- To avoid dewatering, we typically place sensors in pools, suspended above the bed where possible. We use the same channel location each year, except when channel changes require minor adjustment (Section 2.2). A small-scale study of temperature variation within pools found minimal temperature stratification (Appendix E).
- Occasional operational problems include units being dewatered due to natural flow recession or vandalism. Year-round installations are much more vulnerable to disruption by winter high flows/debris and/or burial in sediment deposits.
- To assess weather effects, we use historic temperature and rainfall data from Sedro Woolley, Concrete and Darrington weather stations available on the internet.

2.4. Data Preparation and Analysis Methods

2.4.1. Temperature data preparation

We collected stream temperature data according to the USFS guidelines on temperature logger deployment (Schuett-Hames et al., 1999). Our goal was to document summer stream temperatures and capture the maximum stream temperature at each site.

After retrieving the seasonal loggers each fall, we download data from the loggers using the Hoboware desktop software (version 3.7.26). We first visually check the plotted data to look for obvious periods of anomalous readings. Following the visual check, we trim the data from the first and last few hours during deployment and retrieval. The result is an hourly series of stream temperatures.

We use the hourly measurements for each site to determine the minimum, maximum, and average for each day. We also calculate the maximum 7-day average (7DADM) over the summer monitoring period, for comparison to Washington water quality standards (Washington State Department of Ecology, 2008).

At the year-round sites, we collect 365 days of data per year by alternating two loggers at the site. We place one logger in the spring during deployment of the seasonal loggers and swap it with a second logger in the fall.

2.4.2. Tributary Stream Response to the June 2021 Heatwave

In late June 2021, the Pacific Northwest region experienced extremely hot air temperatures (White, et al. 2023) that exceeded many long-term records (Miller and Bair 2022). We wanted to know if the heatwave generated stream temperatures in the study area that exceeded prior recorded maximum temperatures.

First, we evaluated the severity of the 2021 heatwave within the study area by comparing maximum 2021 air temperatures with historic maxima. We used data records from three weather monitoring stations (available on [Weather.gov/wrh/Climate](https://www.weather.gov/wrh/Climate)) distributed across the study area (Fig. 1): Sedro Woolley, Concrete, and Darrington. All stations have long-term continuous records (112-127 years), so we compared the June 2021 observations with previous highs to evaluate how unusual the June 2021 event was. Although stream temperatures may respond differently from air temperatures, a previous report from this study (Mostovetsky et al. 2015, Fig. 8) found a general correspondence for interannual differences.

Second, to determine the severity of the peak stream temperature response, we compared instantaneous and 7DAD maxima in 2021 against the 14 other summers in our dataset, for stations with 10 or more summers. And third, we evaluated the seasonal patterns across the summer of 2021, by examining data from the Finney Creek air temperature station and comparing to values from 2014-2022, with 2021 excluded. All analyses ranked and compared temperature maxima across years.

2.4.3. Trend Analysis of Summer Maxima

Our goal was to assess whether a statistical trend in the 7DADM stream temperatures is evident in data from throughout the 15-year duration of the study.

We excluded sites with less than 70% of data for the 15-year period (11 or more years) to minimize variation caused by changing stations between years (see Appendix A for complete list of sites). We subset the remaining sites to only include dates from June 15-September 15.

We quantified the time trend using 7DADM as the temperature metric. Instantaneous and daily averages are useful to answer other biological questions but our goal of understanding the habitat conditions salmon are experiencing during the summer is best answered using 7DADM. This metric encompasses seven days of average daily maxima and has been the standard in other stream temperature reports (Kammer, 2020; Washington State Department of Ecology, 2008).

We hypothesized that overall summer stream temperatures have an upward trend at the aggregate scale based on observed and predicted regional trends (Isaak et al., 2016). We used 7DADM as the response variable in a general linear model with years and site as the predictor variables with an interaction between years and site. The interaction with site controls for the known variation between sites of varying drainage areas, elevations, etc. We also modeled the time trend of 7DADM at each site using univariate linear regression to test the hypothesis that there were significant site-specific temperature trends. We used R Statistical Software (v4.2.3; R Core Team 2023) to model the linear regressions and generate statistical indicators (r^2 , p-value, and coefficients) for each site.

2.4.4. Analysis of Year-round Data

The five years of year-round temperature monitoring data are sufficient for characterizing seasonal patterns across sites but not for trend analysis. We wanted to understand if daily average stream temperatures from the four creeks were significantly different from each other outside the summer season

(i.e. October through April). We used an analysis of variance test (ANOVA) to test for differences between sites ($p \leq 0.05$). In the case that we accept the hypothesis that sites differed significantly, we applied a Tukey Honest Significant Difference post-hoc test to determine which of the four sites varied significantly from one another.

To provide a biological context for the statistical analysis of winter temperatures, we conducted a literature review of Chinook, coho, and steelhead incubation temperatures. Note that each of the four sites where temperature data are collected year-round is located in a reach accessible to these and other anadromous species (Fig. 1).

3. Results and Discussion

3.1. Seasonal Stations

3.1.1. Annual Maxima

Seven-day average daily maxima (7DADM) ranged widely within each summer and across the monitoring period (Fig. 2). Kammer et al (2020) and other previous reports (Table 1) have extensively documented and analyzed factors contributing to such differences.

From Figure 2, we note that interannual differences have continued through the four additional summers since the Kammer report (2019-22). Maxima from 2019 and 2020 were somewhat cool, while 2021 and 2022 peaks were warm at virtually all sites. The latter two were the first summers in which 75% of sites peaked above 16 C, the water quality standard based on optimal rearing conditions for salmonids. Still, neither year exceeded 2009, which had the highest median, and more stations exceeding 20°C, as explored further in the following section.

3.1.2. Tributary Response to June 2021 Heatwave Event

As explained in section 2.4.2, we evaluated the severity of the 2021 heatwave event within the Skagit study area using archives from three weather recording stations. Among these three Skagit weather stations, air temperature peaks from the 2021 heatwave exceeded all-time record highs at Concrete and Darrington (Table 3). In both locations, the 2021 records exceeded the previous highs by 4 °F, which is a remarkable increase. At the Sedro Woolley station, the 2021 maximum was 98°F, second to 99°F recorded 106 years previously. Collectively, these results confirm that the 2021 heatwave generated extreme air temperatures in much of the study area that have occurred less than once per century under historic climate conditions.

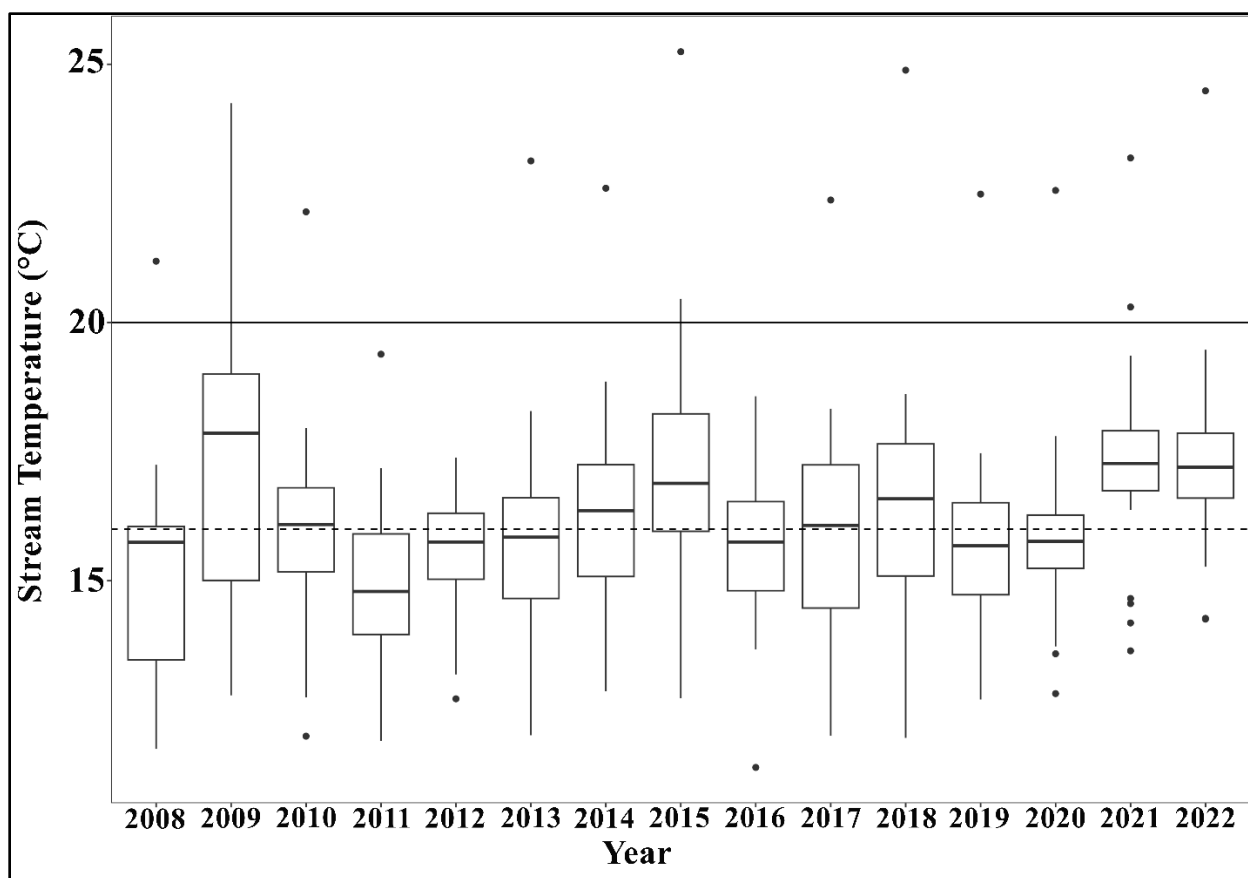


Figure 2. Summary of 7DADM across sites for each year of monitoring. The highest points in all years are from the Mid-Finney site. The dashed horizontal line is set at 16°C, the water quality criterion based on optimal salmonid spawning and rearing. The solid horizontal line is at 20°C, the temperature where salmonids begin to experience higher thermal stress, diseases, and mortality.

Table 2. Record air temperatures at selected weather stations within the study area. Data acquired from: [Weather.gov/wrh/Climate](https://www.weather.gov/wrh/Climate).

Station	Initial year ¹	Record high through 2022		2009 high		2021 high	
		°C (°F)	Date	°C (°F)	Date	°C (°F)	Date
Sedro Woolley	1896	37.2 (99)	6-3-1915	36.7 (98)	7-30-09	36.7 (98)	6-29-21
Concrete (PPL Fish St)	1906	41.1 (106)	6-25-2021	37.2 (99)	7-30-09	41.1 (106)	6-25-21
Darrington	1912	44.4 (112)	6-29-2021	42.2 (108)	7-30-09	44.4 (112)	6-29-21

1. All stations have operated continuously to the present.

Notable high air temperatures were also recorded regionally in late July 2009 (Table 2). At Sedro Woolley, the 2009 maximum was equally hot as 2021 (98°F). At Darrington, the 108°F recorded in 2009 was the all-time record prior to 2021.

In the wake of the June 2021 heatwave event, there were broad expectations that stream temperatures had also reached record highs that were highly detrimental to salmonids (White et al., 2023). The extremely high air temperatures during the 2021 heatwave were captured by our air temperature station located adjacent to Finney Creek at approximately 250ft elevation (Fig. 1). Daily air temperatures reached a maximum of 35.5°C (96°F) on June 26 and had a daily maxima above 30°C from June 25 through 29 (Fig. 3). Figure 3 shows strongly elevated air temperatures at the end of June. The hottest summer air temperatures did occur within the late June period, then the rest of the summer follows the typical pattern of summer air temperatures peaking again between mid-July and mid-August.

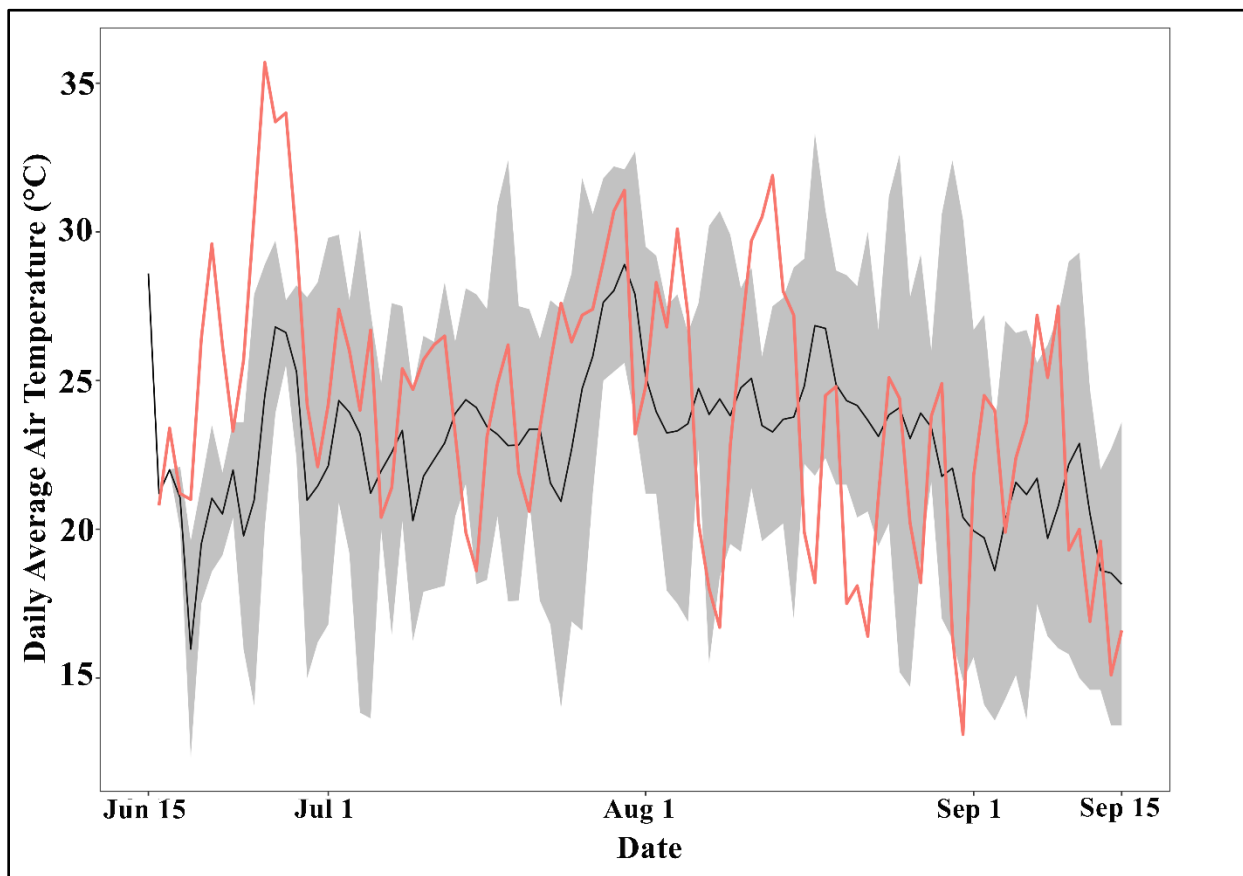


Figure 3. Maximum daily air temperatures at the Shady Grove air monitoring station (2014-2022) from 2021 (orange) compared to average (black line) and daily range (gray) of all other years.

As expected, elevated air temperatures corresponded with elevated stream temperatures during that same period. However, only four sites reached a new 7DADM record in 2021 (Fig. 4) and other sites didn't exceed maxima measured since this study began in 2008. Comparing 2021 summer to all other years, we see that although 2021 experienced record-breaking air temperatures, 2009 still had warmer summer stream temperatures overall (Fig. 2). Interestingly there were some sites that had their peak stream temperature for 2021 occur during a different part of the summer (Table 4).

Additionally, the authors and their colleagues visited many Skagit tributaries in the two months following the late June heatwave and did not observe any evidence of fish mortality. The streams we observed in this period included Finney and Day Creeks, the two streams that had exceeded 20°C (Fig. 4). Although these were not systematic surveys, the results contrast with conspicuous mortality observed in floodplain and estuary environments following the 2021 Heatwave (Raymond et al. 2022).

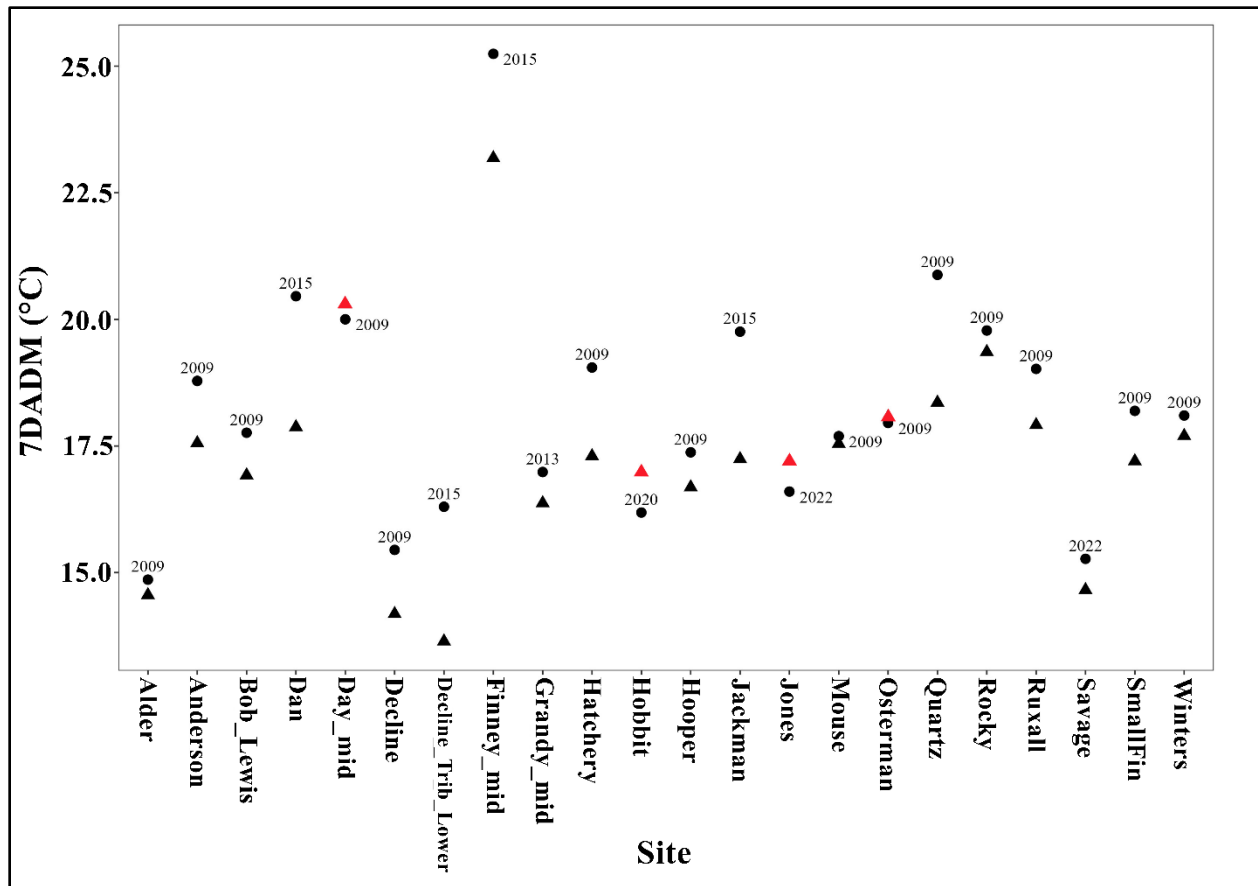


Figure 4. The highest recorded 7DADM prior to 2021 (circle) and 2021 7DADM (triangle) for comparison. Red triangles indicate records broken in June 2021.

The timing of the peak air temperatures in 2009 compared to 2021 likely contributed to the limited amount of new record stream temperatures in June 2021. Peak temperatures in 2009 occurred in mid-July, a more common time to see peak air and stream temperatures and lowest streamflow levels in mid-Skagit tributaries. However, the 2021 heatwave occurred in June, considerably earlier than the usual summer high temperatures. This earlier timing meant that greater soil moisture and headwater snowpack remained at the time of the heatwave. The very high air temperatures also accelerated snowmelt, which provided cold water to creeks in the basin. This cold runoff likely offset rapid warming in downstream reaches during that week. Other habitats lower in the Skagit basin that were more distant from the headwater snowpack showed prolonged stream temperature highs and had documented mortality as a result (Raymond et al., 2022). We theorize that if the same extreme warming conditions had occurred later in the summer season, when streams were already at their lowest flows and the snowpack has been depleted, stream temperatures would have been higher and habitat conditions much more inhospitable to summer-rearing salmon.

Temperature data from 2021 show that the stream temperature peak occurred earlier than usual for Skagit tributaries, directly following the heat dome. The early peak in 2021 was followed by an extended tail with an additional second peak in mid-August (Fig. 5). This second peak was likely caused by high air temperatures following the melt of most seasonal snowpack during the first heat dome event. Figure 5 shows that 2009 has the standard shape for summer maximum stream temperatures; there's a building average that eventually crests and decreases on the other side of a peak that occurs within a short

timeframe. Differences in interannual stream temperature peaks highlight which years rearing salmon may experience higher mortality via a relatively short but significant peak, or through extended higher temperatures. Salmon were exposed to high stream temperatures during multiple temperature peaks in 2021 because of the timing of peak temperatures and the heat dome (Fig. 5).

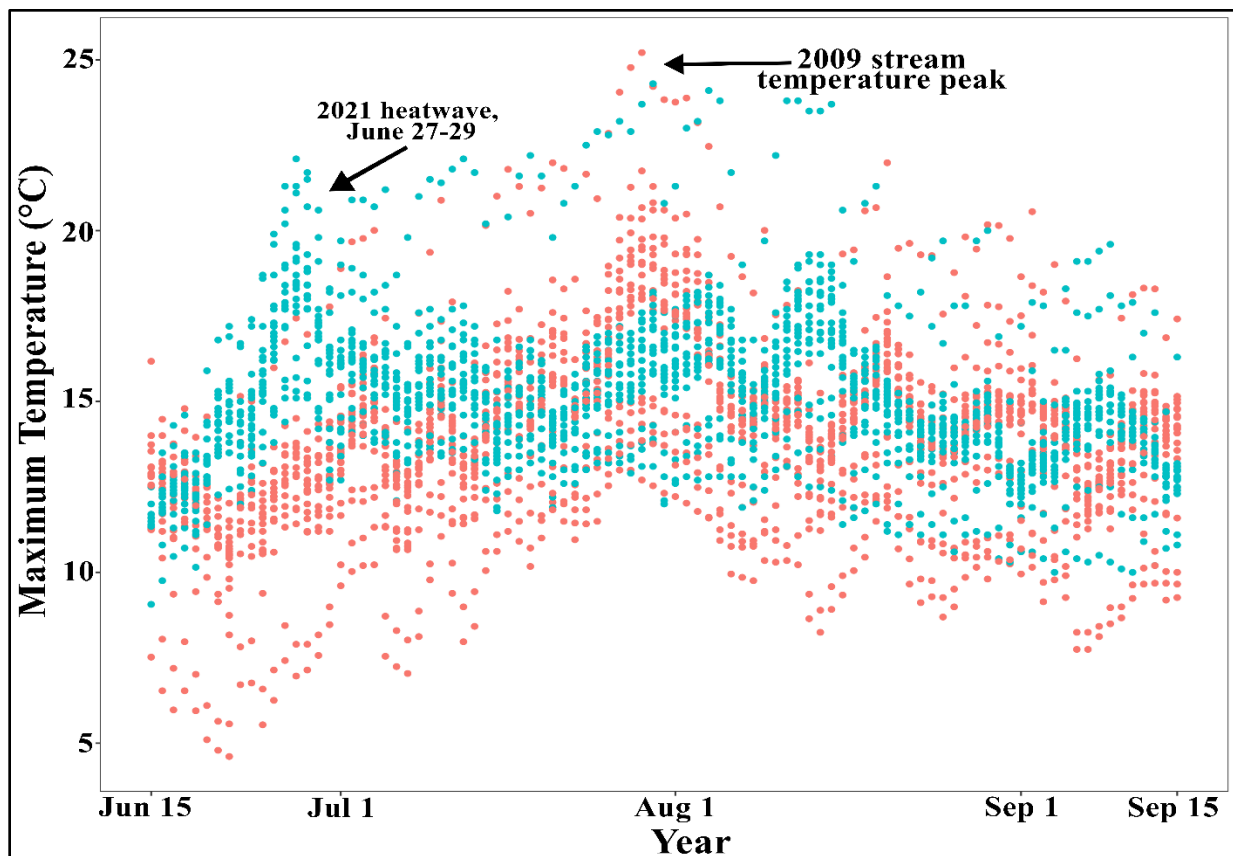


Figure 5. Daily maximum temperatures at all sites in 2009 (red) compared to 2021 (blue), the year with a record-breaking heat dome event.

These results show that the 2021 heatwave created temperatures at our monitoring stations that were very warm in some locations, but seldom unprecedented. Within the 15 years of monitoring, there were other years (mainly 2009) with higher stream temperatures than 2021, suggesting that other factors such as heatwave timing and snow-pack level mitigated the 2021 stream temperature response.

3.1.3 Interannual Trends and Interpretation

The general linear model of 7DAD for all sites (Fig. 6, black line) did not identify a significant time trend ($p=0.65$). The model included an interaction term between year and site. The model's high adjusted r^2 (0.80) and low p -value overall ($p= 2.2e-16$) indicate that the model using site and year as an interaction has a good fit.

Univariate linear regression demonstrated that the Savage Creek and Hobbit Creek sites were the two sites in this analysis with a significant positive trend ($p=0.0066$ and $p= 0.019$ respectively). Table 2 presents r^2 and p -values for linear regressions for each of the 23 stations.

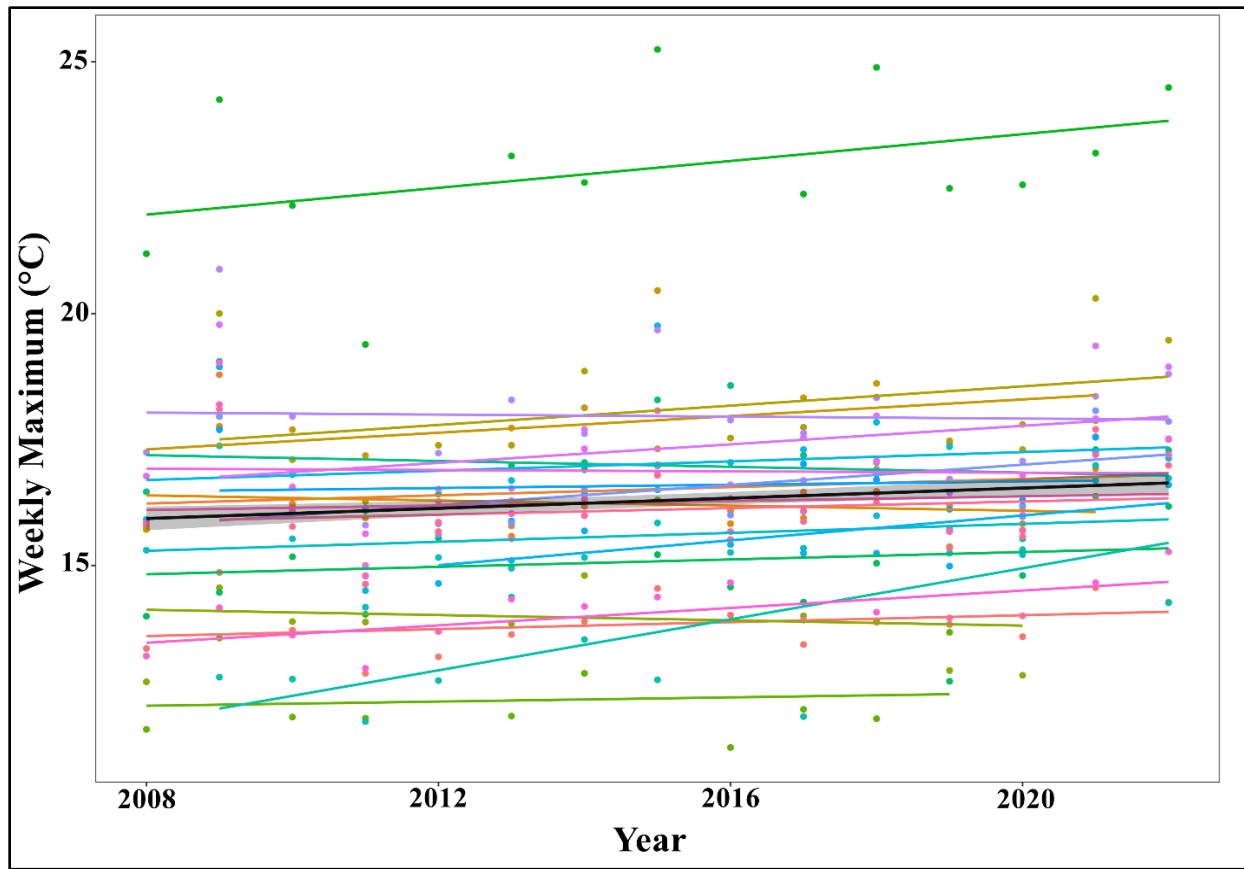


Figure 6. Yearly 7DADM temperatures of sites monitored during the 2008-2022 period and linear regression with interaction for each site (colored lines) and the overall trend line of all sites (black line).

Interannual trends were identified at some individual sites, likely due to site-scale variability in flow, shade, and air temperature. Results from Savage and Hobbit Creeks provide evidence that there are trends at these two sites. All other creeks had p -values >0.10 , indicating that trends were not detected at these locations (Table 3).

The creeks with the most significant p -values all have positive (upward) slope coefficients. These creeks vary in bankfull width, basin size, and elevation. Hobbit Creek has the highest r^2 and a significant p -value (Table 3) indicating that the 7DADM in Hobbit Creek has significantly increased over the monitoring years. The simple linear regression model used in this study means that we can't evaluate the causes of increasing temperatures observed in Hobbit Creek, only that there is a statistical relationship between stream temperature and year.

Table 3. Statistical results of the linear regressions applied to identify trends in each site's yearly 7DADMs over the monitoring period. Sites are listed in decreasing order of significance. See appendix D for plots.

Site	Coefficient	r ²	P-value		Site	Coefficient	r ²	P-value
Savage	0.09	0.44	0.0066		Bob_Lewis	-0.03	0.03	0.60
Hobbit	0.25	0.48	0.019		Grandy_mid	0.04	0.02	0.62
Jones	0.12	0.26	0.11		Winters	0.03	0.02	0.63
Osterman	0.10	0.18	0.14		Hatchery	-0.03	0.02	0.65
Finney	0.13	0.16	0.18		SmallFinn	0.02	0.02	0.66
Day	0.10	0.12	0.24		Decline_Trib_Lower	-0.03	0.02	0.67
Dan	0.08	0.11	0.29		Mouse	0.02	0.01	0.75
Alder	0.03	0.08	0.31		Decline_Trib_Upper	0.02	0.01	0.77
Rocky	0.09	0.09	0.33		Decline	-0.01	0.01	0.81
Hooper	0.04	0.06	0.38		Quartz	-0.01	0.0013	0.90
Anderson	0.04	0.04	0.50		Ruxall	-0.01	0.0010	0.91
Jackman	0.05	0.03	0.58					

3.2. Year-Round Stations

3.2.1. Patterns and Variability

The overall distributions of daily minima during the ‘cool season’ are shown by stream in the box and whisker plots of Figure 7. As noted previously from Figure 7, the Finney year-round station has the widest range of temperatures and the coldest temperatures of year-round stations for all four winters (Fig. 8).

Analysis of Variance (ANOVA) results demonstrated that Day Creek and Finney Creek are not significantly different from each other. Grandy and Jones Creek differ from each other in addition to differing from Day and Finney Creeks (Fig. 7). A significant difference between sites implies that temperature mechanisms differ between basins, though our four monitoring sites are insufficient to provide certainty. Monitoring location characteristics such as drainage basin size, elevation, and amount of shade generated from riparian areas and groundwater inputs could influence ‘cool season’ temperature patterns at these sites (Kammer et al., 2020). Groundwater input is a favorable element of winter habitat refugia because it is comparatively warmer (Johnson et al., 2017). Juvenile coho have been observed seeking out groundwater inputs because of the consistent temperatures they provide (Swales et al., 1986).

Fall cooling and spring warming periods are apparent in every year of data (Fig. 8). Each year has downward ‘spikes’ in mid-winter, presumably driven by extended periods of cold weather. The lowest water temperatures (below 2°C) during these periods are limited to Finney and Day Creeks (green and pink dots on Fig.8). Jones Creek has the mildest temperatures, especially in the midwinter period of December and January. In late winter, Grandy begins warming up by February and matches Jones Creek. During the spring season (March and April), Day Creek is generally the coldest.

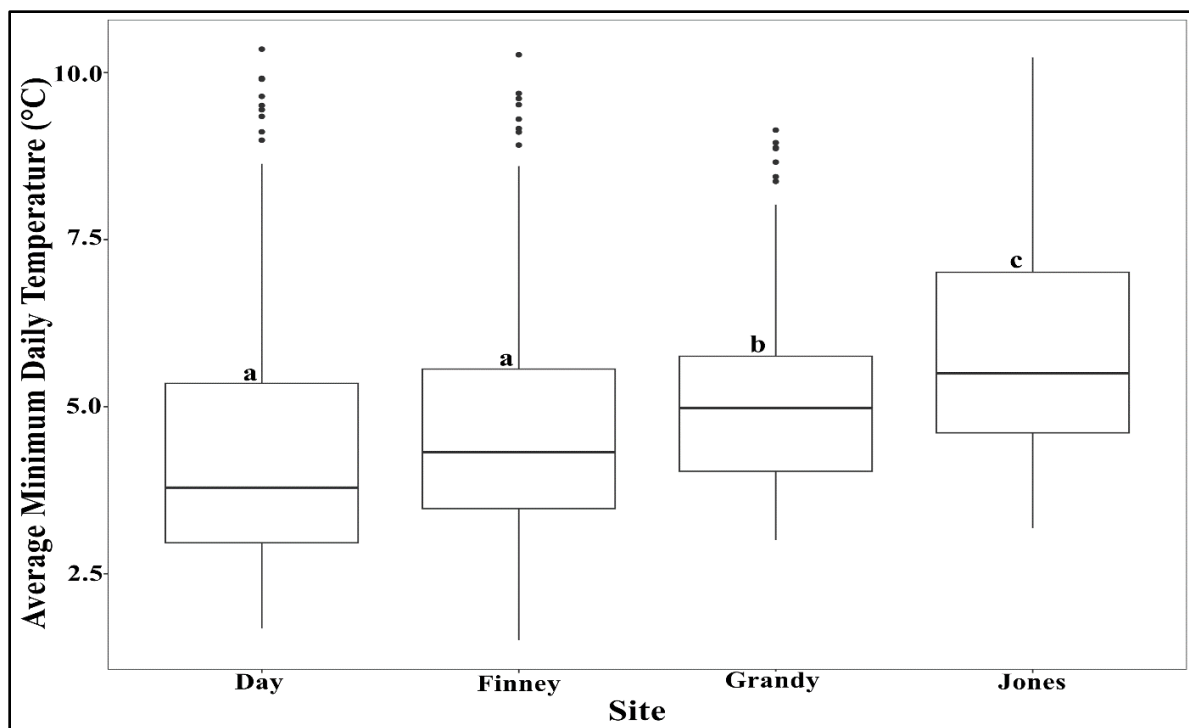


Figure 7. Minimum daily temperatures during the cool season (October 1-April 31) for 2018- 2022. Different letters above boxes represent significantly different distributions between sites.

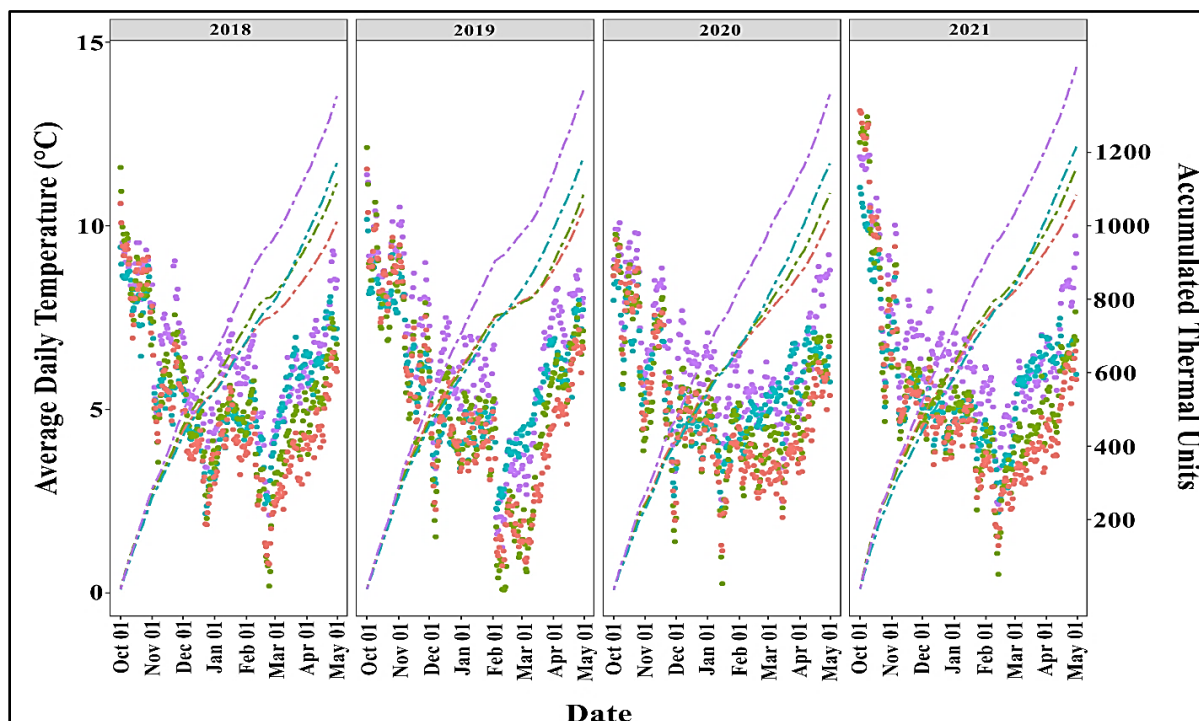


Figure 8. Average daily temperature and accumulated thermal units during monitoring period; Day Cr (red), Finney Cr (green), Grandy Cr (blue), Jones Cr (purple).

3.2.2. Cool Season Results Relative to Temperatures Preferred by Salmon

While salmonids have varying stream temperature optima depending on species and life history stage, this section focuses on three species of interest to the member tribes of the Skagit River System Cooperative: Chinook salmon, coho salmon, and steelhead (*O. mykiss*). At least one life stage of each of these three species is found in all tributaries monitored with annual temperature loggers.

Temperature plays a key role in the growth of salmon from egg to emerged fry (Beacham & Murray, 1990; Murray & McPhail, 1987). Salmon embryos are particularly sensitive to temperature during development (Del Rio et al., 2021). Maturation of salmon eggs incubating in redds is entirely dependent on local environmental conditions, mainly the temperature and oxygen content of streamflow passing through the redd. Table 4 shows the optimal temperatures for the three species of interest at life stages likely to be present between fall and spring in our monitored streams.

The optimum temperature range allows salmon species to utilize a variety of overlapping habitat conditions. Coho, for example, require around 146 days to hatch if they are in 2°C water, whereas Chinook will take 202 days at the same temperature. Coho require 46 days in 14°C water but Chinook would hatch around the 38-day mark (Quinn, 2018).

No natural system stays at a constant temperature for the duration of salmon embryo development. To circumvent this problem, scientists use accumulated temperature units (ATU's) to estimate timing of alevin emergence from the gravel. ATU's required to hatch or emerge are assigned to each species and can capture the fluctuating temperatures that redds are exposed to. ATU's can be estimated as the product of the number of degrees above 0°C times the number of days (Quinn, 2018). The emergence date can be predicted using the estimated number of ATU's for that species and dividing it by the average temperature or by cumulatively adding the daily mean (above 0°C) to the previous day until the ATU threshold is reached for each species (Table 5).

Using a hypothetical spawning date of October 1st, we can get a sense of what conditions eggs in redds and pre-emergence alevin experience at our annual sites. Figure 8 shows both the average daily temperatures at each site as well as the accumulated ATU's for each site calculated and displayed (diagonal lines angling up and right) on the secondary axis. Aside from the warmer Jones site, all three sites have similar thermal unit accumulation rates from October onward. In January, Jones Creek begins to outpace the other three creeks with consistently higher daily temperatures. Spawning times and water temperature during development have been shown to affect the fitness of emergent fry (Beer & Anderson, 2001). Warming daily temperatures beginning earlier in the year at Jones Creek could increase the fitness of fry, resulting in a competitive advantage at emergence.

We wanted to examine how spawning, and incubation would be influenced by the stream temperatures that are occurring during the winter. We've demonstrated through the review of regional literature and hypothetical ATU calculations that there are differences between each creek and fish from Jones are likely to emerge before fish in other creeks. We've also concluded that winter stream temperatures during our data collection are not at a low enough temperature to be detrimental to spawning, incubation, or rearing.

Table 4. Optimal temperature ranges for three species of salmon at different life stages that occur primarily during the fall and winter months.

Species	Incubation (°C)	Rearing (°C)	Spawning (°C)
Chinook (<i>O. tshawytscha</i>)	5.0-8.0 ¹	12-15.6 ²	5-13.4 ²
Coho (<i>O. kisutch</i>)	2.5-6.5 ¹	12.0-15.0 ²	4.4-13.3 ³
Steelhead/ Rainbow trout (<i>O. mykiss</i>)	4.0-9.0 ¹	11.0-15.0 ^{1,2}	10-12.8 ¹

1. (Richter & Kolmes, 2005)

2. (Hicks, 2002)

3. (Bell, 1986)

Table 5. Time (in accumulated thermal units (ATU)) needed for each species to complete the developmental stage.

Species	50 % Hatch (ATU)	Emergence (ATU)
Chinook (<i>O. tshawytscha</i>)	500 ¹	395 ¹
Coho (<i>O. kisutch</i>)	450 ¹	300 ²
Steelhead (<i>O. mykiss</i>)	350 ¹	250 ³

1. (Crisp, 1988)

2. (Billard & Jensen, 1996)

3. (Albrecht, 2016)

4. Implications and Recommendations

Understanding local stream temperature conditions and influences is critical as climate change impacts are an increasing concern for salmon recovery (Crozier et al., 2019). A key to addressing climate change is to have a solid understanding of baseline stream temperatures so that the most effective mitigation measures can be implemented (Isaak et al., 2012). Finney Creek and lower Day Creek exhibit some of the highest summer temperatures recorded of all monitoring locations. These streams are characterized by a wide bankfull width and a riparian area that provides insufficient shade (see Kammer, 2020 Fig. 2 for site characteristics). Wide channels are largely due to the high flows from these relatively large watersheds, but historically elevated sediment inputs have likely contributed as well (Seixas & Veldhuisen, 2023, Beechie, 1998). Reduced shade is partially explained by historic logging practices that involved logging of riparian areas. These streams are flanked by robust second-growth forests that have not yet reached the height of the old (>200 years) conifer stands that preceded them. Modern logging regulations now require protection of riparian forests and there are restoration efforts to increase conifers along both Finney and Day Creeks. These results and associated shade analysis (Hyatt, 2022) emphasize the value of both protection and restoration approaches to further increase shading of wide channels.

Alderdice & Velsen (1978) found that winter temperatures in Skagit tributaries rarely dip below the optimum development temperature of 2°C for longer than a 48-hr period, which is also reflected in our analysis of our year-round sites. Short-term cold-water exposure has the possibility of slowing egg

development (Alderdice & Velsen, 1978), but not on the scale of causing long term individual or population effects in the Skagit. Temperature shifts in winter alone are unlikely to lead to drastic population declines. That's not to say that other water quality characteristics affected by low temperatures won't impact salmon emergence or egg development (low temperature can influence low oxygen transport). Temperature shifts in winter alone are unlikely to lead to drastic population declines.

It is possible to minimize the predicted impacts of climate change through restoration of habitat function and connectivity. Restoration can help mitigate rising stream temperatures by restoring instream flows (Moore & Wondzell, 2005), removing fish barriers (Fausch et al., 2006), restoring off-channel habitat (Nickelson et al., 1992) and reintroducing large wood (Fausch & Northcote, 1992). Our temperature monitoring data can inform restoration projects by establishing baseline conditions for sites with a wide variety of characteristics scattered throughout the Skagit River basin.

The temperature data in this analysis encompasses a sample of tributaries in timberlands of the Skagit basin. Expanding water temperature monitoring efforts across other land uses in the basin will better inform salmon recovery decisions. Such an effort would require broader partnering and coordination with other organizations.

5. Conclusions

Based on stream temperature data for 2008-2022:

- The highest temperatures (peaks above 20 C) continue to be found in wide, unshaded creeks with low gradient and velocity (e.g., Finney and Day Creeks). Most streams peaked between 15 and 18C, which is above the optimal range for salmonids.
- Temperatures from the four additional summers of monitoring fall within the established range, and include two cool years (2019, 2020) followed by two with relatively warm observations (2021, 2022).
- Even though the June 2021 heatwave broke air temperature records across western Washington and the Skagit basin, the impact on water temperatures at our monitoring sites was muted due to timing. When the heatwave occurred, flows were well above mid-summer levels and there was still snowpack contributing cold water to streams. As a result, the heatwave produced summer peaks for the 2021 season at many sites but fell short of 2009 maxima in most cases.
- There was not a significant trend in 7DADM measurements detectable across the aggregated monitoring stations. Our hypothesis, that stream temperature is increasing over the monitoring period, was not supported by statistical analysis. The stations at Savage and Hobbit Creeks have significant ($p < 0.05$) upward trends, while all others did not.
- Based on four year-round stations, winter stream temperatures are within the optimum range for salmon incubating in redds. Development slows when temperatures drop below 2°, an unusual occurrence over the monitoring record at the monitored sites.
- Jones Creek had the warmest winter averages of the sites monitored, accumulating the thermal unit threshold for salmon hatch and emergence well before the other three creeks. Finney and Day Creeks, both larger creeks, had the warmest and coldest temperatures compared to other sites.
- Continuing to monitor streams adjacent to managed timberland will allow us to track any trends in these streams. As our data increases, trends, or the lack thereof, may become more apparent.

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Appendix A. Summary of Sites, Locations, and Years of Available Data

See Kammer et. al, 2020 for site information prior to 2019

Site ID	Stream Name	2019	2020	2021	2022	Location
ALDR	Alder Creek	x	x	x	x	end of O'Hara Road
ANDR	Anderson Creek	x	x	x	x	upstream of South Skagit Hwy
BOBL ¹	Bob Lewis Creek	x	x	x	x	upstream of Sauk Prairie Road
CARP	Carpenter Creek	OOW	x	x	x	upstream of Ervine Road
CONN ¹	Conn Creek	x	x	x	x	upstream of USFS 2435 Road
CUMB	Cumberland Creek	x	x	x	x	upstream of South Skagit Hwy
DALO ²	Day Creek - low	x	x	x	x	RM 0.2 - Lower Day
DAMD *	Day Creek - mid	x	x	x	x	near Rocky Creek confluence
DANC ¹	Dan Creek	x	x	x	x	upstream of Sauk Prairie Road
DCLO ¹	Decline Creek - lower	x	x	x	x	USFS 2435-014 Road
DCUP ¹	Decline Creek - upper	x	x	x	x	USFS 2435-016 Road
DECL ¹	Decline Creek	x	x	x	x	upstream of USFS 2430 Road
FNMD	Finney Creek - mid	x	x	x	x	near Quartz Creek (mid)
FNUP *	Finney Creek - upper	x	x	x	x	upstream of Small Fin
GRAV	Gravel Creek - upper	x	x	x	x	USFS 2140 Road
GRCK *	Grandy Creek	x	x	x	x	downstream of East Fork tributary
GRLK	Grandy Creek - lake	x	x	x	x	Grandy Lake outlet tributary
HATC	Hatchery Creek	x	x	x	x	downstream of Lower Finney Rd
HOBB	Hobbit Creek	OOW	x	x	x	upstream Concrete-Sauk Valley Rd
HOOP	Hooper Creek	x	x	x	x	upstream Concrete-Sauk Valley Rd
JACK	Jackman Creek	x	x	x	x	upstream of Hwy 20
JNCK	Jones Creek	x	x	x	x	upstream of Burrese Road
JNUP *	Jones Creek - upper	x	x	x	x	downstream end of canyon
MOUS ¹	Mouse Creek	x	x	x	x	upstream of Sauk Prairie Road
MUDD	Muddy Creek	x	x	x	x	upstream of SPI property line
OSTR	Osterman Creek	OOW	x	x	x	upstream Concrete-Sauk Valley Rd
PRES	Pressentin Creek	x	x	x	x	upstream of East Pressentin Dr
QUAR	Quartz Creek	x	x	x	x	downstream of Lower Finney Rd
RDCB	Red Cabin Creek	x	x	x	x	below bridge on Crown Mainline
ROCK	Rocky Creek	x	x	x	x	near Day Creek confluence
RUXL	Ruxall Creek	x	x	x	x	downstream of Lower Finney Road
SAVG	Savage Creek	x	x	x	x	Weyerhaeuser 4400 Road
SMFI	Small Finney trib	x	x	x	x	small tributary to Finney Creek
TPTH	TP Thin	x	x	x	x	at campsites on Lower Finney Rd
WINT	Winters Creek	x	x	x	x	tributary to Morgan Creek
WISE	Wiseman	x	x	x	x	downstream of West Elk Run

Bold Site ID indicates 10.5+ years of data.

¹ Data collected by SSIT; ² Data collected by SFEG 2008-2013 and by SRSC 2014 and later. All other sites by SRSC

* Year-round data collection site

BE: Before establishment of monitoring site.

LST: logger lost or not retrieved.

BAT: battery died during monitoring period.

Appendix B. Summary of SMHT Temperatures and Dates

See Kammer et. al, 2020 for temperature data prior to 2019

	2019		2020		2021		2022	
	SMHT	Date	SMHT	Date	SMHT	Date	SMHT	Date
Alder Creek	14.1	8/5/2019	14.0	7/21/2020	15.3	6/28/2021	14.5	7/29/2022
Anderson Creek	16.7	8/5/2019	16.6	8/17/2020	19.2	6/28/2021	18.0	7/29/2022
Bob Lewis Creek	15.7	8/6/2019	16.2	7/31/2020	17.7	6/29/2021	#	#
Carpenter Creek (archery)	-	-	19.2	6/25/2020	21.4	6/28/2021	19.4	7/30/2022
Carpenter Creek (ervine)	15.7	8/2/2019	16.5	8/17/2020	19.0	6/28/2021	18.5	7/30/2022
Cold Spring	13.4	8/29/2019	12.1	8/21/2020	14.2	6/28/2021	13.9	8/31/2022
Conn Creek	14	8/6/2019	14.3	7/31/2020	15.01	8/13/2021	#	#
Cumberland Creek	17	8/5/2019	17.0	8/17/2020	19.7	6/28/2021	19.2	7/29/2022
Dan Creek	18.2	8/6/2019	17.9	7/31/2020	18.6	8/15/2021	#	#
Day Creek (river mile .2)	21.9	8/5/2019	21.6	7/21/2020	25.3	6/28/2021	23.6	7/29/2022
Day Creek (near Rocky Creek) (Day Mid)	18.2	8/5/2019	18.4	7/31/2020	22.1	6/28/2021	20.2	7/29/2022
Decline Creek	-	-	14.5	7/31/2020	15.2	8/13/2021	#	#
East Fork Nookachamps	18	8/5/2019	18.0	8/17/2020	21.9	6/28/2021	20.1	7/29/2022
Finney Creek (near Quartz Creek) (Finney Mid)	23.4	8/5/2019	23.5	7/30/2020	24.3	7/30/2021	25.5	7/29/2022
Finney (Upstream of Small Fin) (Upper Finney)	21.4	8/5/2019	21.3	7/30/2020	22.4	7/30/2021	23.4	7/29/2022
Grandy Creek	13.9	5/31/2019	16.2	7/17/2020	17.8	6/28/2021	16.6	7/29/2022
Grandy Creek (lake outlet trib)	23.5	8/5/2019	23.5	7/31/2020	29.2	6/28/2021	27.3	7/30/2022

Gravel Creek (Upper) Gravel2	18.1	8/6/2019	19.8	8/17/2020	-	-	#	#
Hansen	14.9	8/5/2019	18.7	8/16/2020	17.9	6/28/2021	17.4	7/29/2022
Hatchery Creek - upper	16.3	8/5/2019	16.0	8/17/2020	18.7	6/28/2021	17.9	7/29/2022
Hobbit Creek	-	-	16.8	9/6/2020	18.1	9/9/2021	14.6	7/29/2022
Hooper Creek	15.8	8/5/2019	16.0	8/17/2020	18.3	6/28/2021	17.2	7/29/2022
Jackman Creek	17.9	8/6/2019	17.1	8/17/2020	18.0	8/15/2021	17.9	7/29/2022
Jones Creek	15.6	8/5/2019	15.6	7/31/2020	18.4	6/28/2021	17.0	7/29/2022
Jones Creek Upper	15.2	8/5/2019	15.6	7/21/2020	18.4	6/28/2021	16.8	7/29/2022
Mouse Creek	16.7	8/6/2019	16.8	7/31/2020	18.4	6/28/2021	#	#
Muddy Creek	13.7	7/21/2019	14.0	7/21/2020	15.2	6/28/2021	14.7	6/27/2022
Mundt Ck.	15.7	8/5/2019	15.7	8/17/2020	19.0	6/28/2021	17.5	7/29/2022
Osterman Creek	-	-	16.9	8/17/2020	19.6	6/28/2021	18.6	7/29/2022
Pressentin Creek	16.5	8/6/2019	16.6	7/31/2020	18.0	8/14/2021	18.5	7/29/2022
Quartz Creek	17.4	8/5/2019	17.7	8/17/2020	19.1	8/13/2021	19.6	7/29/2022
Red Cabin Creek	11.7	9/15/2019	11.7	9/25/2020	12.0	6/28/2021	11.6	6/27/2022
Rocky Creek	17	8/5/2019	17.2	7/31/2020	21.1	6/28/2021	19.6	7/29/2022
Ruxall Creek	16.2	8/5/2019	16.6	8/17/2020	19.5	6/28/2021	18.2	7/29/2022
Savage Creek	14.2	9/1/2019	14.3	8/17/2020	15.3	6/28/2021	15.5	7/30/2022
TP Thin	15.2	8/5/2019	16.7	7/27/2020	20.1	6/28/2021	18.2	7/29/2022
Turner	14.8	8/12/2019	15.6	8/17/2020	18.0	6/28/2021	16.7	7/29/2022
Turner Trib	16	8/5/2019	16.0	8/17/2020	19.1	6/28/2021	18.2	7/30/2022
Unnamed Decline tributary LOWER	13.5	8/6/2019	13.9	7/31/2020	14.4	8/14/2021	#	#
Unnamed Decline tributary UPPER	14.2	8/7/2019	-	-	-	-	#	#
Unnamed Finney trib (small Fin)	16.1	8/5/2019	16.2	7/20/2020	18.1	6/29/2021	17.9	7/29/2022
Walker ORV	17.2	8/5/2019	17.2	8/17/2020	20.4	6/28/2021	19.4	7/29/2022
Walker Osborn	17.9	8/5/2019	18.7	7/31/2020	22.1	6/28/2021	20.7	7/29/2022
Winters Creek	15.8	8/5/2019	16.0	8/17/2020	19.1	6/28/2021	17.4	7/29/2022
Wiseman	18.8	8/5/2019	17.7	8/17/2020	21.0	6/28/2021	19.1	7/29/2022

Waiting to receive data from SSIT

- Missing data

Appendix C. Summary of 7-DADM Temperatures and Ranges

See Kammer et. al, 2020 for temperature data prior to 2019

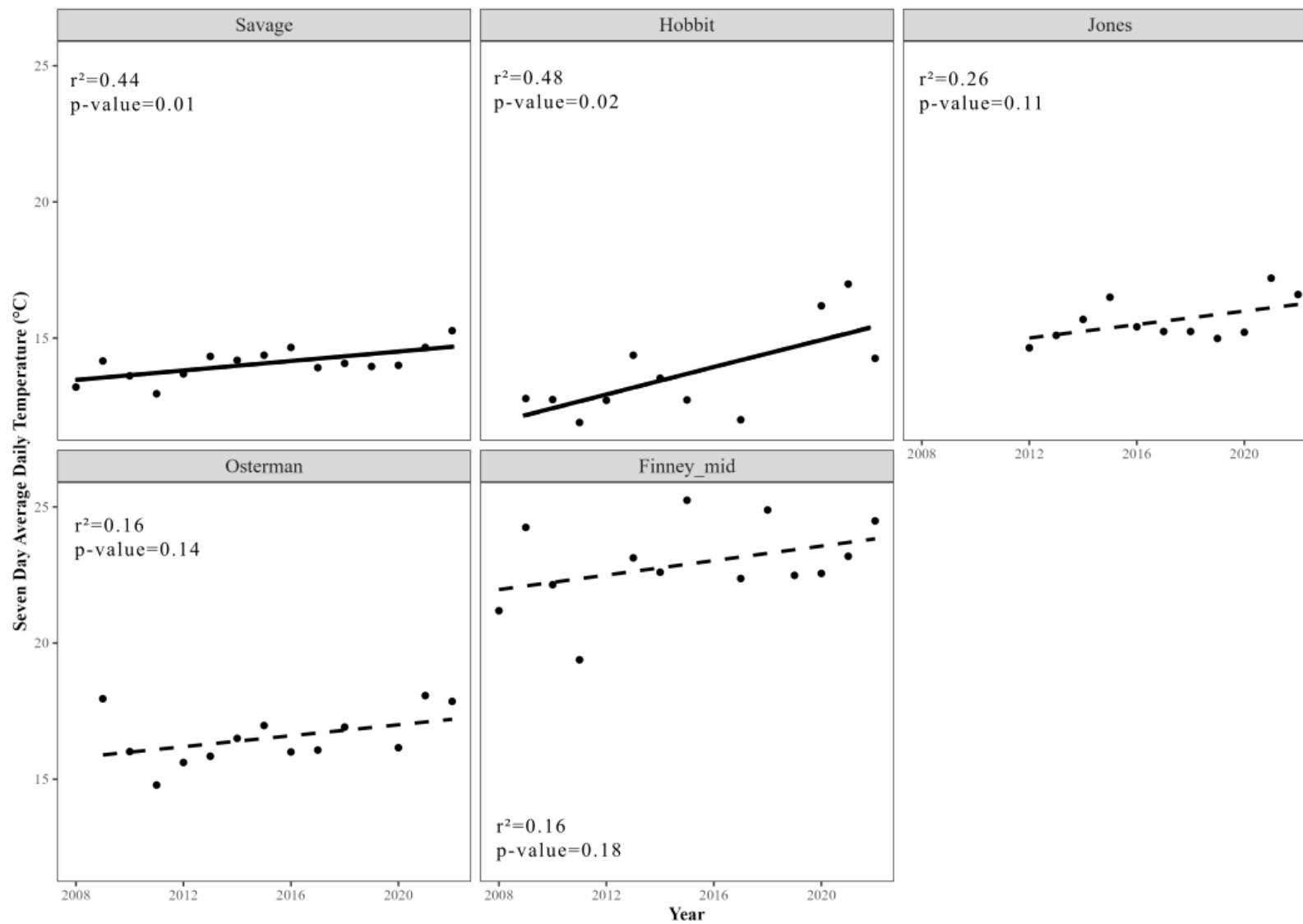
	2019		2020		2021		2022	
	7DAD M	7DAD M Range	7DAD M	7DAD M Range	7DAD M	7DAD M Range	7DAD M	7DAD M Range
Alder Creek	13.8	2.8	13.6	2.7	14.5	3.0	14.3	3.0
Anderson Creek	16.2	1.8	15.8	1.4	17.6	1.6	17.5	1.9
Bob Lewis Creek	15.4	1	15.7	1.2	16.9	1.7	#	#
Carpenter Creek (archery)	-	-	16.9	1.5	19.4	2.2	18.9	2.5
Carpenter Creek (ervine)	15.3	1.4	16.1	1.4	17.6	1.7	17.9	2.3
Cold Spring	13.1	0.8	11.6	0.8	13.4	1.0	13.6	1.3
Conn Creek	13.3	1.2	13.5	1.5	14.16	1.04	#	#
Cumberland Creek	16.4	1.8	16.4	1.6	18.1	1.8	18.5	2.4
Dan Creek	17.4	3.2	17.3	2.7	17.9	0.6	#	#
Day Creek (river mile .2)	21.1	4.8	21.0	4.8	23.4	6.2	23.0	4.8
Day Creek (near Rocky Creek) (Day Mid)	17.5	2.5	17.8	2.4	20.3	2.7	19.5	2.7
Decline Creek	-	-	13.7	1.5	-	-	#	#
East Fork Nookachamps	17.4	2.8	16.9	2.6	-	-	19.5	3.3
Finney Creek (near Quartz Creek) (Finney Mid)	22.5	5.9	22.6	5.9	23.2	6.7	24.5	6.1
Finney (Upstream of Small Fin) (Upper Finney)	20.6	3.6	20.5	4.0	21.6	3.3	22.5	4.2
Grandy Creek	13.2	2.8	14.8	2.6	16.4	3.5	16.2	2.7
Grandy Creek (lake outlet trib)	22.7	4.1	23.1	2.1	27.2	3.0	26.6	2.9
Gravel Creek (Upper) Gravel2	17.4	1.7	18.5	2.8	-	-	#	#
Hansen	14.5	0.9	18.7	5.3	16.1	1.8	16.9	2.1
Hatchery Creek	15.7	1.7	15.5	1.4	17.3	1.6	17.3	2.0
Hobbit Creek	-	-	16.2	5.0	17.0	4.3	14.3	1.8
Hooper Creek	15.3	1.9	15.3	2.0	16.7	2.1	16.7	2.4
Jackman Creek	17.4	3.4	16.0	2.9	17.2	2.7	17.1	3.2
Jones Creek	15	1.5	15.2	2.0	17.2	2.0	16.6	2.2

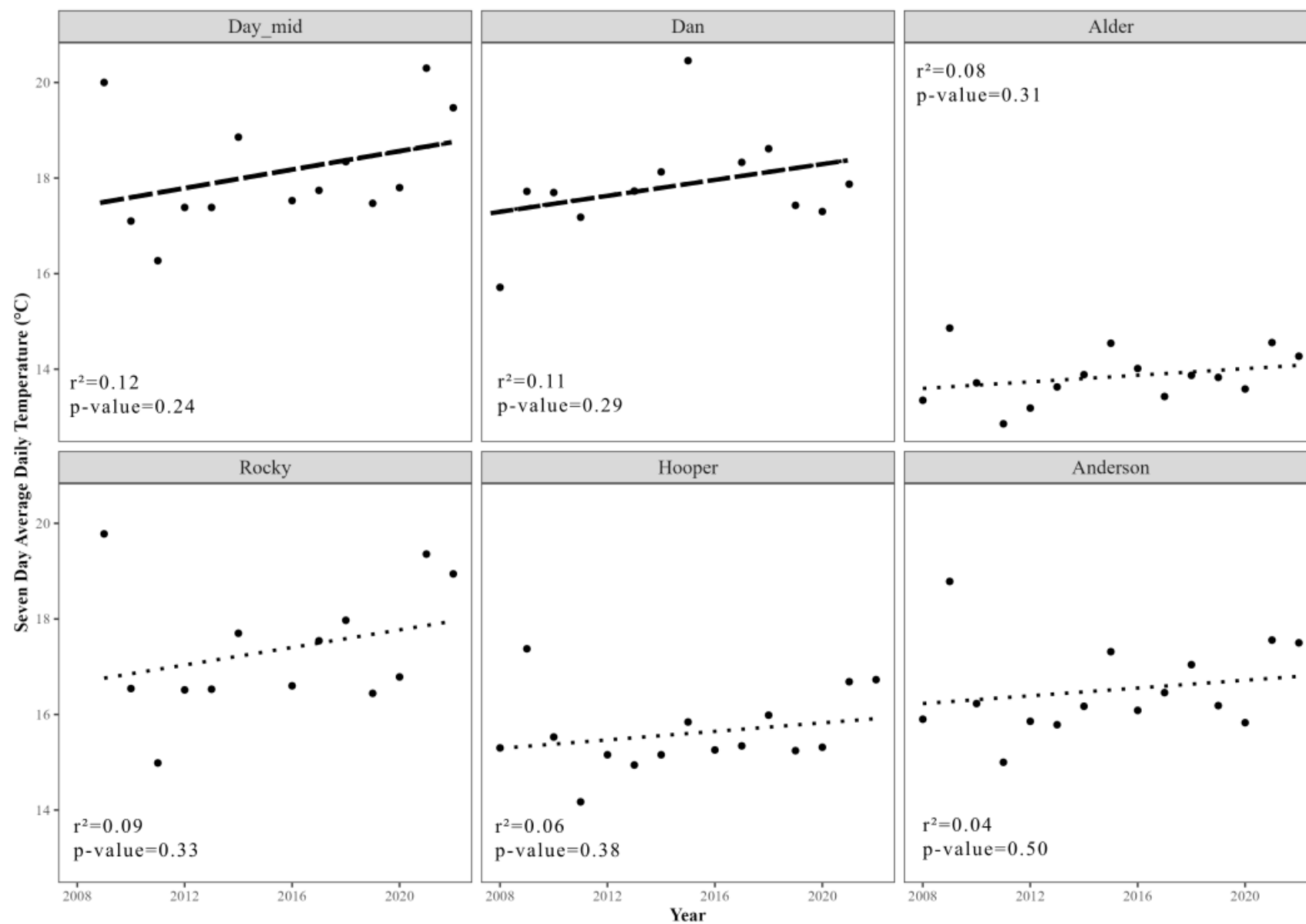
Jones Creek Upper	14.9	1.7	15.1	2.2	17.2	2.4	16.5	2.4
Mouse Creek	16.1	1.5	16.3	1.8	17.5	1.05	#	#
Muddy Creek	13.2	2.8	13.5	2.4	14.4	3.0	14.0	3.3
Mundt Ck.	15.3	1.2	15.2	1.1	17.4	1.4	17.1	1.4
Osterman Creek	-	-	16.1	2.0	18.1	1.9	17.9	2.2
Pressentin Creek	16.1	1.6	16.1	1.7	17.4	1.4	17.8	2.2
Quartz Creek	16.7	2.7	17.1	3.1	18.3	2.6	18.8	3.4
Red Cabin Creek	11	1.4	11.0	1.3	11.5	1.5	11.2	1.5
Rocky Creek	16.5	2	16.8	2.0	19.3	2.3	19.0	2.3
Ruxall Creek	15.7	1.6	16.0	1.7	17.9	2.0	17.5	2.0
Savage Creek	14	1.2	14.0	1.4	14.7	1.2	15.3	1.9
TP Thin	14.8	1.9	16.1	2.3	18.6	2.8	17.5	1.9
Turner	14.2	0.9	15.1	1.3	16.9	1.8	16.2	1.7
Turner Trib	15.5	1.9	15.5	1.4	17.6	1.6	17.7	2.4
Unnamed Decline tributary LOWER	12.9	1.7	12.8	1.9	13.6	0.9	#	#
Unnamed Decline tributary UPPER	13.7	1.4	-	-	-	-	#	#
Unnamed Finney trib (Small Fin)	15.7	1.9	15.7	2.0	17.2	1.5	17.2	2.1
Walker ORV	16.7	1.5	16.6	1.2	19.0	1.6	18.9	1.9
Walker Osborn	17.7	2.3	18.0	2.6	20.7	2.6	20.0	2.9
Winters Creek	15.3	0.8	15.6	0.8	17.7	1.2	17.0	1.0
Wiseman	18	4.8	16.9	2.6	19.0	2.7	18.5	3.4

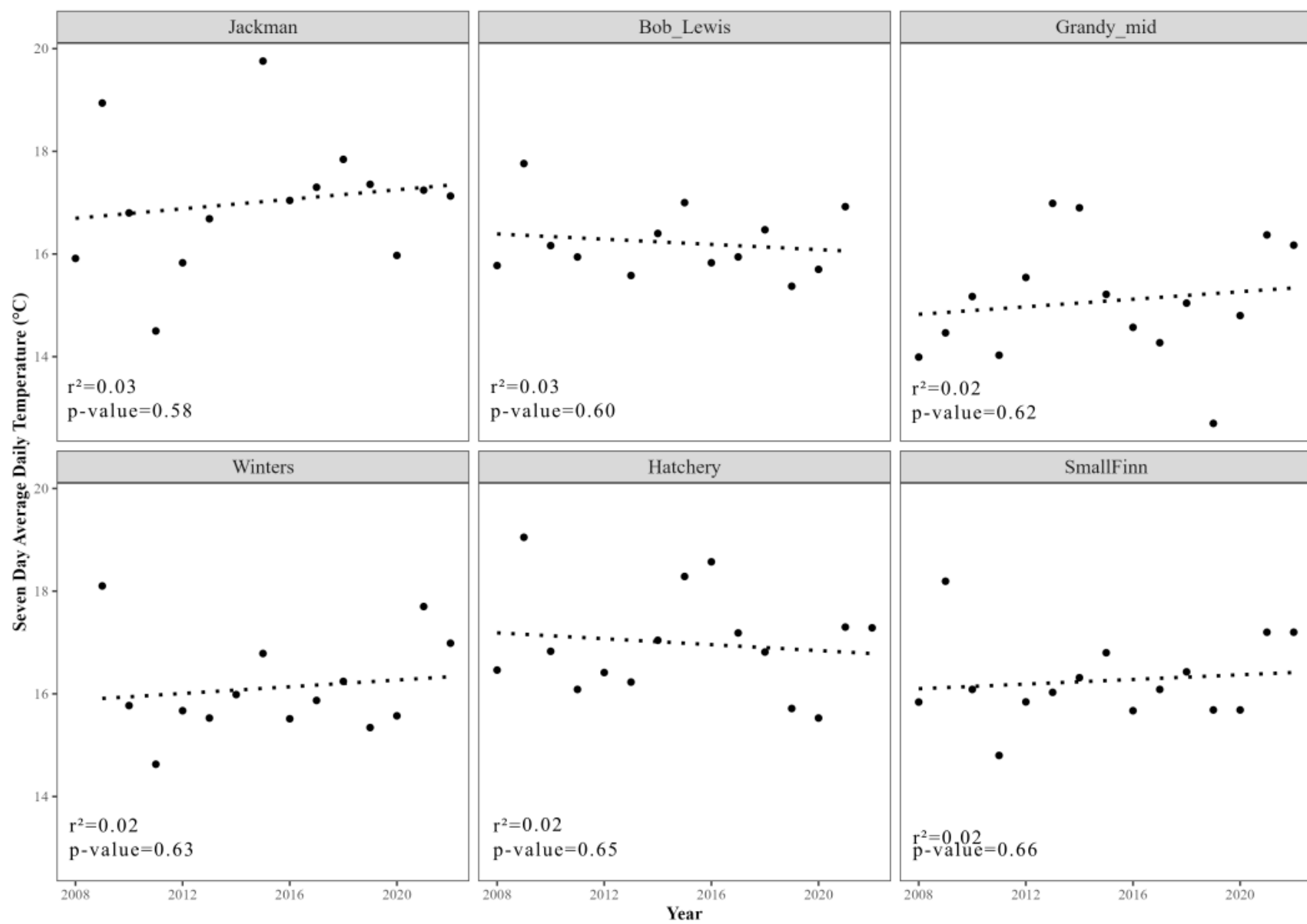
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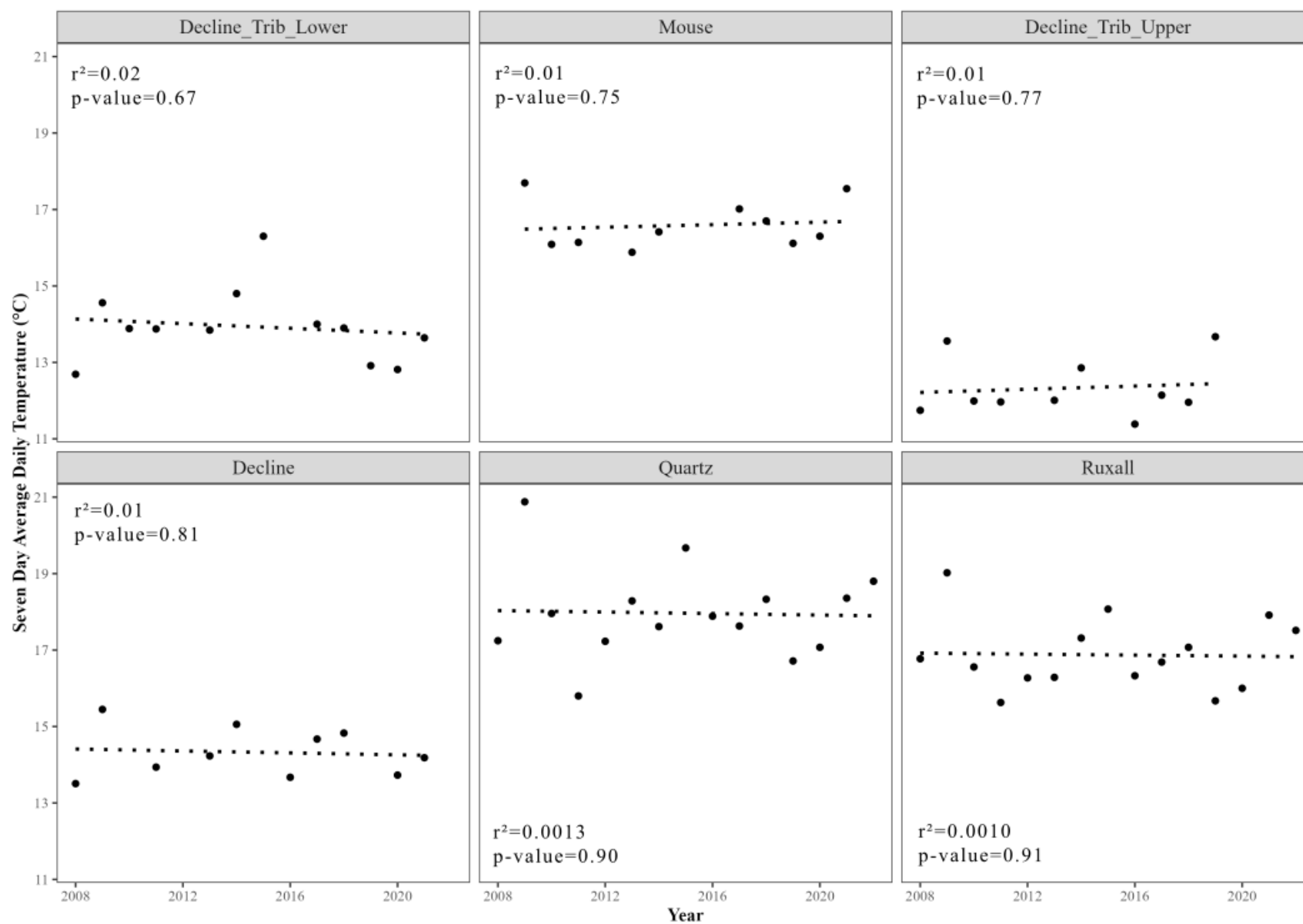
Data not yet received from SSIT

Appendix D. Linear Regressions of yearly 7DADM for seasonal sites









Appendix E

Monitoring Thermal Stratification in Finney Creek Pools - 2014 Pilot Project

**Curt Veldhuisen and Anna Mostovetsky - Skagit River System Cooperative
July 24, 2023**

Since 2008, the SRSC Forest and Fish Program has been monitoring summer temperatures of Skagit tributaries annually, including Finney Creek (Kammer et al. 2020). In summer 2014, we installed eight automated thermal recorders ('therms') in lower Finney Creek (Figure A) to look for vertical thermal stratification in pools. Spatial thermal variation has implications to basin-scale monitoring design, thermal exchange mechanisms and success of cold-water fish in the upper part of their thermal range (Poole, et al. 2001, Quantum Spatial Inc. 2017). Our initial question was whether thermal differences would be large enough to affect monitoring design and/or fish survival. This brief report summarizes the results of this effort, which we refer to hereafter as the '2014 Pilot'. Though 2014 temperature data and site characteristics were archived, they weren't included in prior monitoring reports. After 2014, we discontinued further monitoring toward this topic for reasons explained below.



Figure A. Monitoring reach for the 2014 Pilot Study, with paired sites noted in red. The wide stream with obvious light colored gravel bars is Finney Creek and the narrow white line is the lower Finney logging road. Quartz Creek joins Finney around 5 miles upstream from the Skagit confluence, located left of the map. The base layer is a 2015 digital orthophoto.

The 2014 Pilot monitored four large pools in a reach downstream of the Quartz Creek confluence (Figure A). Lower Finney is a large (bankfull width ~80 m), low gradient (~1%) alluvial stream where summer water temperatures frequently exceed 20 C (Kammer et al. 2020). All monitored pools were associated with large wood, two of which involved constructed log jams (Table A). In each pool, a pair of thermos was anchored at different depths on a single vertical rebar. The lower thermos were mounted 10 or 15 cm above the bed and upper thermos were placed approximately 30% below the water surface (details in Table A), which was deep enough to stay submerged through summer flow declines. All thermos operated between July 10 and September 29 of 2014, recording temperatures every 30 minutes. We placed temperature data into an Excel spreadsheet and calculated the descriptive statistics in Table A below.

Table A. Summary of sites and temperature metrics from summer 2014.

	Pool A	Pool B	Pool C	Pool D
Site information:				
Pool total depth (m)	1.3	1.3	1.4	1.7
Pool surface area (m x m)	33 x 10	9 x 4	65 x 12	43 x 12
Pool forming element(s)	ELJ	Root wad	Bank & log jam	ELJ
Vegetation canopy (%)	21%	48%	4%	52%
Upper therm elevation (m AB)	0.80	0.92	0.95	1.20
Lower therm elevation (m AB)	0.10	0.15	0.10	0.10
Temperatures:				
Seasonal maximum, upper therm (C)	23.26	23.47	22.99	23.47
Seasonal minimum, upper therm (C)	11.35	11.35	11.42	11.44
Difference UML mean (C)	-0.04	0.02	0.02	0.003
Difference UML maximum (C)	0.00	0.29	0.33	0.14
Difference UML minimum (C)	-0.07	-0.05	-0.05	-0.05
Temp. gradient, max difference (C/m)	-0.13	0.38	0.39	0.13
Temp. gradient, @ seasonal max (C/m)	-0.03	0.19	0.03	0.02
Abbreviations: Engineered log jam (ELJ), Above bed (AB), Upper minus lower (UML) temperature				

Results and Conclusions

- The monitoring period of the 2014 Pilot captured dates of summer maxima recorded at other nearby thermos. Peak water temperatures in 2014 were warmer than most summers monitored since 2008 (Kammer et al 2020 - Fig. 13).
- Monitored pools and temperature results are summarized in Table A above.
- The thermal range between monitored pools was modest. Seasonal maxima among upper thermos varied by 0.5 C (Table A). The range among minima was smaller, at 0.1 C.
- Temperature comparisons within most pools (B, C and D) typically found warmer readings at the upper (shallower) therm (Figure B). This directional difference was expected, based on previous studies attributed to solar warming of the water surface and upwelling of cool groundwater from the alluvial bed. In contrast, at Pool A, the upper therm was consistently cooler, which may reflect differing thermal processes or an instrument or data transfer error.

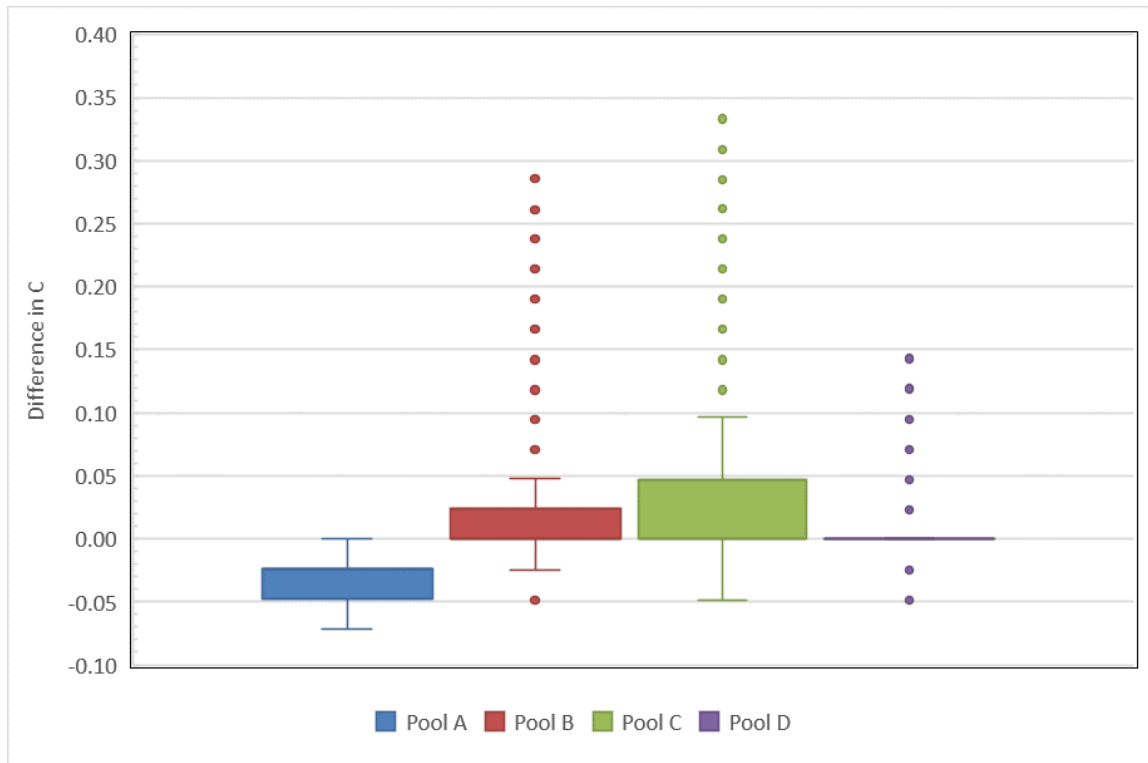


Figure B. Distribution of synchronous differences at sensor pairs (upper therm minus lower) during 2014 Pilot monitoring. Solid boxes indicate middle quartiles, dotted lines are outliers.

- Despite such complexities, temperatures at paired therms in each pool tracked very closely. Average differences among synchronous readings were between 0.02 C and -0.04 C. Most differences were considerably smaller than the stated precision of the instruments (± 0.2 C).
- We used coincidental temperature data to approximate thermal gradients by depth. Such gradients allowed crude extrapolation of total differences between the bed and water surface of each pool. Based on maximum differences in each pool, the total differences within a 2 m deep pool would be less than 1.0 C. Based on mean differences within paired therms, the typical difference would be around 0.1 C.
- These results suggest that vertical stratification in Finney Creek pools is less than other documented locations (e.g. Nielsen et al. 1994) and unlikely to affect fish substantially. This lack of strong stratification may result from the relatively shallow pools and/or large wood (evident in notes and ground photos), which together force water movement and turbulence that prevents stagnation in the pools.
- Based on these results, we discontinued monitoring of these pool sites after 2014. Instead, the SRSC monitoring project has deployed single therms across more streams to concentrate on differences between more streams dispersed across the study area (Kammer et al. 2020).

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