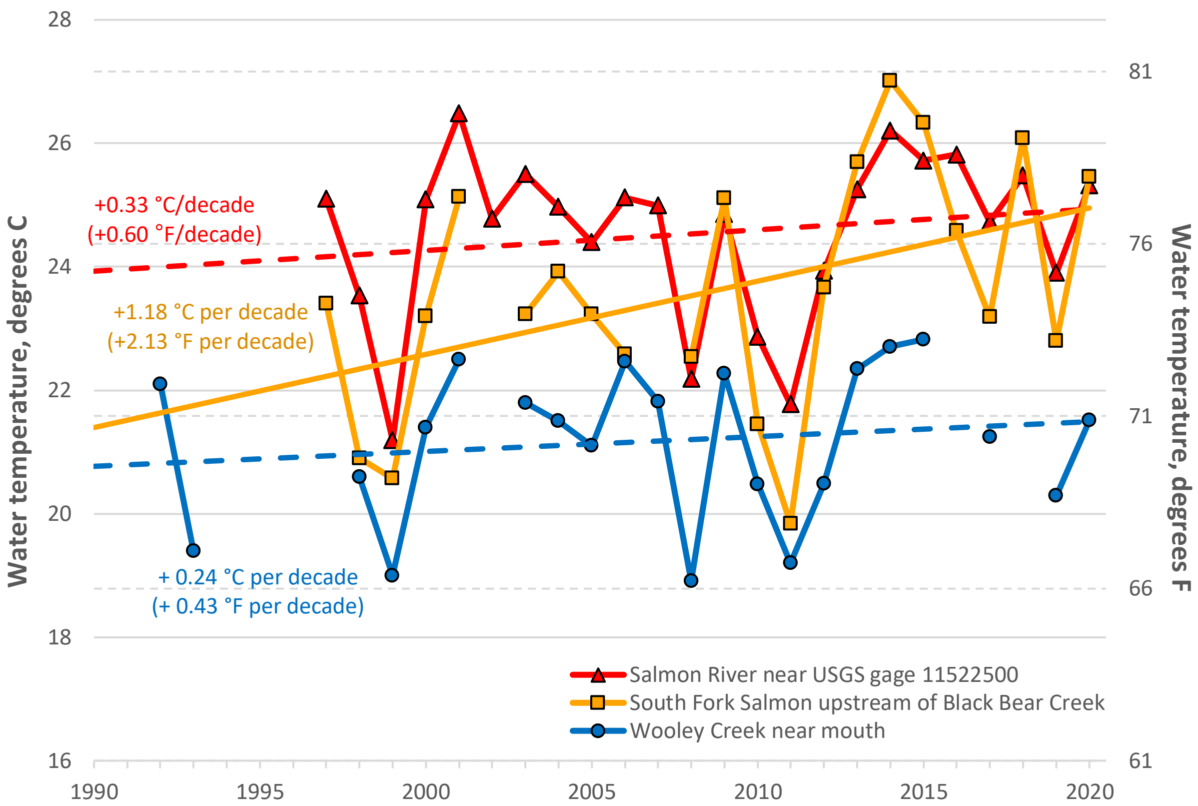
Salmon River water temperature

Water temperatures in the Salmon River and its tributaries have been warming, coincident with warming air temperatures and decreasing snowpack. The Salmon River watershed's relatively modest human influences make it an excellent location for tracking the effect of climate change.

Figure 1. Salmon River Water Temperatures* (1992-2020)



Source: Karuk Tribe, SRCC, and USFS 2021

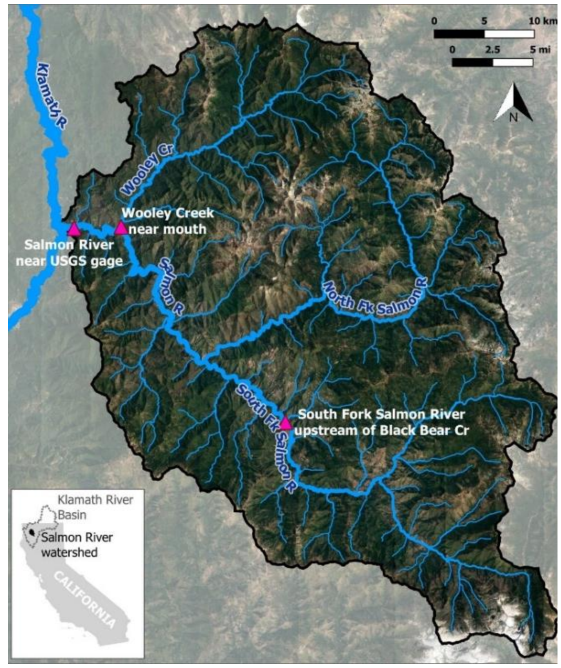
The value for each year is the* ***annual maximum temperature --* *i.e., the highest instantaneous maximum temperature--during the summer. Solid line denotes statistically significant trend ($p<0.05$).*

What does the indicator show?

From 1992 to 2020, water temperatures, measured as annual maximum temperature (AMT) at three sites in the Salmon River watershed (Figure 1) have been variable but trending higher. The Salmon River watershed is a 750-square mile sparsely populated area in Siskiyou County surrounded by subranges of the Klamath Mountains. Temperatures at the South Fork Salmon River site upstream from Black Bear Creek are increasing the fastest, with a rate of 2.13 degrees Fahrenheit (°F) per decade. Water temperatures at the Wooley Creek and Salmon River at US Geological Survey (USGS) gage stations are increasing more slowly, with rates of 0.60°F and 0.43°F per decade, respectively.

The three monitoring sites (shown in Figure 2) are a subset of many sites throughout the Salmon River and its tributaries where water temperatures are monitored. A previous analysis combined 27 long-term sites in the watershed to assess collective trends for the month of August during the period 1995-2017, finding that daily maximum temperatures warmed by 0.70°F per decade and daily mean temperatures warmed at a rate of 0.38°F per decade (Asarian et al. 2019). Years showing higher water temperatures generally coincided with low stream and river flows and high air temperatures; years reporting the lowest stream temperatures coincided with high flows and cool air temperatures (Asarian et al., 2019).

Figure 2. Location of three temperature monitoring sites in the Salmon River watershed



Source: Riverbend Sciences

Why is this indicator important?

Water temperature is a fundamental regulator of river ecosystems. It influences species' metabolism, growth rates, reproduction and distributions (David et al., 2018). The Salmon River watershed provides cold water habitat for anadromous fish, notably steelhead and Coho and Chinook salmon. Identified as a Key Watershed by the US Forest Service, it serves as refugia for at-risk salmon and steelhead stocks in the Pacific Northwest (Elder et al., 2002). This river system still retains wild runs of salmonid species that have disappeared from much of their historic range within California (SRRC, 2020).

Although the Salmon River (pictured in Figure 3) is still affected by the legacy of historic mining that began in the mid-19th century during the California Gold Rush, and some of the watershed's forests have been logged, today's relatively modest human influences make it an excellent location for tracking the effect of climate change on water temperatures (Asarian et al., 2019). The river has no dams and much less water is diverted for human uses in the Salmon River watershed than in other areas of California due to the area's low population density.

Warming summer water temperatures threaten the production and health of culturally and economically important fish in the Salmon River watershed (Asarian et al., 2019). Higher temperatures can increase metabolic demands, susceptibility to disease and pose a threat to fish populations, especially to spring-run Chinook salmon. Fish live in these habitats through the entire summer, and under current conditions peak summer temperatures in portions of the river and its tributaries are likely at or exceeding thermal suitability for this species. The year 2020 marks the second lowest number of returning spring Chinook since surveys began in 1990 and the sixth consecutive year that numbers have been below average (SRRC, 2020). The survival of the dwindling population of spring Chinook salmon, as well as Coho salmon, hangs in the balance. These fish are critical to the food security, cultural survival and well-being of the Karuk Tribe and other indigenous peoples in the Klamath Basin (Karuk Tribe, 2016).

The Karuk Tribe's Ancestral Territory occupies 60 percent of the Salmon River watershed, a sub-basin of the larger Klamath River Basin (Elder et al., 2002). The Karuk consider the Salmon River sub-basin as one of the most culturally significant watersheds within the Klamath National Forest. There is a strong commitment for cooperative stewardship of the watershed among local residents, the Salmon River Restoration Council (SRRC), the Karuk Tribe, the US Forest Service (USFS), and the California Department of Fish and Wildlife (CDFW) (Elder et al., 2002).

Figure 3. Salmon River

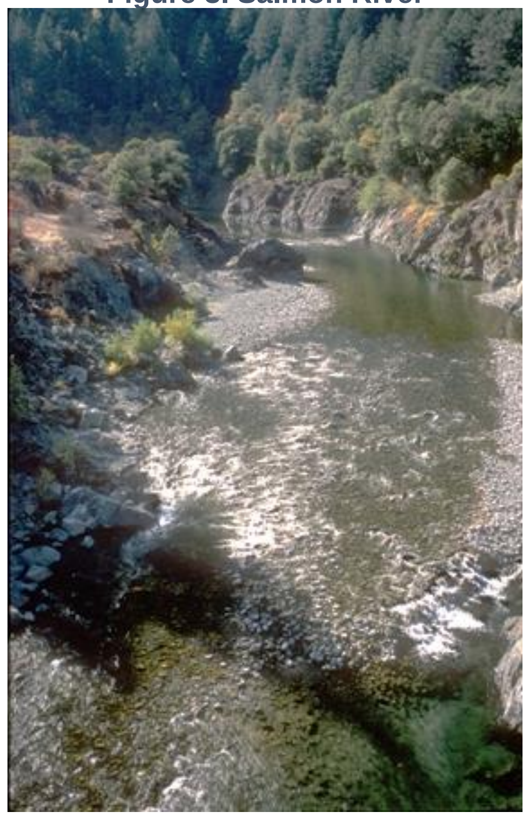


Photo Credit: USDA Forest Service

The Salmon River flows from the high peaks of the Salmon Mountains, a sub-range of the Klamath Mountains, in far Northern California. It is the second largest tributary to the Klamath River and joins the Klamath at Somes Bar, California, about 106 km (66 miles) upstream from the Pacific Ocean.

In 1994, the North Coast California Regional Water Quality Control Board and the US Environmental Protection Agency determined that beneficial uses in the Salmon River, including cold water salmonid fisheries, are impaired due to elevated water temperatures (NCRWQCB, 2005). Regulations intended to address those impairments were adopted in 2005. Coho salmon in the basin are state and federally listed as threatened (NCRWQCB, 2005). Spring Chinook salmon were listed as endangered by the State of California in June 2021 (Karuk Tribe, 2021) and are currently being considered for listing by the federal government (NMFS, 2021).

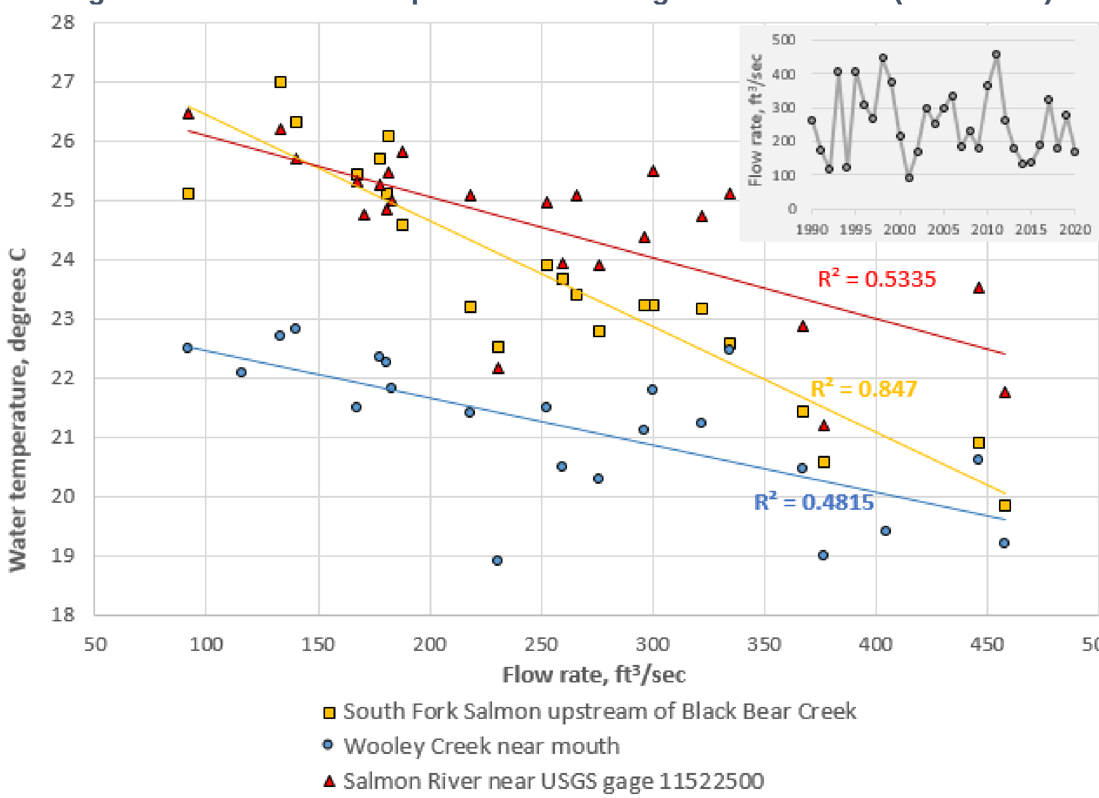
What factors influence this indicator?

Summer stream temperatures in the Salmon River and its tributaries are trending warmer due to warming air temperatures, decreased snowpack, earlier snowmelt and spring runoff, and decreases in water flow (Asarian et al., 2019). Years of low snowpack and snow water runoff tend to yield decreases in stream and river flow in watersheds

(Asarian, 2020). Since the 1940s, April 1 snowpack has been decreasing in the Salmon River watershed (CDEC, 2021; Van Kirk and Naman, 2008). Since summer river flow is strongly influenced by snowpack, temperatures at the South Fork Salmon River site are particularly sensitive to climate change and have warmed relatively rapidly since monitoring began in 1997. Water temperature has been increasing at the highest rate at this location (Figure 1).

Streamflow is an important determinant of water temperature. River and stream temperatures are cooler when flows are high and warmer during years with diminished flows. Figure 4 shows the relationship between stream flow rates during the month of August at the Salmon River monitoring station and maximum temperatures at the three stations shown in Figure 1. Low August flow rates coincided with warmer stream temperatures in 2001, 2014, and 2015. Conversely, higher flow rates in 1999, 2010, and 2011 corresponded with much cooler stream temperatures during those years.

Figure 4. River water temperatures and August stream flow (1992-2020)



Source: Karuk Tribe, SRCC, and USFS 2021 (water temperatures); USGS 2021 (streamflow)

Annual maximum water temperatures at the three monitoring sites are plotted against average August streamflow measured at the Salmon River monitoring station (at Somes Bar, USGS Gage 11522500). (R^2 values indicate the strength of the correlation; a value of 1 indicates a perfect correlation between the variables.) The inset graph presents annual average August streamflow over the past 30 years.

A symptom of warmer temperatures and less snow is the complete melting of the Salmon Glacier in the Trinity Alps at the headwaters of the Salmon River's South Fork in 2015 following a multi-year drought and many decades of ice loss (Garwood et al., 2020; also see *Glacier change* indicator). The nearby Grizzly Glacier which drains to the Trinity River has declined by 97 percent since 1885. When these glaciers were larger in previous decades, they fed cold water to streams during the summer.

A number of other physical factors influence water temperatures in streams and rivers, including solar radiation, heat radiated from objects (e.g., clouds and vegetation), evaporation, convection of heat from air to water, conduction of heat between the water and stream bed, and mixing of water from different sources (Dugdale et al., 2017). During the summer, water temperatures in streams and rivers with wider channels that are more exposed to solar radiation tend to be warmer than water upstream in small well-shaded streams. Water temperatures fluctuate over time in response to atmospheric conditions (air temperatures, clouds, and smoke), hydrologic conditions (snowmelt, rain, stream flow, and groundwater), and growth or loss of vegetation. Factors affecting spatial patterns in water temperature include elevation (cooler air temperatures at higher elevations), topography (mountainous terrain reduces solar exposure), and near-stream vegetation (cooler temperatures where trees provide shade). Wooley Creek flows through steep, mountainous terrain, which partially protects it from solar radiation and keeps its waters relatively cool for its size. As shown in Figure 1, temperatures are increasing at a slower rate at Wooley Creek due to these characteristic features.

Shade provided by near-stream vegetation has the effect of cooling water temperatures. Fire plays an integral role in regulating vegetation in the Salmon River watershed. Prior to fire suppression that became effective in the early/mid-20th century, fires burned more frequently and typically in smaller patches compared to what is occurring today (Skinner et al., 2018). Approximately a century of fire suppression has dramatically altered forest structure and fuel continuity. As a result, when fires now occur and escape containment, the probability of high fire severity is increased, which can reduce stream shade and increase water temperature (Karuk Tribe, 2016).

Researchers have been studying the effects of wildfire smoke and its potential to cool water temperatures. David et al. (2018) analyzed ground-based measurements of air and water temperatures from 12 stations throughout the lower Klamath River Basin in correlation with atmospheric smoke data derived from satellite imagery during six years with widespread wildfires. The analysis indicated that wildfire smoke had a cooling effect on both air and water temperatures at all study locations. This smoke-induced cooling has the potential to benefit cold-water adapted species, particularly because wildfires are more likely to occur during the warmest and driest years and seasons. A follow-up analysis of a larger number of stations showed the cooling effects of smoke were greater in August than in other months and were stronger in larger waterbodies than smaller waterbodies (Asarian et al., 2020). Wildfire smoke has limited increases in August water temperatures, but has not affected annual maximum water temperatures because in most years fires do not start until after the year's hottest water temperatures have already occurred. The Karuk Tribe has used fire to manage the mid-Klamath landscape since time immemorial, and has proposed using prescribed fire smoke as an emergency measure to cool potentially lethal stream temperatures in fish habitat areas (Karuk Tribe, 2019).

Researchers conducted an analysis of both climate and non-climate factors and their comparative influence on August stream temperatures using statistical models (Asarian et al., 2019). The climate parameters evaluated were streamflow, air temperature, snowpack, and smoke; the non-climate parameters included landscape features such as riparian vegetation and river channel morphology. The results of the analysis indicated that the warming stream temperatures observed across the Salmon River watershed are largely attributed to climate conditions. The greatest amount of warming occurred at sites whose temperatures are highly sensitive to river flow, including the South Fork of the Salmon River.

Technical considerations

Data characteristics

The Salmon River Restoration Council (SRRC); the Karuk Tribe; and US Forest Service (USFS) [Klamath National Forest (KNF) and Six Rivers National Forest (SRNF)] have been monitoring water temperatures in the Salmon River Watershed since 1990 using automated probes that record measurements every 15–60 minutes. Probes are placed in well-mixed flowing water and are intended to represent overall conditions (i.e., "stream temperature"), not isolated pockets of cold or warm water. At most sites, probes are deployed in late spring or early summer, remain through the summer, and are retrieved in the fall for data download (KNF, 2011). A few sites are monitored year-round.

Sampling and equipment and monitoring techniques have changed since monitoring began in 1992. Prior to 2010, the KNF, SRNF, and SRRC used a combination of Pro v2 u22-001, Optic StowAway, and other ONSET temperature logger models (Onset Computer Corporation, 1999). Ryan TempMentors data loggers were used only by KNF in 1992–1993 at Wooley Creek (TFWTWG, 1990). At the Salmon River gage, the Karuk Tribe used a Hydrolab 4a for 2005–2006 and a YSI 6600 V2 datasonde for 2007 to present (Karuk Tribe 2006, 2007, 2018). Since 2010, KNF, SRNF, and SRRC have used ONSET Pro v2 data logger u22-001 for all temperature monitoring (KNF, 2011).

Although many sites are monitored, a subset of three sites that have long, relatively complete records were selected for this indicator:

1) Salmon River at USGS gage 11522500, approximately 1 mile upstream from its confluence with the Klamath River. In addition to the seasonal temperature probes placed by the USFS at this site, the Karuk Tribe also operates a

permanent monitoring station here that provides year-round multi-parameter water quality data available online in real-time at: https://waterquality.karuk.us/Data/Location/Summary/Location/11522500

2) Wooley Creek, approximately 0.3 miles upstream from its confluence with the Salmon River. Wooley Creek is one the Salmon River's largest tributaries and its watershed is entirely protected within the Marble Mountain Wilderness, so human impacts are slight.

3) South Fork Salmon River upstream of Black Bear Creek. Long-term data analyses (Asarian et al., 2020) show that water temperatures at this site are highly sensitive to river flow, with temperatures being cool in high-flow years and warm in low-flow drought years.

Strengths and limitations of the data

There are many ways to summarize stream temperature data, and previous Salmon River analyses (Asarian et al., 2019, 2020) evaluated trends for multiple metrics of summer stream temperature. For this indicator, annual maximum temperature is the highest instantaneous maximum temperature recorded during the summer. This metric was chosen because it is simple to calculate, easy to understand, and biologically meaningful. This metric was calculated only for sites and years when there were enough data to be representative (i.e., complete measurements available during the hottest period of the summer) (Asarian et al., 2020). Equipment and techniques for monitoring these sites have improved over time.

Figure 1 shows data gaps for certain years at the Wooley Creek and South Fork monitoring sites. Reasons for data gaps include logistical constraints preventing site access (e.g., fires or staffing shortages), probes malfunctioning, loss of probes due to vandalism, or low water levels exposing probes to air.

OEHHA acknowledges the expert contribution of the following to this report:

Eli Asarian
Riverbend Sciences
(707) 832-4206
eli@riverbendsci.com

Bonnie Bennett
Lyra Cressey
Salmon River Restoration Council
(530) 462-4665
bonnie@srrc.org;
lyra@srrc.org

Grant Johnson
Karuk Tribe
gjohnson@karuk.us

LeRoy Cyr
Six Rivers National Forest
(530) 627-3262
leroy.cyr@usda.gov

Jon Grunbaum
Klamath National Forest
(530) 493-1719
jon.grunbaum@usda.gov

The Klamath Tribal Water Quality Consortium (Karuk Tribe, Yurok Tribe, Hoopa Valley Tribe, Quartz Valley Indian Reservation, and Resighini Rancheria) funded the development of this indicator using resources provided by US EPA Region 9.

OEHHA respects the right of tribal nations to govern the collection, ownership, and application of their data. The Karuk Tribe has given OEHHA permission to use the water temperature data and related information presented in this indicator.

References:

Asarian JE, Cressey L, Bennett B, Grunbaum J, Cyr L, et al. (2019). *Evidence of Climate-Driven Increases in Salmon River Water Temperatures*. Prepared for the Salmon River Restoration Council by Riverbend Sciences with assistance from the Salmon River Restoration Council, Klamath National Forest, Six Rivers National Forest, and Karuk Tribe Department of Natural Resources. 53 p.+ appendices.

Asarian JE, Cressey L, Bennett B, Grunbaum J, Cyr L, et al. (2020). *Influence of Snowpack, Streamflow, Air Temperature, and Wildfire Smoke on Klamath Basin Stream Temperatures, 1995-2017*. Prepared for the Klamath Tribal Water Quality Consortium by Riverbend Sciences with assistance from the Salmon River Restoration Council, Klamath National Forest, Six Rivers National Forest, Karuk Tribe Department of Natural Resources, and Quartz Valley Indian Reservation. 44p. + appendices.

CDEC (2021). California Data Exchange Center. Query Tools: Current and Historical Data, Historical Data Selector. California Department of Water Resources. Queried monthly snow water content for stations Dynamite Meadow, Etna, Middle Boulder 1, Middle Boulder 3, Swampy John, and Wolford, July 7, 2021.

CDFW (2020). California Department of Fish and Wildlife. California Endangered Species Act Status Review for Upper Klamath and Trinity Rivers Spring Chinook Salmon (*Oncorhynchus tshawytscha*). State of California, Natural Resources Agency, Department of Fish and Wildlife, Sacramento, CA.

David AT, Asarian JE and Lake FK (2018). Wildfire smoke cools summer river and stream water temperatures. *Water Resources Research* **54**(10): 7273-7290.

Dugdale, SJ, Hannah, DM and Malcolm IA. (2017). River temperature modelling: A review of process-based approaches and future directions. *Earth-science Reviews* **175**: 97–113.

Elder D, Olson B, Olson A and Villeponteaux J (2002*). Salmon River Sub-basin Restoration Strategy: Steps to Recovery and Conservation of Aquatic Resources: Report for the Klamath River Basin Fisheries Restoration Task Force, Interagency Agreement 14-16-0001-90532*. USDA-Forest Service, Klamath National Forest, Yreka, Klamath National Forest and Salmon River Restoration Council, Sawyers Bar, CA. September 2002: 52 pp.

Garwood JM, Fountain AG, Lindke KT, van Hattem MG, and Basagic HJ (2020). 20th Century Retreat and Recent Drought Accelerated Extinction of Mountain Glaciers and Perennial Snowfields in the Trinity Alps, California. *Northwest Science* **94**(1): 44-61.

Karuk Tribe (2006). Water Quality Assessment Report 2006. Karuk Tribe Department of Natural Resources, Orleans, CA. 52 p.

Karuk Tribe (2007). Water Quality Assessment Report 2007. Karuk Tribe Department of Natural Resources, Orleans, CA. 64 pp.

Karuk Tribe (2016). *Karuk Tribe Climate Vulnerability Assessment: Assessing Vulnerabilities from the Increased Frequency of High Severity Fire*. Karuk Tribe Department of Natural Resources. Compiled by Dr. Kari Marie Norgaard with key input from Kirsten Vinyeta, Leaf Hillman, Bill Tripp and Dr. Frank Lake.

Karuk Tribe (2018). 2018 Quality Assurance Project Plan for Water Quality Sampling and Analysis, CWA 106 grant identification # BG-97991217. Karuk Tribe Department of Natural Resources, Orleans, CA. 64pp.

Karuk Tribe (2019). Karuk Climate Adaptation Plan. Karuk Tribe Department of Natural Resources. March 2019.

Karuk Tribe (2021). Press release: Karuk Tribe Petitions California Water Board to Regulate Scott Valley Water Users. *Tribe calls on agency to use emergency powers to prevent extinction* (July 1, 2021).

KNF (2011) Klamath National Forest. *Klamath National Forest, Water and Air Temperature Monitoring Protocol.* May 2011.

NCRWQCB (2005). North Coast Regional Water Quality Control Board. Salmon River, Siskiyou County, California Total Maximum Daily Load for Temperature and Implementation Plan Adopted June 22, 2005, NCRWQCB Resolution No. R1-2005-0058. Prepared by North Coast Regional Water Quality Control Board, Santa Rosa, California.

NMFS (2021). National Marine Fisheries Service. Endangered and Threatened Wildlife, 90-Day Finding on a Petition To List Southern Oregon and Northern California Coastal Spring-Run Chinook Salmon as Threatened or Endangered Under the Endangered Species Act. 86 FR 14407.

Onset Computer Corporation (1999). StowAway® XTI User's Manual. Onset Computer Corporation, Bourne, MA.

Skinner CN, Taylor AH, Agee JK, Briles CE and Whitlock CL (2018). Chapter Eleven. Klamath Mountains Bioregion. In Fire in California's Ecosystems (pp. 171–194). University of California Press.

SRRC (2020) Salmon River Restoration Council. Brochure supported by the California Department of Fish and Wildlife Fisheries Restoration Grant Program.

TFWTWG (1990). Timber Fish/Wildlife Temperature Work Group. Evaluation of prediction models and characterization of stream temperature regimes in Washington, TFW-WQ3-90-006. Prepared for the TFW/CMER Water Quality Steering Committee and Washington Department of Natural Resources Forest Regulation and Assistance, Olympia, Washington.

Van Kirk RW and Naman SW (2008). Relative Effects of Climate and Water Use on Base-Flow Trends in the Lower Klamath Basin. *Journal of the American Water Resources Association* **44**(4): 1035–1052.