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Guidelines for Handling and Sampling Adult Salmon during Periods of Elevated Water Temperatures in Alaska Rivers

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Cover Photo: Salmon in the East Fork of the Andreafsky River, Alaska. Photo courtesy of Ryan Haggerty, NCTC.

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Abstract

Water temperature is an important hydrological parameter that influences spawning success in Pacific salmon *Oncorhynchus* spp. Suboptimal water temperatures can elicit behavioral and (or) physiological stress responses that have the potential to impact the fitness of spawning stocks. The Environmental Protection Agency (EPA) has identified critical temperature thresholds known to have sublethal and lethal effects on adult Pacific salmon returning to spawn. Water temperatures near or exceeding these sublethal thresholds have recently been recorded within the Yukon River and its tributaries. The duration and intensity of exposure to stressful environments, such as elevated water temperatures, influences individual survival. There is increasing concern among managers and researchers that sampling adult salmon during periods of elevated water temperatures may negatively affect the survival of salmon preparing to spawn. This document provides guidelines for handling adult salmon when sampling during periods of elevated water temperatures. The goal of these guidelines is to minimize the cumulative impacts of handling and heat stress on adult salmon preparing to spawn.

Introduction

Elevated water temperatures have direct effects on the health, reproductive success, and survival of Pacific salmon *Oncorhynchus* spp. Salmonids are poikilotherms whose internal temperature is regulated by ambient environmental temperature (McCullough et al. 2001; Keefer et al. 2018). As a result, suboptimal water temperatures can have sublethal and lethal effects during every life history stage (McCullough 1999; McCullough et al. 2001; Richter and Kolmes 2005; Hinch et al. 2012). These effects include changes in physiology and energy allocation (Bowerman et al. 2017), migration timing and behavior (Goniea et al. 2006; Hinch et al. 2012; Keefer et al. 2018), egg development and emergence (Myrick and Cech 2001; Marine and Cech 2004; Geist et al. 2006), reproductive success (Keefer et al. 2008, 2010; Bowerman et al. 2018), and disease resistance (Fryer and Pilcher 1974; Benda et al. 2015). Although the effects of elevated water temperatures clearly impact every stage of the Pacific salmon life cycle, this document focuses on the impact of elevated water temperature on adult salmon during their upstream migration to reach freshwater spawning grounds.

Water temperatures between 17°C and 25°C have been identified as having adverse effects on adult Pacific salmon (reviewed in McCullough 1999, in Richter and Kolmes 2005; and in Hinch et al. 2012). More specifically, a water quality temperature synthesis released by the Environmental Protection Agency (EPA 2003) identified that (1) water temperatures between 17°C and 18°C reduced migration fitness; (2) water temperatures >20°C reduced swimming performance; and (3) water temperatures >21 or 22°C delayed and (or) blocked migration. Elevated rates of mortality have been documented in water temperatures >18°C (Crossin et al.

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2008; Jefferies et al. 2014), with near immediate mortality reported at water temperatures ≥25°C (Brett 1952, cited in McCullough 1999).

Water temperatures within or exceeding ranges identified as thermal barriers to migration (i.e., >21 or 22°C) are routinely observed in areas of the Pacific Northwest (PNW; Goniea et al. 2006; Strange 2010; Keefer et al. 2015, 2018), British Columbia (Macdonald et al. 2000; Farrell et al. 2008; Martins et al. 2012), and Alaska (Leba 2011; Mears and Morella 2017; Carlson and Edwards 2017). Within these areas, elevated temperatures have been attributed to delayed migration rates (Goniea et al. 2006; Keefer et al. 2018), elevated heat shock protein (HSP70) levels (von Biela et al., *In prep*), and excessive mortality rates during upstream spawning migrations (i.e., en route mortality) or upon arrival at spawning grounds before spawning can occur (i.e., prespawn mortality; Macdonald et al. 2000; Keefer et al. 2010; Bowerman et al. 2016). Warmer water temperatures are being observed in rivers and streams throughout the contiguous United States (Mantua et al. 2010; Isaak et al. 2012) and Alaska (Mauger et al. 2017). This poses a significant threat that is expected to continue impacting the ecology, distribution, and survival of salmon stocks throughout their range (Lynch et al. 2016).

There is an increasing concern among managers and researchers about the impacts of elevated water temperatures on the vitality of salmon populations in Alaska (ADF&G 2013; Schindler et al. 2013). Recently, a controlled study examined HSP70 levels and gene activity in Yukon River Chinook Salmon *Oncorhynchus tshawytscha* held at 15, 18, and 21°C. The results from this study illustrated clear differences in gene activity of fish held at 21°C when compared to fish held at 15 and 18°C (von Biela et al., *In prep*). In a comparative study, Yukon River Chinook Salmon sampled during upstream spawning migrations in elevated water temperatures (i.e., >18°C) had higher HSP70 levels than Yukon River Chinook Salmon sampled in cooler temperatures (i.e., <18°C). This is thought to be indicative of thermal stress (von Biela et al., *In prep*). Further, unprecedented numbers of premature spawning mortalities were reported for summer Chum Salmon *Oncorhynchus keta* during periods of elevated water temperatures in 2019 within the Yukon and Kuskokwim drainages (J. Conitz, USFWS, pers. com.; Stephanie Quinn-Davidson, Tanana Chiefs Conference, pers. com.).

The U.S. Fish and Wildlife Service (USFWS) is tasked with managing and conserving Alaska's trust resources to maintain the viability of fish and wildlife populations and provide subsistence opportunities for resource users (ANILCA 1980; Yukon River Salmon Act 2000). As part of this ongoing effort, the USFWS Fairbanks Fish and Wildlife Conservation Office (FFWCO) oversees several escapement monitoring projects within the Yukon River drainage to help inform the management of Chinook Salmon and Chum Salmon (Carlson and Edwards 2017; Conitz 2019). Similar sampling and research programs, designed to monitor one or several specific salmon species of interest, are operated by state and federal agencies and native organizations throughout Alaska (e.g., McKenna 2014; Lescanec 2017; Head and Smith 2018). At many of these projects, fish are non-lethally handled and sampled for age, sex, length, or other specified data. These data collection events are necessary to characterize the demographics of spawning populations and ultimately contribute to further understanding of long-term demographic trends and variability between spawning stocks and among Pacific salmon species (Lewis et al. 2015; Brown et al., *In review*). However, handling when sampling can elicit both physiological and behavior stress responses in fish (EPA 2003) that may become increasingly lethal when it coincides with warmer temperatures.

In response to concerns that sampling fish during periods of elevated water temperatures may further compromise the fitness of adult salmonids preparing to spawn, FFWCO staff developed guidelines to help biologists and technicians identify water temperatures during which handling of adult salmon should be avoided. We recommend these guidelines be used by projects in Alaska that non-lethally handle adult salmon during their upstream migration to avoid subjecting sampled fish to additional stress.

Objectives

The overarching goal of these guidelines is to minimize the amount of time adult salmon are exposed to multiple stressors (i.e., elevated water temperatures during handling). To achieve this goal, the following objectives were established for these sampling guidelines:

1. Identify critical water temperature thresholds that may negatively impact fitness, swimming performance, and (or) survival of salmon.
2. Characterize specific actions to take when critical water temperature thresholds have been reached.
3. Specify baseline water temperature thresholds that must be met before standard operating procedures (SOPs) for sampling can resume.

Methods and Results

Data sources

A combination of sources were used to develop a set of guidelines for handling adult salmon during periods of elevated water temperatures in Alaska rivers. These sources included literature reviews, empirical evidence, published research, and expert opinion.

Data Logger

Thermometers are generally classified as one of two types: (1) liquid-in-glass or (2) electronic thermistor. Both types are recommended for field use, with the exception of mercury-filled thermometers (Radtke et al. 2004). We encourage projects to select data loggers accurate to ±0.25°C as recommended by several water temperature monitoring protocols (Dunham et al. 2005; Toohey et al. 2014; Mauger et al. 2015). However, we recognize that costs or design aspects associated with this level of accuracy may be limiting for some projects (Conitz 2019). Therefore, we recommend a minimum data logger accuracy of ±0.5°C in an effort to maximize the number of cost-effective, flexible options for projects whose main goal is not water temperature data collection. Further, this accuracy meets the EPA's best practices for monitoring water temperatures (EPA 2014).

Data loggers should be calibrated on an annual basis prior to being deployed in the field (Dunham et al. 2005; Toohey et al. 2014; Mauger et al. 2015). A specific calibration thermometer (i.e., either National Institute of Standards and Technology (NIST) certified or manufacturer-certified as NIST traceable) should be used as a calibration standard in the laboratory (Dunham et al. 2005; Toohey et al. 2014; Mauger et al. 2015), and not for field use (Radtke et al. 2004). It is recommended that data loggers are calibrated using a 4-point calibration (e.g., 0, 10, 20, and 30°C) that encompass a range of temperatures expected to be observed at the sampling site (Mauger et al. 2015). Data logger water temperature measurements should be within 0.5°C of the NIST thermometer for at least three measurements (EPA 2014). If a logger is unable to meet these standards, it should not be used. Several detailed calibration protocols are available for further reference (Radtke et al. 2004; EPA 2014).

Finally, we recommend every project have a minimum of two back-up thermometers which will allow water temperature to be recorded even if the main logger becomes damaged or malfunctions.

Site Selection

Water temperature measurements at salmon projects should represent the mean temperature at the sample site. For projects that have yet to establish a specific sampling site (or are sampling at multiple sites), there are several detailed protocols that summarize the necessary steps to ensure proper site selection (Wagner et al. 2006; EPA 2014; Toohey et al. 2014; Mauger et al. 2015). Ideally, water temperature measurements used to inform sampling regimes should occur at or near the sampling and handling areas.

Water Temperature Monitoring

We recommend that projects monitor water temperature in two ways. First, monitor water temperatures at specified time intervals to inform real-time sampling decisions (in season). Second, long-term assessment projects (e.g., weir projects) should deploy in-river data loggers in an effort to collect high quality, standardized water temperature data that can be archived in regional and (or) national databases (Mauger et al. 2015; data logger). This recommendation meets both immediate operational goals as well as providing data to inform longer-term conservation and monitoring efforts.

Water temperature monitoring – In Season

During periods of 'optimal' stream temperatures (i.e., <16°C), we recommend a 4-hour water temperature sampling interval. However, if any water temperature reading is ≥16°C, then begin one-hour measurement intervals until hourly water temperature (HWT) readings are <16°C for four consecutive hours. The water temperature instrument should be submerged for no less than 60 seconds prior to recording temperature. Temperature readings should be recorded in a water-proof notebook before being transferred to a computer spreadsheet.

An initial 4-hour water temperature sampling interval is recommended because qualitative comparisons between hourly measurements and twice-daily temperature readings (0800 and 2000 hours, respectively) indicated 12-hour measurement intervals underestimated the number of hours in a 24-hour period during which temperatures were ≥17°C (Conitz 2019). Although the error rates and biases associated with 4-hour sampling intervals are not recommended for comprehensive stream temperature data collection efforts (Dunham et al. 2005; Mauger et al. 2015), we believe this sampling interval is appropriate for the sole purpose of determining whether water temperatures are approaching critical thresholds for handling salmon. As water temperatures approach critical thresholds, measurements and subsequent calculations should be more precise to not only minimize the potential for sublethal or lethal effects to adult salmon but to maximize valuable data collection efforts. One-hour temperature measurements enable more accurate daily mean water temperature (DMWT) calculations and ensure the probability of missing the true daily maximum temperature by more than 1°C is <1% (Dunham et al. 2005).

The two measurement intervals recommended in these guidelines ensure that monitoring during optimal water temperatures does not pose an unnecessary burden for projects whose primary goal is to non-lethally count and sample adult salmon, while allowing temperature thresholds to be precisely identified during potential sub-lethal or lethal conditions. However, these water temperature data should not be used as a proxy for continuous, standardized stream temperature monitoring data.

Water temperature monitoring – Data Logger

We recommend that long-term assessment projects (e.g., weirs, fish wheels, etc.) also deploy in-river data loggers at project sites that meet the minimum standards described by Mauger et al. (2015). This ensures that standardized, high quality water temperature data are collected and made available for post season analysis. These data should then be submitted to regional and (or) national databases for future research and monitoring efforts.

Water Temperature Thresholds – Suspend Sampling

Suspending salmon sampling activity is recommended when these critical temperature thresholds have been met: (1) DMWT readings are ≥17°C for three consecutive days; or (2) an HWT reading of ≥20°C. These thresholds are based on temperatures identified by the EPA (2003) as having negative impacts on fitness, migration, and swimming performance of salmon. Negative physiological responses caused by stressful environments become increasingly lethal to fish over time with continuous exposure (Barton 2002). As a result, mean daily and weekly temperature values—not single daily temperature readings—better reflect behavioral responses to elevated temperatures (Strange 2010).

A third critical temperature threshold is recommended specifically for projects that require seasonal in-water structures (e.g., picket weir, resistance-board weir, etc.) that direct fish passage to limited sections of a stream. If DMWT is ≥20°C for more than three consecutive days, structures that impede fish migration should be modified (e.g., remove a select number of weir panels, open weir trap, etc.) to facilitate unobstructed and rapid upstream movement. These temperature thresholds are summarized in Table 1.

Water Temperature Thresholds – Resume Sampling

Temperature thresholds during which we recommend that sampling activities should be resumed are: (1) DMWT <17°C for one day; and (2) HWT readings <17°C for four consecutive hours. Both of these thresholds should be met before sampling resumes to account for extreme daily temperature fluctuations (e.g., >16°C), which can occur in smaller streams (Dunham et al. 2005; Mauger et al. 2017) and less extreme daily fluctuations (e.g., <4°C) generally observed in larger systems (Contiz 2019). For projects that have in-water structures, structures can be modified back to their original design once DMWT is <17°C for one day.

Carcass-Based Mortality Estimates

For all projects that elect to adopt these guidelines into their standard sampling practices, we also recommend conducting annual carcass-based mortality estimates at project sites, regardless of water temperature. These estimates will help to establish a benchmark from which to evaluate changes in the rates of premature (i.e., prespawn and (or) en route) mortality. Establishing this benchmark is critical to inform how elevated water temperatures impact the magnitude of premature mortality observed in Alaska rivers. We recognize mortality estimates might not be feasible for all projects. However, carcass-based mortality estimates are well suited for projects where dead or moribund fish are routinely observed near sampling sites (e.g., washed up on weir panels; Bowerman et al. 2016). For projects that encounter multiple salmon species (hence, carcasses of multiple species), we suggest prioritizing which carcasses to examine for signs of premature mortality based on project-specific goals and objectives. This may be especially important for projects that experience high volumes of one (or more) salmon species that are considered a low management priority (e.g., Pink Salmon *Oncorhynchus gorbuscha*) in some areas.

Table 1. Summary of water temperature thresholds and corresponding actions. SPT = Single-point temperature measurements. DMWT = daily mean water temperature.

Threshold	Action
<16°C (SPM)	Take water temperature readings at 4-hour intervals.
≥16°C (SPM)	Take hourly temperature readings. Calculate DMWT upon completion of each day. *Resume taking water temperature readings at 4-hour intervals when hourly measurements are <16°C for four consecutive hours.*
≥17°C DMWT for 3 consecutive days	**NO HANDLING OR SAMPLING** *Resume once DMWT <17°C for 1 day.* When feasible, monitor carcasses for incidences of prespawn mortality. Assess carcasses of all salmon species <u>except pinks</u>. Internally inspect each carcass for signs of prespawn mortality (i.e., unspent gametes). Record: species, sex, whether pre- or post-spawn, and collect ASL (age, sex, length) data. *Continue evaluating carcasses regardless of temperature until the last day of project operation.*  Postspawn (<100 eggs)  Prespawn (>100 eggs)
≥20°C hourly water temperature measurement	**NO HANDLING OR SAMPLING** *Resume sampling if hourly water temperature measurement is <17°C for four consecutive hours* <u>*and*</u> *DMWT is <17°C for 1 day.* When feasible, monitor carcasses for incidences of prespawn mortality. Assess carcasses of all salmon species <u>except pinks</u>. Internally inspect each carcass for signs of prespawn mortality (i.e., unspent gametes). Record: species, sex, whether pre- or post-spawned, and collect ASL (age, sex, length) data. *Continue evaluating carcasses regardless of temperature until the last day of project operation.*
≥20°C DMWT for 3 consecutive days	**Modify structure to allow for more rapid passage.** *Re-install structure once DMWT <17°C for 1 day.*

Each observed carcass of a target species that can be safely retrieved should be examined. For each carcass examined, the following data should be recorded: date, time, location, species, sex, fork length (FL), and condition (e.g., signs of physical injury). In addition, 1 scale (Chum Salmon, Sockeye Salmon *Oncorhynchus nerka*, or Coho Salmon *Oncorhynchus kisutch*) or 3 scales (Chinook Salmon) should be collected from carcasses to maximize age, sex, and length (ASL) data collection efforts. However, we recommend only female carcasses be categorized as pre- or post-spawned. Differentiating between pre- and post-spawn male fish is more difficult because males may spawn multiple times or not at all (Scholz et al. 2011). In addition, heat stress mortality disproportionately affects females (Crossin et al. 2008; Keefer et al. 2010; Jeffries et al. 2014). A female fish should be characterized as post-spawn if there are <100 eggs in the body cavity upon internal inspection (Figure 1A); if there are >100 eggs in the body cavity, a fish should be characterized as prespawn (Figure 1B; Quinn et al. 2007). Monitor and sample carcasses until the last day of project operations because rates of premature mortality have been shown to be highly variable throughout the spawning season (Bowerman et al. 2016). Although there are recognized biases and limitations associated with carcass-based premature spawning mortality data (reviewed in Bowerman et al. 2016), these collection efforts will help to quantify mortality and assess the possibility that escapement is overestimated when water temperatures are elevated.

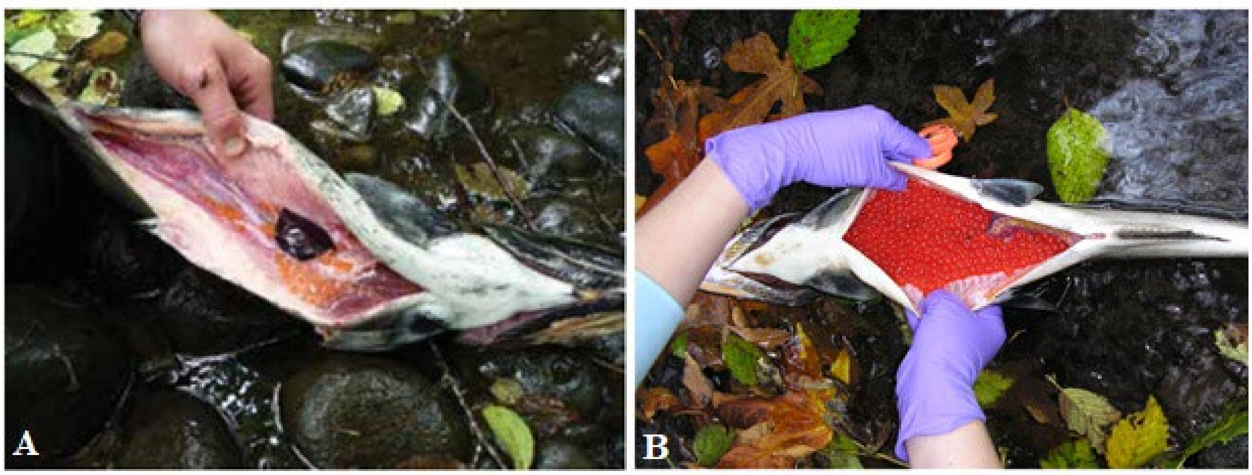

Figure 1. Examples of (A) a fully spawned salmon carcass with only a few eggs remaining in the body cavity, and (B) a carcass with 100% egg retention that should be categorized as prespawn mortality. Images from Bowerman et al. 2016 and Scholz et al. 2011, respectively.

Conclusions

In an effort to limit the stress experienced by adult salmon during their upstream migration, critical temperature thresholds were identified during which we recommend projects that non-lethally handle adult salmon suspend sampling efforts. Sampling during periods of elevated water temperatures increases the risk of mortality. Because the goal of the USFWS is to preserve and protect fish and wildlife populations, minimizing the impact of sampling is a key objective in monitoring the health of Alaska salmon stocks. We encourage projects with similar objectives to use these guidelines as they develop and implement their sampling regimes. Ultimately, these guidelines aim to find a balance between fish health and critical data collection needs that inform short- and long-term management actions.

The temperature thresholds recommended in these guidelines were informed by peer-reviewed research and empirical evidence. However, they should be considered conservative estimates that will likely have varying degrees of impact on different species and populations (Crozier et al. 2006; Lisi et al. 2013; Kovach et al. 2015). For example, Chinook Salmon have been documented migrating successfully in water temperatures ≥23°C within the Columbia and Willamette rivers (Goniea et al. 2006; Strange 2010; Keefer et al. 2015). In contrast, prolonged exposure to water temperatures between 17°C and 18°C was attributed to the en route and prespawn mortality of over 3.3 million Sockeye Salmon in the Fraser River, British Columbia (Macdonald et al. 2000). As a precautionary measure, evidence suggests that a lower threshold of 17°C is warranted in Alaska because (1) premature adult mortality was observed for an alarming number of Summer Chum during periods of elevated water temperatures within the Yukon River drainage (J. Conitz, USFWS, pers. comm.; P. Westley, UAF, pers. comm.); and (2) recent research efforts within the Yukon River drainage suggested Chinook Salmon sampled in water temperatures >18°C showed signs of thermal stress (von Biela et al., *In prep*). Although these thresholds will not eliminate the negative impact of elevated water temperature on spawning success, it will lessen any impacts from research and monitoring efforts.

There is a clear need for additional research on the physiological and behavioral response of Alaska salmon stocks to changing thermal regimes (Schoen et al. 2017; Carey et al. 2019). To date, a single study has examined the relationship between water temperature and HSP70 in adult Yukon River Chinook Salmon (von Biela et al., *In prep*) and there is no data available for premature adult mortality during periods of elevated water temperatures for any Pacific salmon species in Alaska. This highlights the need for local research efforts throughout Alaska drainages to more accurately assess the impact of elevated water temperature on the vitality and persistence of salmon stocks in Alaska. As such, these guidelines should be revisited and revised in accordance with newly publicized research.

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