Technical Report 2009-7

INFLUENCE OF WATER TEMPERATURE ON ADULT SALMON AND STEELHEAD PASSAGE AND BEHAVIOR AT LOWER GRANITE DAM, 2008

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Table of Contents

Acknowledgements

Many people provided their time and assistance during the course of this study T. Dick, D. Joosten, K. Johnson, and K. Tolotti installed and maintained radiotelemetry equipment. T. Dick, D. Joosten, S. Lee, and M. Donohue helped with field operations and data collection. Funding for this study was provided by the U.S. Army Corps of Engineers, Walla Walla District. We also thank F. Higginbotham and S. Milligan, U.S. Army Corps of Engineers, for their cooperation and assistance during all phases of this project.

Abstract

Previous studies have identified Lower Granite Dam fish ladder as having as high temperature differentials during summer months. In 2008, we monitored water temperatures within the fish ladder and the passage of radio-tagged adult salmonids at Lower Granite Dam. Water temperatures in the fish ladder were cooler than in previous study years, with only five percent or less of all radio-tagged fish passing the dam when water temperatures differences between upper and lower segments of the fishway exceeded 1 °C. The warmest average monthly temperatures occurred in August and differences in temperature between the top and bottom of ladder the ladder exceeding 1 °C occurred on one day in July and one day in October. A significantly higher percentage of spring-summer Chinook salmon (*O. tshawytscha*) exited the fish ladder to the tailrace when temperatures exceeded 18 °C than when water ladder temperatures were less than 18 °C. We did not find differences in the percent of steelhead (*O. mykiss*) and fall Chinook salmon that exited the ladder when temperatures were greater than or less than 18 °C. Median dam and transition pool passage times were higher for all runs of radio-tagged fish when water ladder temperatures exceeded 18 °C. Most tagged fish that exited the dam to the tailrace did so after reaching the transition pool area of the ladder regardless of temperature. We found a higher percentage of fish overnighted when water temperatures were greater than 18 °C. Since 2008 was a relatively cool year, future studies may be needed to more effectively evaluate the relationship between fish passage and temperature gradients within the fish ladder at Lower Granite Dam.

Introduction

Temperature is perhaps the most important environmental factor affecting salmonid distribution, behavior, and physiology (Groot and Margolis 1991; Brett 1995; Newell and Quinn 2005). It has played a significant role in the evolution of life history strategies for Pacific salmonids (*Onchorhynchus spp.*; e.g., Brannon et al. 2004) and affects their distributions and migratory behavior (Behnke 1992; Quinn 2005). Construction of hydroelectric projects on the mainstem Columbia and Snake rivers, along with regional climate changes and patterns of land and water use, have altered water temperatures within the basins compared to historical conditions (Raymond 1988; Quinn and Adams 1996; Quinn et al. 1997; Peery et al. 2003). Prior to impoundment, water temperatures in the Snake River were highest in mid- to late summer, often exceeding 20 ºC (Sylvester 1958). Peery et al. (2003) found evidence that some Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) will postpone entry into the Snake River during warm water conditions and will pass dams later, on average, in years when mean summer-time water temperatures are high. Currently, similar or higher maximum temperatures occur during the summer and warm water conditions begin earlier in the spring and persist longer into the fall than historically (Quinn and Adams 1996; Quinn et al. 1997).

Fish ladders have been identified as areas where adult migrants encounter warm temperatures (USACE 2004). Body temperatures of salmon and steelhead outfitted with archival temperature sensors were warmest during fish ladder passage compared to tailrace and reservoir passage at lower Columbia and Snake River dams (Clabough et al. 2008). In addition to the effects of warm temperatures per se, thermal gradients in fish ladders are associated with slowed migration (Caudill et al. 2006). At Lower Granite Dam differences in water temperatures between the top and bottom of the ladder (ΔT) can frequently exceed 1°C during fish passage events (Caudill et al. 2006). Caudill et al. (2006) found events when $\Delta T \geq 1$ ºC increased in frequency and magnitude during the warmest periods of the year and among the lower Snake River dams, were highest at Lower Granite Dam, with few fish passing during periods of $\Delta T > 4$°C. The objectives of this study were to monitor 1) water temperatures in the fish ladder at Lower Granite Dam and 2) relate radio-tagged fish passage behavior in relation to the observed water temperatures. Times to pass the dams and movement behaviors within the ladder were related to ambient water temperature and to ΔT values at time of passage.

Methods

Tagging and Monitoring

We radio-tagged 360 spring–summer Chinook salmon, 275 fall Chinook salmon, and 300 steelhead at Ice Harbor Dam from 15 April through 25 October 2008 using established methods. Three regurgitated tags were found (two at the release site and one in the Lower Granite Dam adult trap). Detailed descriptions of tagging methods are provided in Mann and Peery (2005) and Keefer et al. (2004).

We monitored movements of radio-tagged fish using fixed radio telemetry sites similar to those used during previous studies at Lower Granite Dam (Figure 1). We used SRX/DSP receivers/processors (Lotek Wireless) connected to nine-element aerial Yagi and underwater antennas to determine when fish first reached the tailrace, approached a fishway opening, entered a fishway, moved within a fishway, and/or exited a fishway. Seven underwater antennas at Lower Granite Dam were used to monitor the movements of tagged fish within the transition pool area. Telemetry data were downloaded from receivers every 1-2 weeks. Outages at Lower Granite Dam radio receivers occurred on a total of 18 days at transition pool antennas (9 days in April, 5 days in May, and 4 days in June; totaling 8% of the total receiver-time) and 16 days at count window antennas (4 days in May and 12 days in October-November; totaling 7% of the total receiver-time) in 2008.

Temperature Monitoring

Eight Onset Hobo temperature loggers (H08-002-02) with external temperature sensor cables (TMC20-HD; accuracy ± 0.5 °C) were deployed at mid-water column throughout the fish ladder (Figure 1). Temperature loggers recorded hourly water temperatures and were downloaded every two weeks. Several outages occurred at two logger locations: above the adult fish trap (LG5) one outage for 12 days from late June to early July (4.9% of total time) and above the transition pool (LG2) for 54 days (22.1 % of total time) during three separate outages that occurred in September, October, and November. The external temperature probe at LG3 (at the count window) consistently recorded 0.8 °C low relative to the other temperature loggers in the ladder and previous data (USACE 2004); therefore, all LG3 records were corrected by adding 0.8.

Passage Times and Fish Behaviors

Passage time analyses included initial dam passage events only, i.e., we excluded passage attempts after fallback events. We calculated two passage time metrics for radio-tagged salmon and steelhead at Lower Granite Dam. Specifically, we calculated the time fish used to swim from: (1) the first record in transition pool to the last record in transition pool, and (2) first tailrace record to last record at the top-of-ladder antenna. We also classified passage routes into one of three categories for each fish: (1) fish that swam straight through the transition pool, (2) fish that exited the transition pool into the collection channel, or (3) fish that exited the transition pool into the tailrace. For fish that exited to the tailrace, we examined how far they migrated

upstream in the fish ladder prior to exiting. We also evaluated transition pool passage times as they related to overnighting behavior. Specifically, we compared transition pool passage times for tagged fish that did or did not pass the transition pool on the same day as their first detection in the transition pool. We did not test for an association between overnighting and temperature gradients in the fish ladder because sample sizes were too small (e.g., Caudill et al. 2006). We also looked at overnighting compared to time of arrival in the tailrace and temperature (at LG1). Fifty-nine fall Chinook and 88 steelhead were missing tailrace arrival times but the missing records were distributed throughout the passage of radio-tagged fish. We defined ΔT as LG8-LG1 and matched the hourly temperatures recorded at LG1 to the time fish first entered the transition pool (FP) to determine ΔT in the ladders in relation to overnighting behavior. Thirty-five fall Chinook salmon were diverted at the Lower Granite Dam fish trap, transported to hatcheries, and were excluded from our analyses.

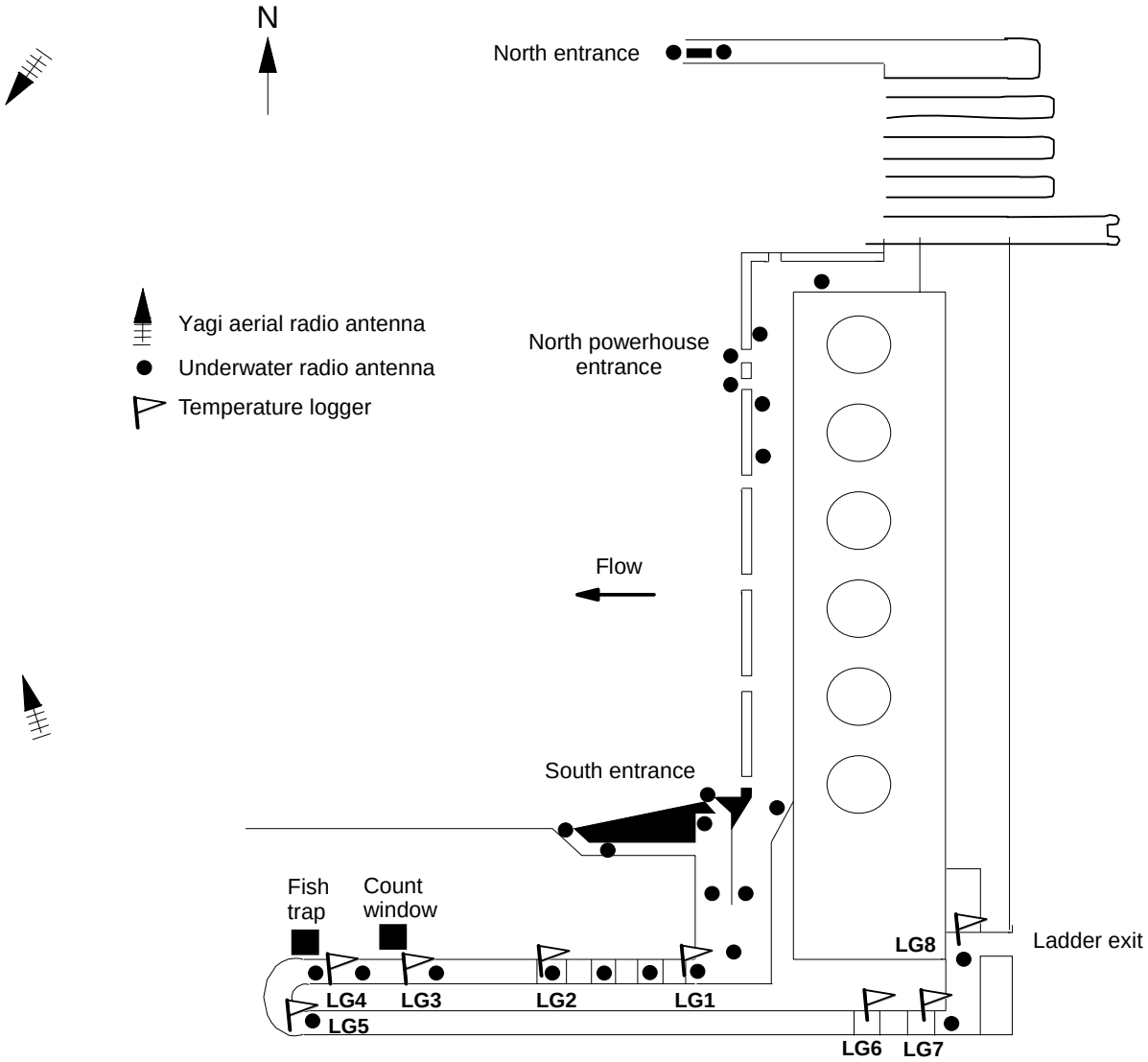

Figure 1. Aerial view of radio antennas and temperature logger locations at Lower Granite Dam during 2008. Tailrace aerial antennas were approximately 1 km downstream from the dam.

Statistical Analysis

We used a Chi-square test (Zar 1999) to evaluate whether a greater percentage of fish exited the fish ladder when temperatures were greater than 18 °C. For each fish, ladder temperatures from the LG1 site (just downstream from the first weir of the fish ladder) were matched to the first pool record of the fish, categorized as <18°C or ≥18°C, and compared to whether the fish passed straight through the transition pool and up the fish ladder or whether it turned around in the ladder and exited to the tailrace.

Results

Temperature Monitoring

From April through November 2008, mean daily water temperatures within the fish ladder ranged from 5.9 to 22.3 °C. The coolest temperatures occurred near the bottom of the fish ladder (LG1) and the warmest temperatures occurred near the top of the fish ladder (LG8; Figure 2; Table 1). Overall, differences in temperature between sites were low on most days.

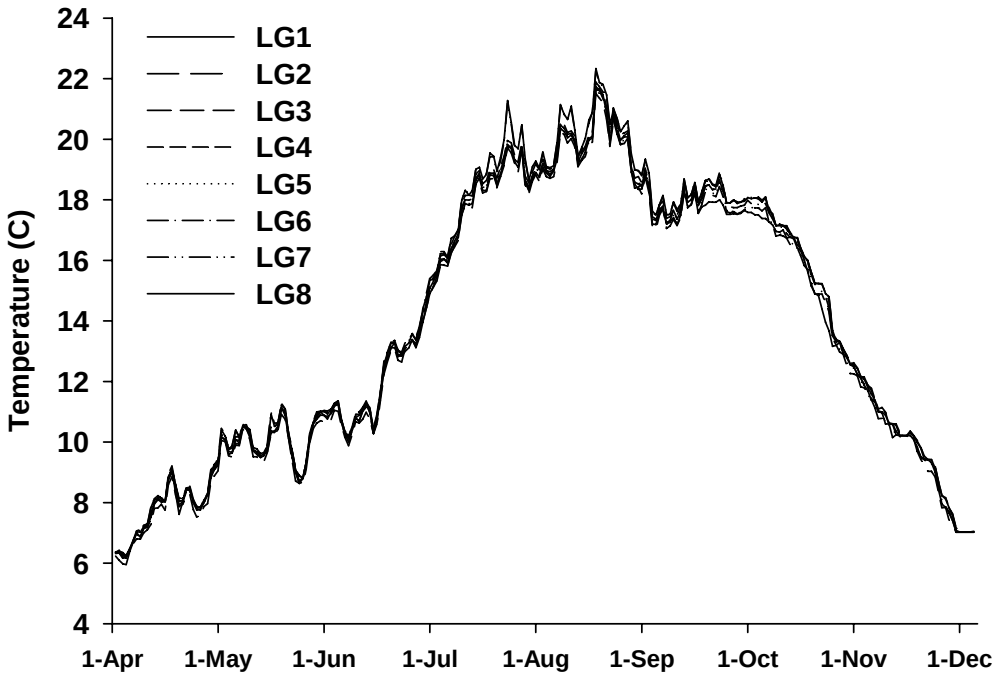

Figure 2. Mean daily water temperatures at eight monitoring locations in the fish ladder at Lower Granite Dam: LG1-below first weir, LG2-above transition pool, LG3-at the count window, LG4- below adult fish trap, LG5-above adult fish trap, LG6-below diffuser grate near top of ladder, LG7-above diffuser grate near top of ladder, and LG8-top of fish ladder (see Figure 1 for antenna and temperature logger locations).

Table 1. Monthly minimum, mean, and maximum daily water temperatures at the eight monitoring locations in the fish ladder at Lower Granite Dam in 2008.

Temperature (ºC)	Month	LG1	LG2	LG3	LG4	LG5	LG6	LG7	LG8
Minimum	April	6.2	6.2	5.9	6.2	6.2	6.2	6.2	6.2
	May	8.6	8.7	8.6	8.8	8.8	8.6	8.8	8.7
	June	10.1	10.1	9.9	10.2	10.2	10.0	10.2	10.2
	July	15.5	15.5	15.3	15.7	15.9	15.5	15.7	15.6
	August	17.2	17.3	17.1	17.4	17.2	17.4	17.6	17.6
	September	17.2	17.2	17.0	17.4	17.1	17.3	17.5	17.5
	October	11.7	11.2	11.6	11.9	11.6	11.8	11.9	11.8
	November	7.0	9.9	7.0	7.0	7.0	7.0	7.0	7.0
	All months	6.2	6.2	5.9	6.2	6.2	6.2	6.2	6.2
Average	April	7.7	7.8	7.6	7.8	7.8	7.7	7.9	7.8
	May	10.0	10.1	9.9	10.2	10.2	10.0	10.2	10.2
	June	12.1	12.2	12.0	12.3	11.6	12.2	12.3	12.3
	July	18.1	18.2	18.0	18.4	18.3	18.2	18.6	18.6
	August	19.7	19.7	19.6	19.9	19.7	19.8	20.1	20.2
	September	17.6	17.9	17.7	18.1	17.8	17.9	18.1	18.1
	October	14.8	15.3	14.8	15.2	14.9	15.0	15.2	15.1
	November	9.2	10.4	9.1	9.3	9.2	9.2	9.3	9.3
	All months	13.7	14.1	13.6	13.9	13.7	13.8	14.0	14.0
Maximum	April	9.2	9.4	9.0	9.4	9.4	9.3	9.4	9.3
	May	11.1	11.1	10.9	11.3	11.3	11.1	11.3	11.2
	June	15.2	15.3	15.1	15.4	13.3	15.2	15.5	15.4
	July	19.8	19.8	19.7	20.0	19.9	20.0	21.2	21.3
	August	21.7	21.7	21.5	21.9	21.6	21.6	22.3	22.3
	September	18.3	18.5	18.4	18.8	18.6	18.7	18.9	18.8
	October	17.4	17.8	17.7	18.1	17.8	17.9	18.1	18.1
	November	11.4	11.0	11.4	11.8	11.4	11.4	11.7	11.6
	All months	21.7	21.7	20.7	21.9	21.6	21.6	22.3	22.3

During July, August, and September, mean daily water temperatures in the fish ladder ranged from 18.1-20.2 °C, with August being the warmest. Maximum water temperatures during the same three months ranged from 18.8-22.3 °C, with the highest maximum temperature occurring in August. Mean ΔT values exceeded 1°C on July 21 and October 20 in 2008 (Figure 3). Compared to previous years when the top of the fish ladder temperatures were monitored, 2008 was a relatively cool year (Figure 4). The average July-August top of the ladder (LG8) temperature in 2000-2003 was 21.3 °C compared to 19.4 °C in 2008.

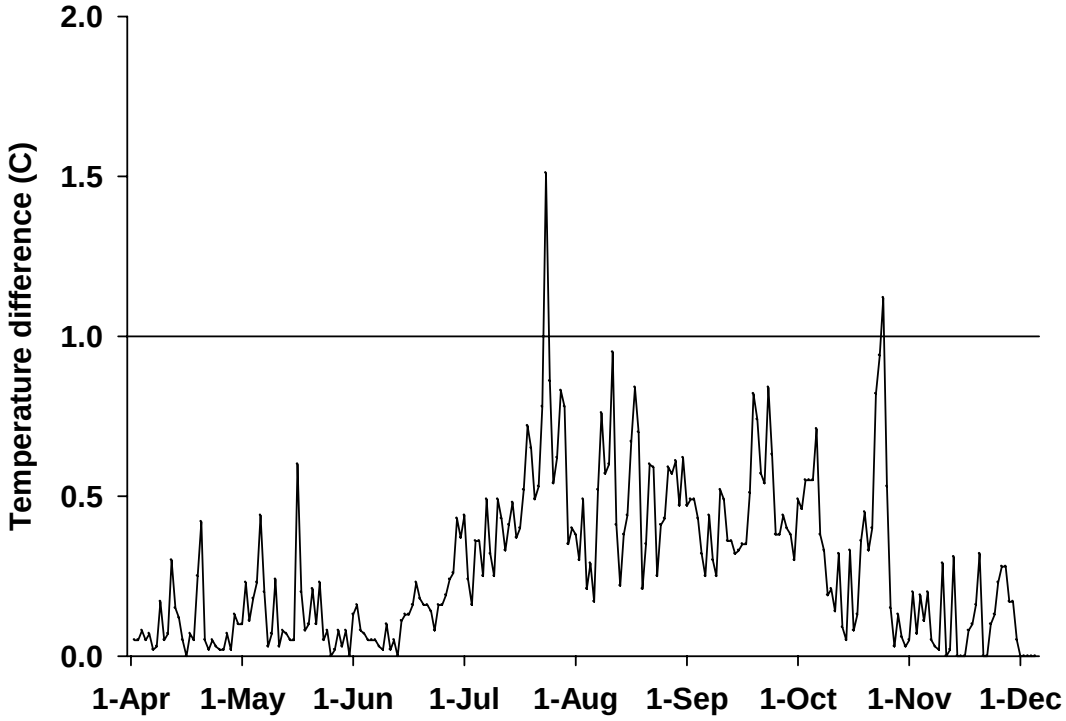

Figure 3. Lower Granite Dam daily fish ladder water temperature differences between the top of the fish ladder (LG8) and the bottom of the fish ladder (LG1) in 2008.

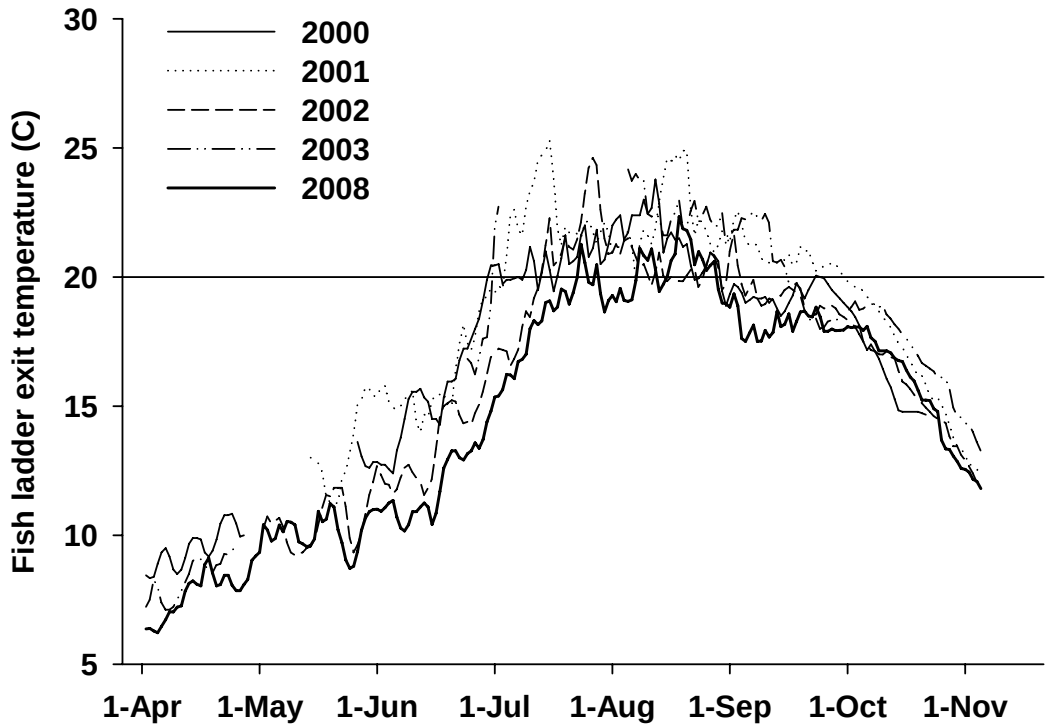

Figure 4. Mean daily water temperatures at the top of the fish ladder at Lower Granite Dam, 2000-2003, and 2008.

Fish Passage and Behavior

Of the 360 spring–summer Chinook salmon, 275 fall Chinook salmon, and 300 steelhead radio-tagged at Ice Harbor Dam in 2008, 162 (45%) spring-summer Chinook, 144 (52%) fall Chinook salmon, and 190 (63%) steelhead had first pool (FP), last pool (LP), and top of the ladder records (LT; indicating dam passage) at Lower Granite Dam and were used in the temperature analyses. During the warmest months July and August, 92 (19%) out of 496 radio-tagged salmon and steelhead passed Lower Granite Dam (Figure 5). In 2008, less than five percent of all radio-tagged fish runs experienced temperature difference (LG8-LG1) exceeding 1 ºC during dam passage. In contrast, 22-37% of the radio-tagged salmonids passing at Lower Granite Dam during previous years (2000-2003) experienced temperature differences exceeding 1 ºC (Table 2).

We examined the proportion of tagged fish that exited the ladder to the tailrace when temperatures were either less than 18 °C or greater than or equal to 18 °C. For spring-summer Chinook salmon, a significantly (Pearson $\chi^2 = 10.15$; $P < 0.01$) higher percentage of fish exited the fish ladder to the tailrace when ladder temperatures exceeded 18 °C (Table 3). Similar patterns were observed in fall Chinook salmon and steelhead, though there were no significant differences in the percentages of fish that exited to the tailrace during the two temperatures categories (Table 3; $P > 0.05$).

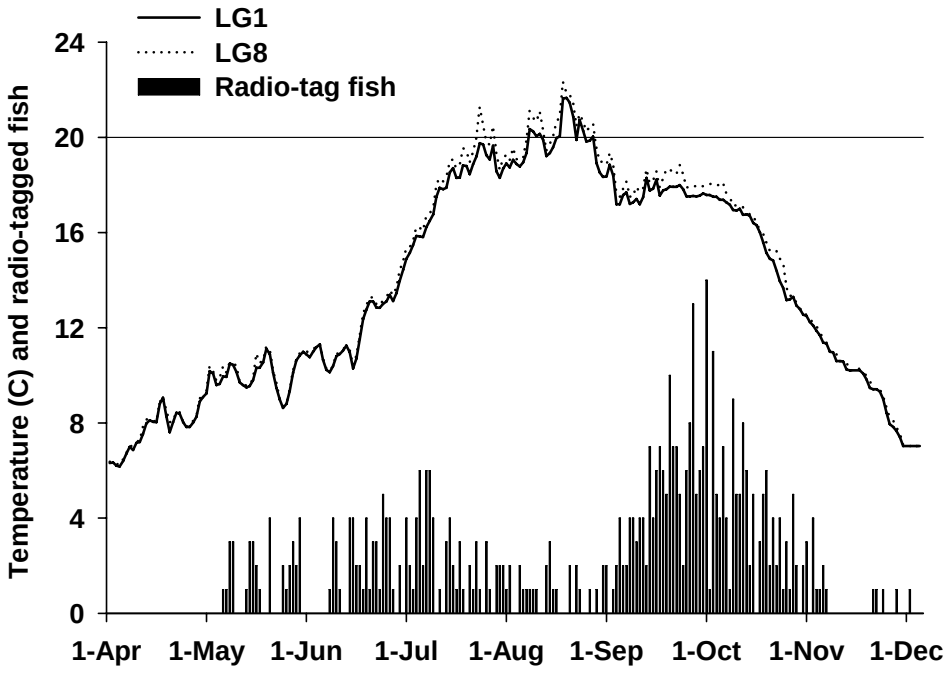

Figure 5. Fish ladder temperatures at the bottom (LG1) and top of fish ladder (LG8) and number of radio-tagged fish passing Lower Granite Dam in 2008.

Table 2. The percentage of radio-tagged fish that reached the base of the fish ladder at Lower Granite Dam when $\Delta T \geq 1°C$ (as indicated by the first transition pool record, FP) in 2008 compared to prior years.

Species	Year	N	≥1 °C
Spring-summer Chinook	2000-2003	830	27.3%
	2008	162	4.3%
Fall Chinook	2000-2003	147	36.7%
	2008	144	4.9%
Steelhead	2000-2003	970	22.2%
	2008	190	2.1%

Table 3. Percentage of fish that did and did not exit the fish ladder to the tailrace after reaching their first pool (FP) in the Lower Granite Dam fish ladder when temperatures were less than and greater than or equal to 18 °C in 2008. * $P < 0.05$.

Species/run	Behavior	<18 °C	≥18 °C
Spring-summer Chinook*	Did not exit	71.5%	43.6%
	Exited	28.5%	56.4%
	n	123	39
Fall Chinook	Did not exit	47.1%	38.7%
	Exited	52.9%	61.3%
	n	51	93
Steelhead	Did not exit	56.0%	49.1%
	Exited	44.0%	50.9%
	n	84	106

Tagged salmon swam similar distances up the ladder before exiting to the tailrace when water temperatures were both below and above 18 °C, (Table 4). The majority (58-92%) of all runs of radio-tagged fish turned around after reaching the transition pool area of the fish ladder regardless of temperature. However, we did find that transition pool passage times for all runs were higher for fish that passed the dam when ladder water temperatures were ≥18°C (Table 5). Similarly, total passage times (F1LT) were longer when water temperatures were ≥18°C. We also found that 23% of spring-summer Chinook salmon, 35% of fall Chinook salmon, and 21% of steelhead did not pass the dam on the same day they entered the transition pool (Table 6). A higher percentage of fish overnighted when water temperatures were ≥18°C (Table 7). Temperature differentials (ΔT) could not be statistically related to overnighting because only two days had $\Delta T > 1°C$.

Table 4. The highest (most upstream) location in the fish ladder before fish turned around and exited the ladder to the tailrace when ladder water temperatures were less than 18 °C or greater than or equal to 18 °C. Sample sizes are in parentheses.

Species	Highest upstream location	Percent of fish <18 °C	Percent of fish ≥18°C
Spring-summer Chinook	Ladder entrance	14.7 (5)	0
	Transition pool	67.6 (23)	86.4 (19)
	Count window	17.6 (6)	13.6 (3)
Fall Chinook	Ladder entrance	13.8 (9)	10.5 (2)
	Transition pool	66.2 (43)	57.9 (11)
	Count window	20.0 (13)	31.6 (6)
Steelhead	Ladder entrance	7.8 (5)	0
	Transition pool	87.5 (56)	92.6 (25)
	Count window	4.7 (3)	7.4 (2)

Table 5. Median times for adult radio-tagged salmonids to pass Lower Granite Dam and its transition pool when ladder temperatures were less than and greater than or equal to 18 °C.

Species/run	Passage metric	Median time (h) <18 °C	n	≥18°C	n
Spring-summer Chinook	Transition pool	0.6	125	4.6	37
	Tailrace to Ladder top	24.0	125	26.4	34
Fall Chinook	Transition pool	2.5	109	4.4	35
	Tailrace to ladder top	12.0	66	19.2	16
Steelhead	Transition pool	1.0	137	2.3	53
	Tailrace to ladder top	9.6	137	14.4	32

Table 6. Number of fish that did or did not pass the dam on the same day as they entered the transition pool when ΔT was less than or greater than or equal to 1 °C in 2008.

Species	Overnight	<1 °C	≥1 °C
Spring-summer Chinook	Yes	34	4
	No	121	3
Fall Chinook	Yes	50	1
	No	88	5
Steelhead	Yes	39	0
	No	147	4

Table 7. Time fish arrived in the tailrace (F1), temperature and percent of fish that overnighted at Lower Granite Dam in 2008.

F1 arrival time (h)	<18°C	% of fish overnighted	≥18 °C	% of fish overnighted
0 – 3	41	12.2	9	44.4
4 – 7	48	6.3	11	0
8 – 11	56	25.0	22	18.2
12 – 15	47	19.1	18	55.6
16 – 19	41	26.8	13	38.5
20 – 23	29	20.7	11	27.3

Discussion

Fish ladders have been identified as areas of passage where adult salmon and steelhead encounter warm temperatures during their upstream migration (USACE 2004; Clabough et al. 2008). Lower Granite Dam fish ladder in particular can have high water temperatures and relatively large temperature differentials during summer (Caudill et al. 2006). In 2008, we monitored water temperatures in the fish ladder at Lower Granite Dam to identify areas of temperature gradients. However, in 2008 water temperatures at Lower Granite Dam were relatively cool compared to previous years and water temperature differences between the bottom and top of the fish ladder exceeded 1 °C on only two days. Only a small percent (<5%) of all radio-tagged fish runs passing Lower Granite Dam in 2008 experienced ladder temperature differences ≥1 °C.

Consistent with previous studies, we found that warmer temperatures alone were related to slowed passage. A significantly higher percentage of tagged fish exited the fish ladder to the tailrace when water temperatures were greater than or equal to 18 °C than when water temperatures were less than 18 °C. This difference was significant for spring-summer Chinook salmon but not for fall Chinook salmon and steelhead. We also found that fish that passed the dam when ladder temperatures were ≥18 °C took longer to pass the transition pool and the dam. We did not find a relationship between fish that overnighted at the dam and ΔT because of the low number of days with ΔT > 1°C. However, we did find a higher percentage of fish overnighting at the dam when water temperatures were greater than 18°C. We also did not find a relationship between overnighting behavior and the time a fish arrived in the tailrace. We have found in previous studies that if fish arrive later in the day (> 2000 hrs) they are less likely to pass the dam that day than fish that arrive earlier (Naughton et al. 2005; Caudill et al. 2007).

Due to interannual variation, understanding the dynamics of water temperature and fish passage at Lower Granite Dam is hard to achieve in one study year. It is well documented that Lower Granite Dam ladder temperatures exceed 20 °C during the summer months in many years and that ladder ΔT values frequently exceed 1°C or more. In order to document temperature gradients in the fish ladder and fish passage behavior, future studies may be needed to fully assess the relationships between ladder temperature, ΔT, and adult salmonid passage behaviors.

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