Temperature in the Lower Snake River during Fall Chinook Salmon Egg Incubation, Fry Emergence, Shoreline Rearing, and Early Seaward Migration

A file report by

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3 February, 2015

Introduction

Temperature in the lower Snake River salmon during fall Chinook salmon egg incubation, fry emergence and shoreline rearing in riverine habitat, and during early seaward migration in Lower Granite Reservoir was an important consideration during the writing of the recovery plan. This file report briefly addresses three sets of questions asked during that process.

1. What is the average water temperature in the mainstem Snake River (a. below Hells Canyon Dam to the Salmon River and b. Salmon River to Lower Granite Res) during egg incubation? What temperature(s) triggers emergence timing from the gravel to shoreline riverine areas?

2. What temperature triggers dispersal from these areas to Lower Granite Reservoir? Our example in the plan says peak dispersal from upper and lower reaches of the Snake River into Lower Granite Reservoir were May 28 and June 4, respectively, in 1995 (Connor et al. 2002). Do we have anything more recent? What is the relationship between these migration dates and temperature? Are the fish leaving the reaches before temperature becomes a concern? How do operations at Hells Canyon Complex contribute to these temperatures and dispersal timing?

3. What are the average temperatures when juvenile fall Chinook pass Lower Granite Dam? We say that in 2011 the median date for passage of juveniles from the Hells Canyon-Salmon River reach was June 16 (Connor et al. 2012). What was the temperature in mid-June? Again, are the fish getting out before temperature becomes a big concern?

After providing a brief description of the influence of operation of the Hells Canyon Complex of dams on temperature in the Snake River upper and lower reaches and Lower Granite Reservoir, this report focuses on answering the above three sets of questions. Tables and figures are attached after the text before the acknowledgements section.

Hells Canyon Complex and Temperatures Downstream

Water stored in Brownlee Reservoir passes rapidly through Oxbow and Hells Canyon reservoirs that have little storage capacity, thus the temperature of water released at Brownlee Dam is the primary determinant of temperature in the tailrace of Hells Canyon Dam. As has been pointed out in the recovery plan, the Snake River upper reach extends from Hells Canyon Dam to the Salmon River mouth. The majority of flow through the upper reach is provided by releases of water from Hells Canyon Dam; hence the water temperature in that reach is determined almost solely by the temperature of the water released from Brownlee Dam. Discharge downstream of the Salmon River mouth in the Snake River lower Reach is also dominated by outflow from Hells Canyon Dam. For example in brood year 1993 (fall of 1993 through spring of 1994) discharge from Hells Canyon Dam made up 69%, 66%, 70%, and 46% of the flow volume in the lower reach during immigrations, spawning, and early and late incubation (Nelle and Connor 1996). Therefore, temperature in the lower reach is also affected by operation of the Hells Canyon Complex of Dams but not to the extent observed in the upper reach.

The thermal structure in Brownlee Reservoir is principally determined by the amount of inflow and spring flood control operations. In a high inflow year, with a corresponding flood control draft, the average reservoir temperature will be warmer in late summer and fall than it will be in a low inflow year. During a high flow year, the reservoir is re-filled with warmer inflowing water, whereas during a low flow year, the reservoir retains more of the cold water stored over the winter. Thus, in a high flow year, the hypolimnetic water is warmer than in a low flow year. In a high flow year, Brownlee Reservoir is also significantly drafted in late summer and early fall in preparation for the stable fall Chinook salmon spawning flow program. In low flow years, the reservoir is drafted less in preparation for these flows. The extent of the fall drawdown influences the temperature of the discharge from Hells Canyon Dam. In a high flow year, much of the warm water collected during the summer months is evacuated early and the cooler fall inflows has a greater influence on downstream water temperatures. In low flow years, much of the warmer summer water is retained and delays the effect of the cooler inflows. Thus in high flow years, salmonid spawning temperatures are cooler than in low flow years, as a reflection of reservoir draft.

Brownlee Dam passes water over the spillways during spring months in some years and through the turbine intakes year round. The turbine intakes draw water generally from the epilimnion and metalimnion of the reservoir. The elevation of the intake channel to the powerhouse dictates the elevation of the metalimnion and establishes the hypolimnion deeper than the intakes to the power house. Drawing water from this level in the reservoir typically allows for outflows to be cooler than the inflowing water from generally mid-March to mid-September. Brownlee Reservoir is dimictic mixing during the spring and late fall and stratifying in the summer and winter. Summer stratification usually occurs in late April to early May and is typically very strong, with much colder hypolimnetic waters than the epilimnion, whereas thermal differences in the winter are less structured, with colder water near the surface but much of the reservoir volume is uniform in temperature. Around mid-September, inflowing water begins to cool, but outflowing water from Brownlee is still reflective of the large thermal mass in the epilimnion. Thus water temperatures in the discharge generally exceed the inflowing water temperature until late fall. During the winter months, inflowing water and surface waters in the reservoir are typically colder than the deeper waters. Thus water temperature in the discharge during winter months is typically warmer than the inflows. In the spring, the influence of the warming inflowing water is delayed because of the large cold mass of water in the reservoir. The warming inflow water begins to flow over the colder deep water and accelerates the thermal stratification. Thus, water passed through the turbines during summer is cooler than reservoir surface temperatures and water passed through the turbines in the winter is warmer than reservoir surface water, with periods during these transitions where these conditions switch. The ability to manage these thermal dynamics of the reservoir and temperature of the discharge with operations of the reservoir alone would be difficult because of the many variables that influence the thermal structure. In some conditions, the ability to increase or decrease discharge volume could change the thermal characteristics of the outflow. Similarly, the ability to draft or fill the reservoir under certain thermal conditions or time periods could alter temperatures in the outflow.

Question Set 1: Temperature, Incubation, and Fry Emergence

Temperature is warmer from October through January during spawning and incubation in the upper reach than in the lower reach (Figure 1). Water temperature is similar between the two reaches from February until roughly the third week of April depending on year, after which the upper reach becomes warmer than the lower reach through emergence (Figure 1).

Compared to mean temperature during incubation, the initial temperature at fertilization is a more powerful indicator of habitat suitability for fry production along the lower Snake River. Geist et al. (2006) fertilized Lyons Ferry Hatchery fall Chinook salmon eggs and then assigned them to replicated, starting temperature treatments (13.0^{o}C, 15.0^{o}C, 16.0^{o}C, 16.5^{o}C, and 17.0^{o}C). Dissolved oxygen in the 13.0^{o}C and 17.0^{o}C treatment replicates was held at saturation, whereas the remaining three treatment replicates were subdivided and held at oxygen levels of 4 mg/L, 6 mg/L, 8 mg/L and saturation. The apparatus that produced each temperature treatment was programmed to drop the temperature by approximately 0.2^{o}C/d for 40 d, while increasing the dissolved oxygen level by 2 mg/L/d starting 16 d post fertilization. The 40-d temperatures were selected to bound the1991–2003 interannual mean thermal regime in the Snake River upper reach, and the 4 mg/L oxygen treatment represented the lowest level observed at a spawning site along the upper reach. After 40 days, the temperatures were equilibrated among the treatments to match the 2001 drought year temperatures. Mean (± SD) survival from fertilization to emergence calculated across the three coolest temperature treatments and the corresponding oxygen treatments was 92.7 ± 4.7% compared to 93.1 ± 1.4% for fish in the 16.5^{o}C treatment and 1.7 ± 1.6% for fish in the 17.0^{o}C treatment. Geist et al. (2006) concluded that exposure to water temperatures up to 16.5^{o}C will not have deleterious effects on survival or growth from egg to emergence if temperatures decline at a rate of 0.2^{o}C/d or more after spawning and dissolved oxygen levels remain above 4 mg/L.

The results of Geist et al. (2006) support rephrasing part of Question Set 1 as such "What percentage the eggs fertilized in the Snake River upper and lower reaches are fertilized at initial temperatures above 16.5^{o}C?" Answering that question requires information on time of spawning and temperature. Redd count data collected along the Snake River upper and lower reaches (see Groves et al. 2013 for details) provide the best available science on spawn timing. The first date of spawning in a given year was estimated here by subtracting 7 days from the flight date when redds were first counted in each reach. For example, the first redds counted during 1991 in the lower reach were counted on a flight made on 28-Oct. Thus, 21-Oct was assigned as the start date for the "first spawning interval redds were constructed" (Table 1). The end date for that interval was equal to the flight date of 28-Oct minus 1, which resulted in a survey interval duration of 6 days (Table 1). The same steps were taken to establish the second and third survey intervals and to populate Tables 2 and 3. Together the three intervals covered contiguous periods of time (e.g., 1991 lower reach; first interval 21-Oct to 27-Oct; second interval 28-Oct to 3-Nov; third interval 4-Nov to 10-Nov; Tables 1–3). After defining the intervals, the tables were populated with interval mean, interval minimum daily mean, and interval maximum daily mean temperatures. The temperatures in Table 1 were then compared to the 16.5^{o}C threshold for high survival from fertilization to emergence established by Geist et al. (2006).

Survival from fertilization to fry emergence was probably low in the Snake River lower reach in the drought year 2001 through some portion of the second survey interval, and in 2014 during the first survey interval redds were constructed (Table 1). Observations of temperatures above 16.5^{o}C were more common and possibly more detrimental to survival from fertilization to emergence in the Snake River upper reach than in the Snake River lower reach. Temperature above 16.5^{o}C were observed during the first survey interval redds were counted in the upper reach in 1994, 1996, 1999–2001, 2003–2007, 2010–2012, and 2014 (Table 1). Temperatures above 16.5^{o}C were observed during the second survey interval in the upper reach in 2001 and 2005 and during the third survey interval in 2001 (Tables 2 and 3). This simple assessment points to temperature during spawning as a factor for fry loss, but it did not quantify the extent of that loss.

The first step to quantifying fry loss due to warm temperatures was to calculate the cumulative percentage of the total annual redd count made in each reach by interval (Tables 1–3). In the lower reach during 2001, the first 0.5% of the all redds that were eventually counted were counted when temperature remained between 17.4^{o}C and 18.3^{o}C (Table 1) during the first survey interval when redds construction was observed. No new redds were constructed during the second spawning interval when the maximum temperature observed was also above 16.5^{o}C (Table 2). Thus, estimated fry loss due to temperature in the lower reach during 2001 was 0.5% (Tables 1 and 2). Estimating fry loss was not as simple in the lower reach during 2014 when 2.6% of all the redds that were eventually counted were counted between a nonlethal temperature of 14.1^{o}C and a lethal temperature of 17.0^{o}C (Table 1). To estimate fry loss in that instance, a method that used the data Table 1 was applied as shown below by example where 13 is the interval duration.

	Date	Daily estimates of cumulative (%) redd counts			Mean daily temperature
Interval start date ==>	10/13/2014	2.6% / (13+1)	=	0.2%	17.0
	10/14/2014	2.6% / (13+1) + 0.2%	=	0.4%	16.6
	10/15/2014	2.6% / (13+1) + 0.4%	=	0.6%	16.2
	10/16/2014	2.6% / (13+1) + 0.6%	=	0.7%	15.8
	10/17/2014	2.6% / (13+1) + 0.7%	=	0.9%	15.6
	10/18/2014	2.6% / (13+1) + 0.9%	=	1.1%	15.7
	10/19/2014	2.6% / (13+1) + 1.1%	=	1.3%	15.7
	10/20/2014	2.6% / (13+1) + 1.3%	=	1.5%	15.6
	10/21/2014	2.6% / (13+1) + 1.5%	=	1.7%	15.4
	10/22/2014	2.6% / (13+1) + 1.7%	=	1.9%	15.2
	10/23/2014	2.6% / (13+1) + 1.9%	=	2.0%	15.0
	10/24/2014	2.6% / (13+1) + 2.0%	=	2.2%	14.6
	10/25/2014	2.6% / (13+1) + 2.2%	=	2.4%	14.5
Interval end date ==>	10/26/2014	From (Table 1)		2.6%	14.1

That method allocates the cumulative percentage of redds constructed during the interval across the individual days within the interval, and then compares those daily cumulative percentages to temperature on those individual days. Fry loss due to warm water temperatures in the lower reach during 2014 was estimated to be 0.4% of the total fry production in that reach and year. The same method was then applied to data collected in the upper reach. Annual fry loss in the upper reach due to exposure to temperatures above 16.5^{o}C averaged (± SD) 2.0 ± 2.3% and ranged from 0.2% to 7.3% (Table 4).

With respect to the second question in Question Set 1, fry emergence is not triggered by a daily mean temperature threshold. Development of fall Chinook eggs and the timing of fry emergence primarily proceed according to the accrual of temperature units (Wallach 1901). For example, 10 temperature units would accrue if average temperature was 10°C the first 24 h after fertilization and cumulative temperature units would be 20 if temperature remained at 10°C during the following 24 h. In the lower and upper reaches of the Snake River, it takes just over 1,000 cumulative temperature units for fry to emergence (Connor et al. 2003a). The nature of the thermal regime (e.g., Figure 1) insures that the fry emerge at temperatures well above freezing and well below annual maxima. That conclusion was confirmed with empirical data as follows.

On average, and during 13 years of the 1994–2013 time period when both reaches were beach seined, the median date of fry (≤ 45-mm fork length; Connor et al. 2002) presence along the shorelines (i.e., the best available science on emergence timing) was earlier in the Snake River upper reach compared to the lower reach (Table 5). During the other 6 years, the median dates of fry emergence timing were identical (Table 5). Under the thermal regimes observed in the two reaches there is little difference in the water temperature experienced by fry in those two reaches (Table 5).

Question Set 2: Temperature and Dispersal into Lower Granite Reservoir

Timing of temperature-related parr (≥ 45-mm fork length; Connor et al. 2002) dispersal from the shorelines of the Snake River lower and upper reaches into Lower Granite Reservoir can be assessed by using beach seine data to calculate the median date of parr presence. Time of dispersal becomes earlier as the median catch date becomes earlier and vice versa. Connor et al. (2013) evaluated the factors affecting the median date of parr presence by analyzing data collected jointly on fish in the Snake River upper and lower reaches. They reported the results for the following model fitted from data collected by beach seining during 1992–2011 (R^2 = 0.64; N = 20; P < 0.0007):

$\log_e$ Annual median day of capture = 5.164 - 7.003 * CPUE - 0.012 * Max°C + 0.031 * Flow;

where CPUE was annual mean catch per unit effort used to represent relative abundance during shoreline rearing, Max°C was the annual maximum spring temperature, and Flow was the annual mean spring flow.

The r^2 value for a bivariate regression model fitted from annual mean CPUE to predict the annual median day of parr capture was roughly five times higher than the r^2 values for the maximum spring river temperature and mean spring river flow partial regression models (0.46 versus 0.07 and 0.10) suggesting that competition for food and space was a stronger factor for dispersal timing into the reservoir from the two reaches compared to the factors flow and temperature. Annual median day of capture was inversely proportional to annual maximum spring river temperature indicating that fish began downstream dispersal earlier during warm springs compared to cool springs, but there was no evidence for a temperature trigger per se. Annual median day of capture was directly proportional to annual mean spring river flow suggesting that fish began downstream later in high flow years compared to low flow years, seining efficiency was low early and high late during high flow years, or a combination of those two explanations.

The results in the preceding paragraph provided some evidence for temperature-related dispersal, but do not answer the question "Are the fish leaving the reaches before temperature becomes a concern?" To answer that question; the peak, first, and last dates of parr presence were tabulated with the mean daily temperatures on that peak and the seasonal mean and maximum daily mean temperatures during rearing (Table 6). Here, the peak date represented the point in time when downstream dispersal into the reservoir exceeded recruitment to the shorelines of the two reaches, and the last date of parr presence defined the point in time when shoreline rearing was complete and all survivors had entered the reservoir.

The work of Geist et al. (2010) with natural-origin fall Chinook salmon juveniles transferred from the upper reach to a laboratory was used in part to evaluate the suitability of temperature for growth. They found that growth in both fork length and weight increased as temperature increased from 14.0°C to 20.0°C and declined slightly up to a temperature of 22.0°C. The work of Yankee (2006) conducted with juvenile Lyons Ferry Hatchery fall Chinook salmon, was also used to evaluate the suitability of temperature for growth, but also to address physiological development, and survival. He observed severely reduced growth and large

physiological responses in blood plasma indicative of acute stress, cellular damage, and impaired nutrition in fish reared in a 24.0^{o}C treatment that started at approximately 14.0^{o}C and then gradually increased over 3 weeks to 24.0^{o}C where it was held for an additional 3 weeks. He also documented 100%mortality several hours after temperature exceeded 26.0^{o}C in a 28.0^{o}C treatment that also started at 14.0^{o}C and was increased over time as described for the 24.0^{o}C treatment. The combined work of Yankee (2006) and Geist et al. (2010) showed that: (1) exposure of juvenile fall Chinook salmon to a naturally increasing thermal regime of 14.0^{o}C to 20.0^{o}C does not raise large concerns relevant to growth, physiological development, and survival; (2) exposure to 24.0^{o}C can have severe growth and physiological consequences, and (3) temperatures above 26.0^{o}C are almost instantaneously lethal even if the fish are gradually acclimated to warm water.

The above three temperature criteria were then compared to the temperatures experienced by parr in the Snake River lower and upper reaches (Table 6). That comparison suggested that temperature was not a concern at the peak of parr presence in the upper and lower reaches (Table 6). Maximum temperature at the end of shoreline rearing, however, did exceed 20.0^{o}C in the lower reach during 6 of 19 years, and in the upper reach during 1 of 19 years (Table 6). In all of those cases, temperature did not exceed the 24.0^{o}C benchmark for severely reduced growth and retarded physiological development, or the 26.0^{o}C for direct mortality. The results on growth were particularly important because a high rate of parr growth in the upper reach is a large factor for parr-to-smolt survival (Connor et al. 2012).

Question Set 3: Temperature and passage through Lower Granite Reservoir

During summer, cold water from Dworshak Reservoir (11–16ºC) moves underneath the warmer water from Brownlee Reservoir and the lower Snake River tributaries (20–23ºC) at the confluence of the lower Snake and Clearwater rivers to create large variations in both vertical and cross-channel temperature distributions (Figure 2; Cook et al. 2006). The temperature distributions change as water is mixed and moves downstream; however, strong vertical gradients persist. Tiffan et al. (2009) fitted juvenile fall Chinook salmon with temperature sensing radio tags and found that the majority of the subyearlings maintained average body temperatures that differed from average vertical profile temperatures during most of the time they were tracked in the reservoir. The mean proportion of the time subyearlings were tracked within the 16–20°C temperature range was larger than the proportion of time this range was available, which confirmed temperature selection opposed to random use. The subyearlings also selected a depth and temperature combination that allowed them to increase their exposure to temperatures of 16-20ºC when temperatures <16 and >20ºC were available at lower and higher positions in the water column. Those results confirmed that juvenile fall Chinook salmon are capable of "behavioral thermoregulation."

Constant recording of temperature throughout Lower Granite Reservoir to explicitly document annual temperature regimes in three dimensions would be labor intensive, so managers rely on a water quality monitor installed in the tailrace of Lower Granite Dam that reports the mean temperature of the reservoir water after it is mixed by the turbines (CBR 2015). A 2000 decision by the State of Idaho to deny waivers for exceeding dissolved gas levels above 110% in the tailrace of Dworshak Dam affected the implementation of summer flow augmentation. To avoid exceeding that "gas cap," the maximum volume of water that could be released from Dworshak Dam was reduced to approximately 397 m^3/s/d (14,000 ft^3/s/d). Thus in some years, the full 1.2 million acre feet of stored water in Dworshak Reservoir available for summer flow augmentation could not be released by the end of August. Managers subsequently extended the flow augmentation period from August 31 through the first two weeks of September. For that reason, analyses were restricted here to the years 2000–2013.

Connor et al. (2014) reported daily estimates of passage abundance for natural-origin fall Chinook salmon at Lower Granite Dam during 2000–2013. Annual daily mean tailrace temperatures were plotted against those estimates and compared here to the temperature criteria established for Question Set 2 (Figures 3–16). In most years, daily passage decreased after temperature approached 20.0^{o}C. The 20.0^{o}C temperature threshold was not exceeded in 2000, 2002, 2004, 2005, and 2008–2012. Temperature in 2001 ranged from 20.2–20.8^{o}C between 6 and 7 July and was 20.1^{o}C from 9 to 11 September that year (Figure 4). Temperature averaged 20.1^{o}C on 30 August 2003 (Figure 6). On 1 July 2006 temperature averaged 20.3^{o}C and ranged from 20.1^{o}C to 20.6^{o}C between 1 and 7 July that year (Figure 9). Temperature averaged 20.1^{o}C on 5 July 2007 (Figure 10). Temperature averaged 20.1^{o}C on 22 August 2013 and between 20.1^{o}C to 20.4^{o}C between 19 and 22 September that year (Figure 16).

Given that juvenile fall Chinook salmon are capable of behavioral thermoregulation; the above results do not raise concerns relevant to growth, physiological development, and survival reductions directly linked to temperature. Parr-to-smolt survival, however, decreases as the

passage season becomes later (Connor et al. 2003b, 2012; Smith et al. 2003). Temperature-related predation is likely the source of late-season mortality——and as such—predation is a large concern.

Tables and Figures

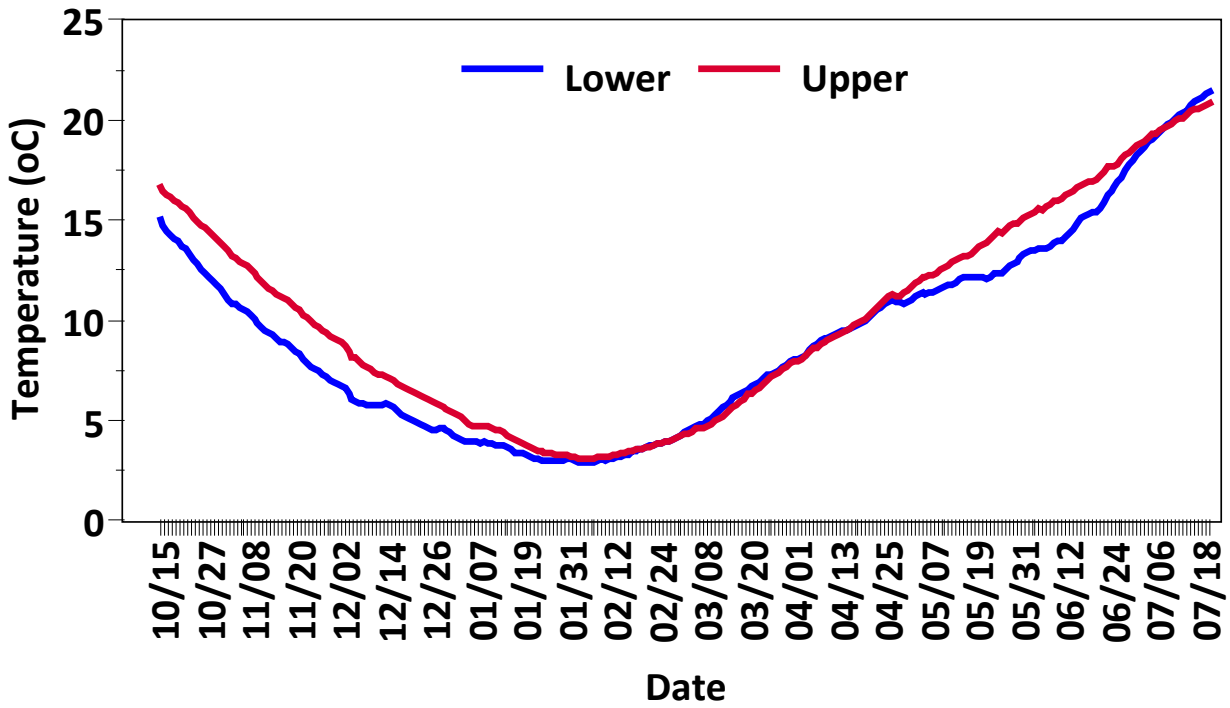

Figure 1.—Twenty-year mean daily water temperature in the Snake River upper and lower reaches during spawning, fry emergence and shoreline rearing, brood years 1994 to 2013. Water temperature in this and all figures and tables were collected using reach-specific thermographs by the Idaho Power Company.

Table 1.—Information mean daily temperature (°C) and cumulative (%) redd counts in the Snake River upper and lower reaches during the first survey interval, 1991–2014. The first survey interval was established based on the flight date when redds were first counted minus 7 (i.e., start date) and the flight date minus 1 (End date). Temperatures above 16.5°C are given underlined in bold.

	Lower reach							Upper reach						
				Temperature							Temperature			
Year	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count
1991	21-Oct	27-Oct	6	14.0	13.1	15.0	5.0	4-Nov	10-Nov	6	12.6	12.3	12.9	9.1
1992	29-Oct	4-Nov	6	12.8	11.9	13.4	6.9	29-Oct	4-Nov	6	14.7	13.9	15.3	12.5
1993	18-Oct	24-Oct	6	14.1	13.3	15.1	4.3	25-Oct	31-Oct	6	14.2	13.7	14.7	35.7
1994	25-Oct	31-Oct	6	13.0	11.7	13.7	4.5	17-Oct	23-Oct	6	16.1	15.4	**16.8**	2.9
1995	23-Oct	29-Oct	6	11.5	10.7	11.9	7.7	16-Oct	22-Oct	6	15.3	14.6	16.1	14.3
1996	21-Oct	27-Oct	6	11.7	11.1	12.1	22.7	14-Oct	20-Oct	6	16.0	15.3	**16.8**	4.1
1997	13-Oct	19-Oct	6	14.5	13.7	15.0	3.4	20-Oct	26-Oct	6	13.3	12.6	13.8	40.0
1998	19-Oct	25-Oct	6	12.4	12.1	13.1	42.3	19-Oct	25-Oct	6	14.6	14.2	15.1	15.6
1999	11-Oct	17-Oct	6	15.5	14.5	16.2	4.2	11-Oct	17-Oct	6	16.5	15.6	**17.1**	1.3
2000	16-Oct	22-Oct	6	13.8	13.2	14.1	2.9	2-Oct	8-Oct	6	**17.1**	**16.7**	**17.4**	0.5
2001	2-Oct	8-Oct	6	**18.3**	**17.4**	**19.3**	0.5	2-Oct	8-Oct	6	**19.0**	**18.4**	**19.8**	2.7
2002	14-Oct	20-Oct	6	13.8	13.4	14.0	2.9	14-Oct	20-Oct	6	15.3	14.9	15.6	3.8
2003	20-Oct	26-Oct	6	15.0	13.9	15.6	5.9	13-Oct	19-Oct	6	**17.6**	**17.2**	**18.1**	0.7
2004	11-Oct	17-Oct	6	15.8	15.6	16.0	0.2	18-Oct	24-Oct	6	**16.8**	16.2	**17.4**	7.4
2005	11-Oct	17-Oct	6	14.9	14.8	15.1	0.3	11-Oct	17-Oct	6	**16.8**	**16.6**	**17.1**	1.1
2006	16-Oct	22-Oct	6	14.0	13.2	15.0	4.4	16-Oct	22-Oct	6	16.1	15.6	**16.6**	5.3
2007	23-Oct	29-Oct	6	11.8	11.0	12.6	12.1	8-Oct	14-Oct	6	**17.1**	16.5	**17.6**	0.2
2008	13-Oct	19-Oct	6	13.6	13.2	14.6	3.7	13-Oct	19-Oct	6	16.1	16.0	16.5	0.8
2009	12-Oct	18-Oct	6	13.7	13.0	14.3	2.4	12-Oct	18-Oct	6	15.9	15.5	16.5	0.5
2010	18-Oct	1-Nov	14	13.5	12.4	14.6	4.0	18-Oct	1-Nov	14	16.1	15.0	**16.9**	2.5
2011	17-Oct	30-Oct	13	13.9	12.4	15.2	1.2	17-Oct	30-Oct	13	15.6	14.4	**17.1**	2.4
2012	15-Oct	28-Oct	13	13.7	11.8	15.8	5.2	15-Oct	28-Oct	13	16.0	14.5	**17.6**	1.4
2013	14-Oct	27-Oct	13	12.9	12.0	14.1	4.7	14-Oct	27-Oct	13	15.5	14.6	16.5	4.9
2014	13-Oct	26-Oct	13	15.5	14.1	**17.0**	2.6	13-Oct	26-Oct	13	**17.6**	**16.6**	**18.7**	1.3
Mean ± SE							6.4 ± 1.8							7.1 ± 2.1

Table 2.—Information mean daily temperature (°C) and cumulative (%) redd counts in the Snake River upper and lower reaches during the second survey interval, 1991–2014. Temperatures above 16.5°C are given underlined in bold.

	Lower reach							Upper reach						
				Temperature							Temperature			
Year	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count
1991	28-Oct	3-Nov	6	11.4	10.2	12.6	10.0	11-Nov	18-Nov	7	11.6	11.1	12.1	40.9
1992	6-Nov	15-Nov	9	10.9	10.2	11.7	48.3	6-Nov	15-Nov	9	12.8	12.1	13.7	37.5
1993	25-Oct	31-Oct	6	12.0	11.4	12.9	32.6	1-Nov	7-Nov	6	13.1	12.4	13.7	71.4
1994	31-Oct	5-Nov	5	11.2	10.5	11.7	36.4	25-Oct	30-Oct	5	14.9	14.3	15.2	11.4
1995	30-Oct	4-Nov	5	9.4	8.5	10.4	92.3	23-Oct	29-Oct	6	13.9	13.3	14.2	42.9
1996	28-Oct	3-Nov	6	10.8	10.2	11.2	50.0	21-Oct	27-Oct	6	14.6	13.9	14.9	46.9
1997	20-Oct	26-Oct	6	11.9	11.0	12.6	31.0	27-Oct	2-Nov	6	12.2	11.7	12.6	75.0
1998	26-Oct	1-Nov	6	11.6	11.0	12.1	73.1	26-Oct	1-Nov	6	13.5	13.0	13.9	47.7
1999	18-Oct	24-Oct	6	13.2	12.8	13.8	22.9	18-Oct	24-Oct	6	14.9	14.7	15.2	15.6
2000	23-Oct	29-Oct	6	12.2	11.8	12.5	8.7	9-Oct	15-Oct	6	15.8	15.5	16.4	2.7
2001	8-Oct	14-Oct	6	16.0	15.1	**17.4**	0.5	8-Oct	14-Oct	6	17.4	16.8	**18.4**	2.7
2002	21-Oct	27-Oct	6	12.6	11.6	13.5	17.4	21-Oct	27-Oct	6	14.3	13.6	15.0	26.6
2003	27-Oct	2-Nov	6	12.7	10.6	14.3	21.7	20-Oct	26-Oct	6	**16.8**	16.1	**17.3**	7.6
2004	18-Oct	24-Oct	6	14.4	13.4	15.2	8.4	25-Oct	31-Oct	6	15.5	14.9	15.9	33.4
2005	18-Oct	23-Oct	5	14.8	14.4	15.0	14.7	18-Oct	23-Oct	5	16.3	16.0	**16.6**	11.8
2006	23-Oct	6-Nov	14	11.3	9.5	13.0	56.4	23-Oct	6-Nov	14	14.1	13.1	15.5	38.2
2007	30-Oct	6-Nov	7	10.5	10.1	11.4	52.6	15-Oct	22-Oct	7	15.7	15.3	16.4	4.1
2008	20-Oct	26-Oct	6	12.8	12.3	13.5	22.0	20-Oct	26-Oct	6	15.2	14.9	15.9	15.4
2009	19-Oct	25-Oct	6	13.2	12.5	13.8	10.2	19-Oct	25-Oct	6	14.9	14.5	15.4	8.6
2010	2-Nov	15-Nov	13	11.4	10.1	12.4	46.4	2-Nov	15-Nov	13	13.9	12.7	15.0	60.9
2011	31-Oct	13-Nov	13	10.3	9.3	12.4	34.0	31-Oct	13-Nov	13	12.5	11.3	14.3	67.8
2012	29-Oct	11-Nov	13	11.6	9.8	12.4	50.3	29-Oct	11-Nov	13	13.8	12.3	14.6	78.3
2013	28-Oct	10-Nov	13	10.5	9.4	11.8	66.9	28-Oct	10-Nov	13	13.1	12.1	14.4	87.6
2014	27-Oct	9-Nov	13	13.1	11.9	13.9	36.2	27-Oct	9-Nov	13	15.5	14.4	16.3	70.3
Mean ± SE							35.1 ± 4.7							37.7 ± 5.5

Table 3.—Information mean daily temperature (°C) and cumulative (%) redd counts in the Snake River upper and lower reaches during the third survey interval, 1991–2014 interval. Temperatures above 16.5°C are given underlined in bold.

	Lower reach							Upper reach						
	Start	End	Interval	Temperature			Cumulative (%)	Start	End	Interval	Temperature			Cumulative (%)
Year	date	date	duration (d)	Mean	Min	Max	redd count	date	date	duration (d)	Mean	Min	Max	redd count
1991	4-Nov	10-Nov	6	10.0	9.5	10.3	50.0	19-Nov	24-Nov	5	10.2	9.6	10.8	72.7
1992	16-Nov	26-Nov	10	9.0	7.4	10.0	93.1	16-Nov	26-Nov	10	11.1	9.8	12.0	68.8
1993	1-Nov	7-Nov	6	10.7	9.9	11.2	50.0	8-Nov	14-Nov	6	11.6	11.0	12.1	100.0
1994	6-Nov	13-Nov	7	10.0	9.4	10.4	40.9	31-Oct	5-Nov	5	13.6	12.9	14.1	42.9
1995	5-Nov	12-Nov	7	8.4	8.0	8.7	100.0	30-Oct	4-Nov	5	12.3	11.6	13.0	67.9
1996	4-Nov	11-Nov	7	9.5	9.0	10.1	95.5	28-Oct	3-Nov	6	13.5	12.9	13.8	81.6
1997	27-Oct	2-Nov	6	10.6	9.9	11.0	34.5	3-Nov	9-Nov	6	11.5	11.2	11.6	85.0
1998	2-Nov	9-Nov	7	10.2	9.6	10.9	92.3	2-Nov	9-Nov	7	12.2	11.6	12.9	75.2
1999	25-Oct	3-Nov	9	12.0	11.1	12.8	43.8	25-Oct	3-Nov	9	13.7	12.7	14.5	46.7
2000	30-Oct	5-Nov	6	11.1	10.6	11.7	42.0	16-Oct	22-Oct	6	15.3	14.6	15.5	11.3
2001	15-Oct	21-Oct	6	14.5	14.2	15.2	2.4	15-Oct	21-Oct	6	16.3	15.9	**16.8**	2.7
2002	28-Oct	3-Nov	6	10.1	9.0	11.7	47.5	28-Oct	3-Nov	6	12.2	11.4	13.7	61.7
2003	3-Nov	12-Nov	9	9.5	8.9	10.7	58.5	27-Oct	2-Nov	6	15.1	14.0	16.4	33.6
2004	25-Oct	31-Oct	6	12.5	11.8	13.0	31.9	1-Nov	7-Nov	6	14.0	13.6	14.5	82.9
2005	24-Oct	30-Oct	6	13.7	12.9	14.3	38.3	24-Oct	30-Oct	6	15.5	15.1	15.9	33.5
2006	7-Nov	12-Nov	5	9.9	9.2	11.1	58.1	7-Nov	12-Nov	5	12.4	12.0	13.2	86.4
2007	7-Nov	12-Nov	5	9.7	9.3	10.0	72.8	23-Oct	29-Oct	6	14.5	14.1	15.2	25.9
2008	27-Oct	2-Nov	6	11.8	11.6	12.3	56.0	27-Oct	2-Nov	6	14.1	13.9	14.5	68.5
2009	26-Oct	1-Nov	6	11.3	10.7	12.3	40.7	26-Oct	1-Nov	6	13.5	13.0	14.4	64.4
2010	16-Nov	28-Nov	12	8.0	6.3	10.1	83.1	16-Nov	28-Nov	12	10.9	9.6	12.6	88.6
2011	14-Nov	20-Nov	6	8.6	8.0	9.2	89.6	14-Nov	20-Nov	6	10.7	10.0	11.3	93.6
2012	12-Nov	25-Nov	13	9.1	8.2	9.6	100.0	12-Nov	25-Nov	13	11.3	10.5	12.2	97.5
2013	11-Nov	26-Nov	15	8.3	6.6	9.5	100.0	11-Nov	26-Nov	15	10.8	9.5	12.0	98.7
2014	10-Nov	23-Nov	13	8.4	7.2	11.5	99.3	10-Nov	23-Nov	13	11.8	10.3	14.2	96.4
Mean ± SE							63.3 ± 5.7							66.1 ± 5.8

Table 4.—Estimated fry loss associated with temperatures above 16.5°C in the Snake River upper reach during years of the period 1991–2014 when temperature did exceed 16.5°C at the onset of spawning. Abbreviations: %, estimated daily cumulative (%) redd count; °C, mean daily temperature. Continued on next page.

	1994		1996		1999		2000		2001		2003		2004	
Date	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C
2-Oct							0.1	17.4	0.1	19.8				
3-Oct							0.1	17.3	0.3	19.5				
4-Oct							0.2	17.4	0.4	19.2				
5-Oct							0.3	17.3	0.5	18.9				
6-Oct							0.4	17.1	0.7	18.7				
7-Oct							0.4	16.8	0.8	18.5				
8-Oct							0.5	16.7	0.9	18.4				
9-Oct								16.4	1.1	18.0				
10-Oct								16.1	1.2	17.4				
11-Oct					0.2	16.8		15.9	1.4	17.1				
12-Oct					0.4	17.0		15.8	1.5	16.9				
13-Oct					0.6	17.1		15.6	1.6	16.8	0.5	18.1		
14-Oct			0.6	16.8	0.7	16.9		15.6	1.8	17.2	1.1	18.0		
15-Oct			1.2	16.5	0.9	16.1		15.5	1.9	16.8	1.6	17.4		
16-Oct			1.8	16.2	1.1	15.8			2.0	16.6	2.2	17.2		
17-Oct	0.4	16.8	2.3	16.0	1.3	15.6			2.2	16.4	2.7	17.3		
18-Oct	0.8	16.7	2.9	15.7					2.3	16.0	3.3	17.5	1.1	17.4
19-Oct	1.2	16.3	3.5	15.7					2.4	15.9	3.8	17.4	2.1	17.0
20-Oct	1.7	16.3	4.1	15.3					2.6	16.1	4.3	17.3	3.2	17.0
21-Oct	2.1	16.0							2.7	16.0	4.9	17.3	4.2	17.0
22-Oct	2.5	15.5									5.4	17.2	5.3	16.7
23-Oct	2.9	15.4									6.0	17.0	6.3	16.3
24-Oct											6.5	16.5	7.4	16.2
25-Oct											7.1	16.1		
26-Oct											7.6	16.1		
Loss (%)	0.8		0.6		0.7		0.5		2.0		6.0		5.3	

Table 4.—(Continued)

	2005		2006		2007		2010		2011		2012		2014	
Date	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C
8-Oct					0.0	17.6								
9-Oct					0.1	17.5								
10-Oct					0.1	17.2								
11-Oct	0.9	17.1			0.1	17.0								
12-Oct	1.8	16.9			0.1	16.9								
13-Oct	2.7	16.8			0.2	16.7							0.1	18.7
14-Oct	3.6	16.8			0.2	16.5							0.2	18.4
15-Oct	4.5	16.7									0.1	17.6	0.3	18.2
16-Oct	5.4	16.6	0.8	16.6							0.2	17.4	0.4	18.0
17-Oct	6.4	16.6	1.5	16.4					0.2	17.1	0.3	16.9	0.5	17.9
18-Oct	7.3	16.6	2.3	16.2			0.2	16.9	0.3	16.9	0.4	16.8	0.6	17.9
19-Oct	8.2	16.4	3.0	16.1			0.3	16.7	0.5	16.7	0.5	16.7	0.7	17.8
20-Oct	9.1	16.3	3.8	16.0			0.5	16.7	0.7	16.5	0.6	16.7	0.7	17.6
21-Oct	10.0	16.3	4.5	15.7			0.7	16.7	0.9	16.3	0.7	16.3	0.8	17.5
22-Oct	10.9	16.1	5.3	15.6			0.8	16.7	1.0	15.9	0.8	15.9	0.9	17.2
23-Oct	11.8	16.0					1.0	16.6	1.2	15.7	0.9	15.5	1.0	17.0
24-Oct							1.2	16.4	1.4	15.5	1.0	15.3	1.1	17.0
25-Oct							1.3	15.9	1.5	15.0	1.1	15.1	1.2	16.8
26-Oct							1.5	15.8	1.7	14.7	1.2	14.8	1.3	16.6
27-Oct							1.7	15.8	1.9	14.7	1.3	14.6		
28-Oct							1.8	15.7	2.1	14.4	1.4	14.5		
29-Oct							2.0	15.5	2.2	14.5				
30-Oct							2.2	15.2	2.4	14.4				
31-Oct							2.3	15.2						
1-Nov							2.5	15.0						
Loss (%)	7.3		0.8		0.2		1.0		0.5		0.6		1.3	

Table 5.—Date of fry presence along the Snake River upper and lower reaches, and mean water temperature (°C) on those dates, 1995–2013.

		Date of fry presence			Mean water temperature		
Year	Reach	First	Median	Last	First	Median	Last
1995	Lower	02-Apr	30-Apr	04-Jun	8.5	10.7	13.2
1996	Lower	15-Apr	06-May	24-Jun	8.5	10.7	13.9
1997	Lower	20-Apr	04-May	29-Jun	9.8	11.7	18.2
1998	Lower	12-Apr	26-Apr	14-Jun	9.6	10.7	15.5
1999	Lower	04-Apr	02-May	27-Jun	8.5	10.6	15.4
2000	Lower	03-Apr	10-Apr	05-Jun	9.3	10.3	14.8
2001	Lower	01-Apr	06-May	03-Jun	7.8	11.4	14.9
2002	Lower	31-Mar	05-May	16-Jun	6.8	11.0	16.2
2003	Lower	23-Mar	20-Apr	22-Jun	7.6	10.1	15.6
2004	Lower	22-Mar	03-May	07-Jun	7.4	12.8	15.2
2005	Lower	27-Mar	17-Apr	05-Jun	6.8	10.0	13.8
2006	Lower	26-Mar	14-May	11-Jun	6.8	13.1	14.9
2007	Lower	25-Mar	29-Apr	03-Jun	8.6	12.9	16.7
2008	Lower	24-Mar	28-Apr	16-Jun	6.8	9.9	13.8
2009	Lower	22-Mar	26-Apr	14-Jun	6.2	10.0	14.9
2010	Lower	21-Mar	25-Apr	20-Jun	7.5	9.9	14.2
2011	Lower	27-Mar	08-May	10-Jul	7.7	11.3	16.8
2012	Lower	26-Mar	07-May	11-Jun	7.0	11.3	12.6
2013	Lower	24-Mar	28-Apr	16-Jun	5.5	11.6	16.1
Mean ± SD		30-Mar ± 9 d	30-Apr ± 8 d	15-Jun ± 10 d	7.7± 1.2	11.1± 1.0	15.1± 1.4
1995	Upper	02-Apr	23-Apr	21-May	8.2	10.1	14.0
1996	Upper	15-Apr	29-Apr	06-May	10.7	12.0	12.7
1997	Upper	20-Apr	20-Apr	20-Apr	9.9	9.9	9.9
1998	Upper	12-Apr	19-Apr	10-May	9.3	9.7	13.9
1999	Upper	04-Apr	02-May	23-May	8.9	11.3	15.8
2000	Upper	03-Apr	10-Apr	15-May	9.1	10.3	13.9
2001	Upper	01-Apr	29-Apr	20-May	7.4	9.9	12.5
2002	Upper	31-Mar	21-Apr	02-Jun	6.1	10.3	14.3
2003	Upper	23-Mar	13-Apr	25-May	7.2	9.8	13.7
2004	Upper	22-Mar	19-Apr	24-May	6.7	11.4	14.0
2005	Upper	27-Mar	17-Apr	15-May	6.6	9.0	12.7
2006	Upper	26-Mar	16-Apr	21-May	6.2	9.6	14.9
2007	Upper	25-Mar	22-Apr	03-Jun	7.5	10.8	15.9
2008	Upper	31-Mar	28-Apr	26-May	7.2	10.0	13.6
2009	Upper	22-Mar	19-Apr	17-May	5.1	8.9	13.8
2010	Upper	21-Mar	25-Apr	06-Jun	7.2	10.5	14.0
2011	Upper	27-Mar	08-May	12-Jun	7.4	11.2	15.0
2012	Upper	26-Mar	30-Apr	18-Jun	6.9	12.8	16.7
2013	Upper	24-Mar	21-Apr	26-May	4.8	9.9	14.0
Mean ± SD		30-Mar ± 8 d	23-Apr ± 7 d	23-May ± 13 d	7.5± 2.0	10.4± 2.3	14.0± 3.1

Table 6.—Dates of parr presence along the Snake River upper and lower reaches (see Connor et al. 2002) including and temperature (°C) on the peak of rearing, and mean and maximum temperature over the rearing period, 1995–2013.

		Date of parr presence			Mean water temperature		
Year	Reach	Peak	First	Last	On Peak	Mean	Max
1995	Lower	07-Jun	05-Apr	06-Jul	11.6	12.2	16.8
1996	Lower	29-May	17-Apr	18-Jul	12.8	13.3	20.4
1997	Lower	13-Jun	22-Apr	16-Jul	13.5	14.0	19.8
1998	Lower	26-May	14-Apr	08-Jul	12.4	13.6	19.6
1999	Lower	16-Jun	06-Apr	15-Jul	14.3	12.7	19.8
2000	Lower	10-May	05-Apr	29-Jun	12.0	13.5	19.4
2001	Lower	22-May	04-Apr	27-Jun	13.9	13.0	19.8
2002	Lower	29-May	02-Apr	16-Jul	13.3	13.3	22.3
2003	Lower	21-May	25-Mar	02-Jul	11.5	12.1	19.4
2004	Lower	19-May	01-Apr	30-Jun	12.9	13.1	19.7
2005	Lower	11-May	29-Mar	05-Jul	11.1	12.7	19.7
2006	Lower	16-May	11-Apr	27-Jun	13.2	13.2	19.5
2007	Lower	08-May	27-Mar	03-Jul	11.9	13.3	20.5
2008	Lower	14-May	27-Mar	17-Jul	10.5	12.0	19.9
2009	Lower	19-May	08-Apr	07-Jul	12.6	13.0	20.3
2010	Lower	18-May	30-Mar	20-Jul	13.0	12.9	20.6
2011	Lower	27-May	30-Mar	13-Jul	11.6	11.9	17.9
2012	Lower	13-Jun	11-Apr	11-Jul	13.1	13.3	20.7
2013	Lower	08-May	27-Mar	26-Jun	12.9	12.0	17.2
Mean ± SD		24-May ± 12 d	04-Apr ± 8 d	08-Jul ± 8 d	12.5 ± 1.0	12.9 ± 0.6	19.6 ± 1.3
1995	Upper	01-Jun	13-Apr	22-Jun	16.0	13.2	17.0
1996	Upper	24-May	19-Apr	21-Jun	13.8	14.2	18.1
1997	Upper	29-May	24-Apr	20-Jun	15.0	14.3	17.1
1998	Upper	12-May	16-Apr	06-Jul	14.5	14.4	19.1
1999	Upper	26-May	15-Apr	02-Jul	14.0	14.7	19.5
2000	Upper	27-Apr	07-Apr	16-Jun	12.9	13.7	17.2
2001	Upper	03-May	06-Apr	14-Jun	8.9	11.9	16.1
2002	Upper	25-Apr	12-Apr	03-Jul	10.8	13.5	18.8
2003	Upper	08-May	27-Mar	26-Jun	11.7	12.6	18.5
2004	Upper	07-May	02-Apr	25-Jun	13.2	13.7	18.0
2005	Upper	05-May	31-Mar	23-Jun	11.2	12.3	17.1
2006	Upper	18-May	31-Mar	29-Jun	14.5	13.8	19.0
2007	Upper	03-May	05-Apr	05-Jul	11.9	14.0	19.6
2008	Upper	16-May	11-Apr	18-Jul	12.8	14.1	20.0
2009	Upper	14-May	02-Apr	18-Jun	13.0	12.8	18.5
2010	Upper	13-May	01-Apr	22-Jul	12.0	13.7	20.3
2011	Upper	17-May	07-Apr	07-Jul	12.6	13.3	19.0
2012	Upper	11-May	20-Apr	29-Jun	13.0	14.5	18.5
2013	Upper	02-May	18-Apr	27-Jun	11.0	13.8	17.5
Mean ± SD		12-May ± 10d	09-Apr ± 8 d	29-Jun ± 10d	12.8 ± 3.0	13.6 ± 2.9	18.4 ± 3.9

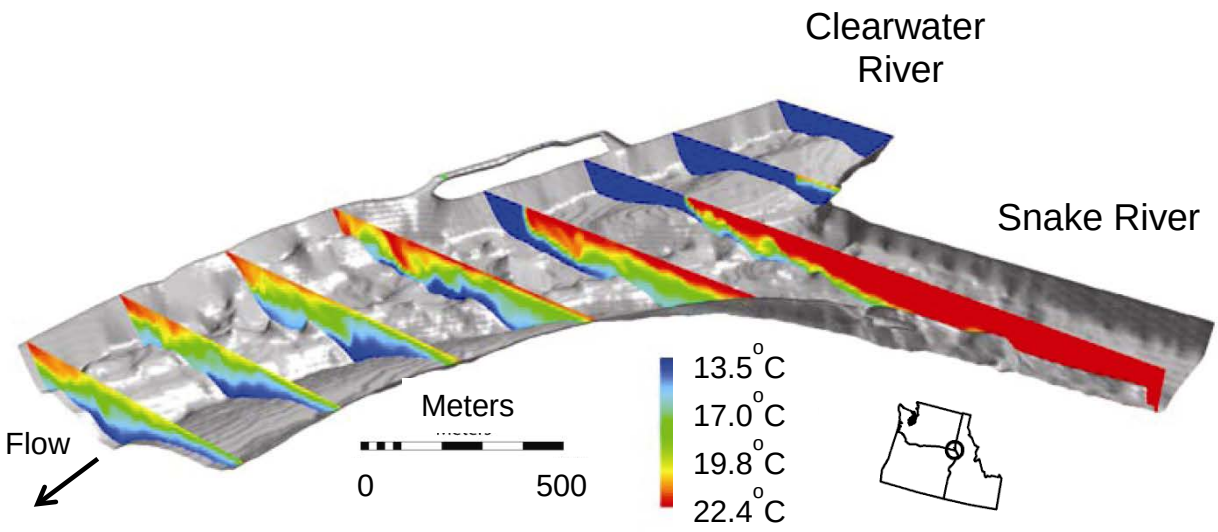

Figure 2.—Thermal layering modeled in Lower Granite Reservoir at the confluence of the Snake and Clearwater rivers during the implementation of summer flow augmentation (Cook et al. 2006).

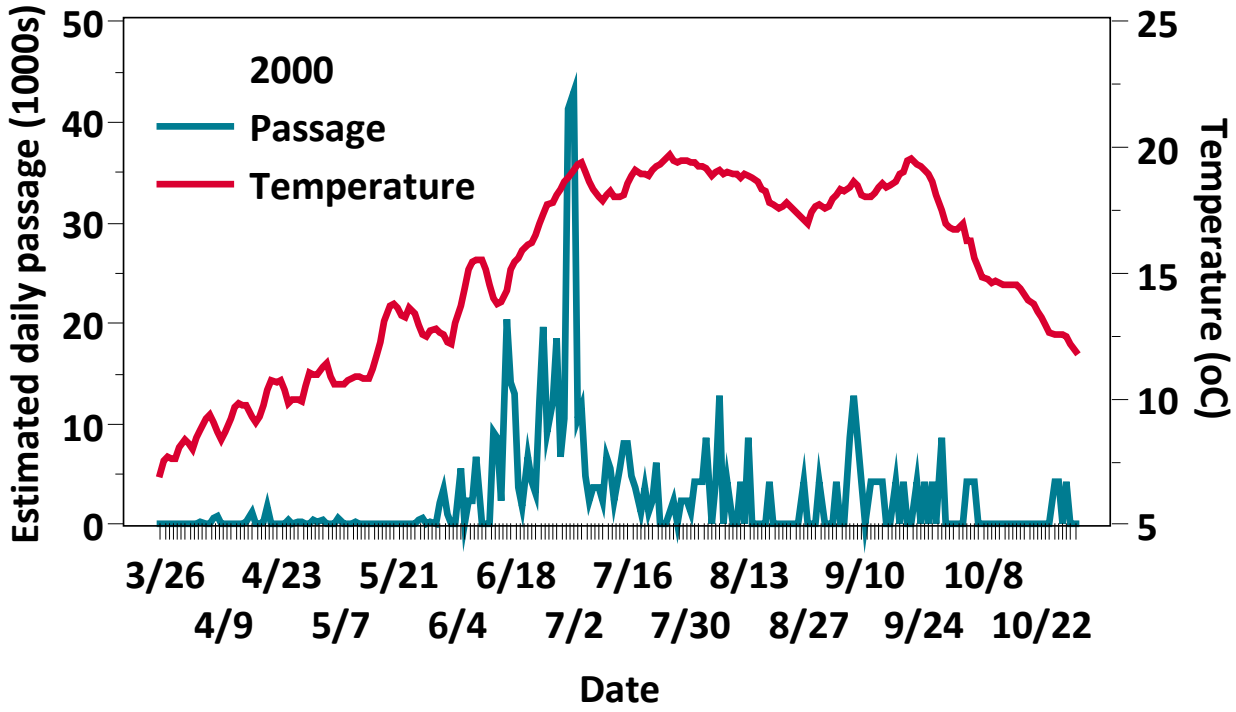

Figure 3.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2000.

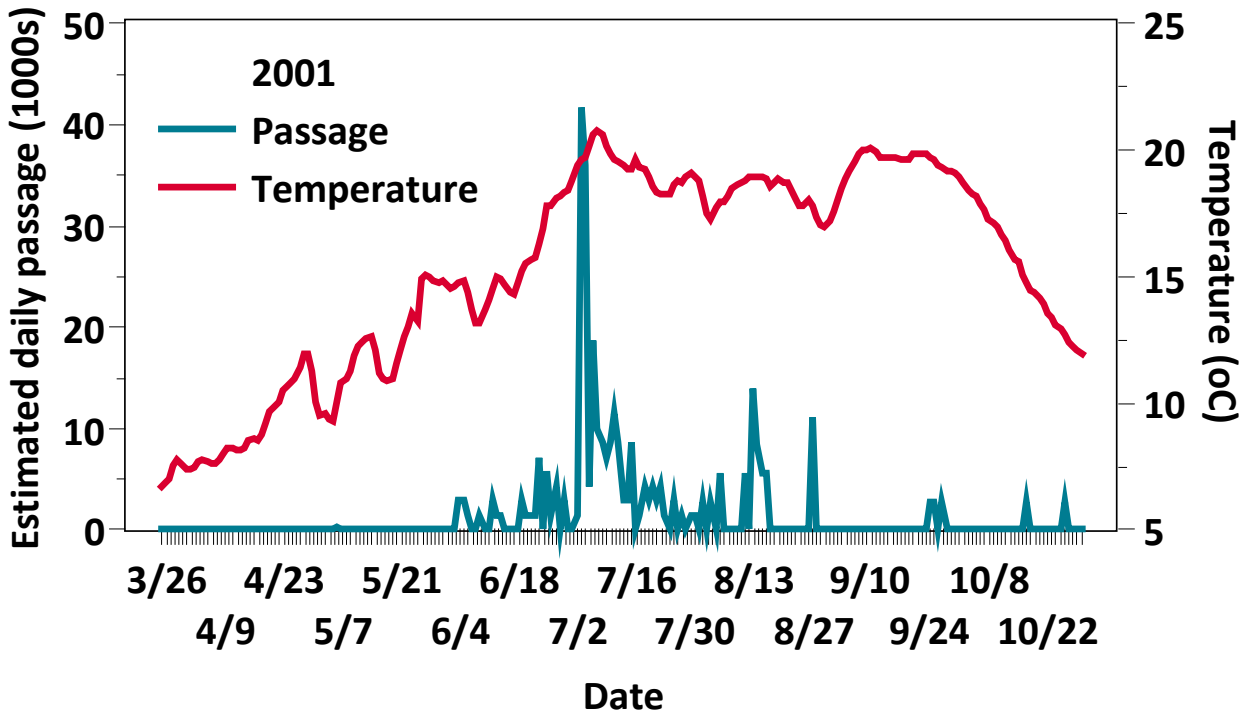

Figure 4.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2001.

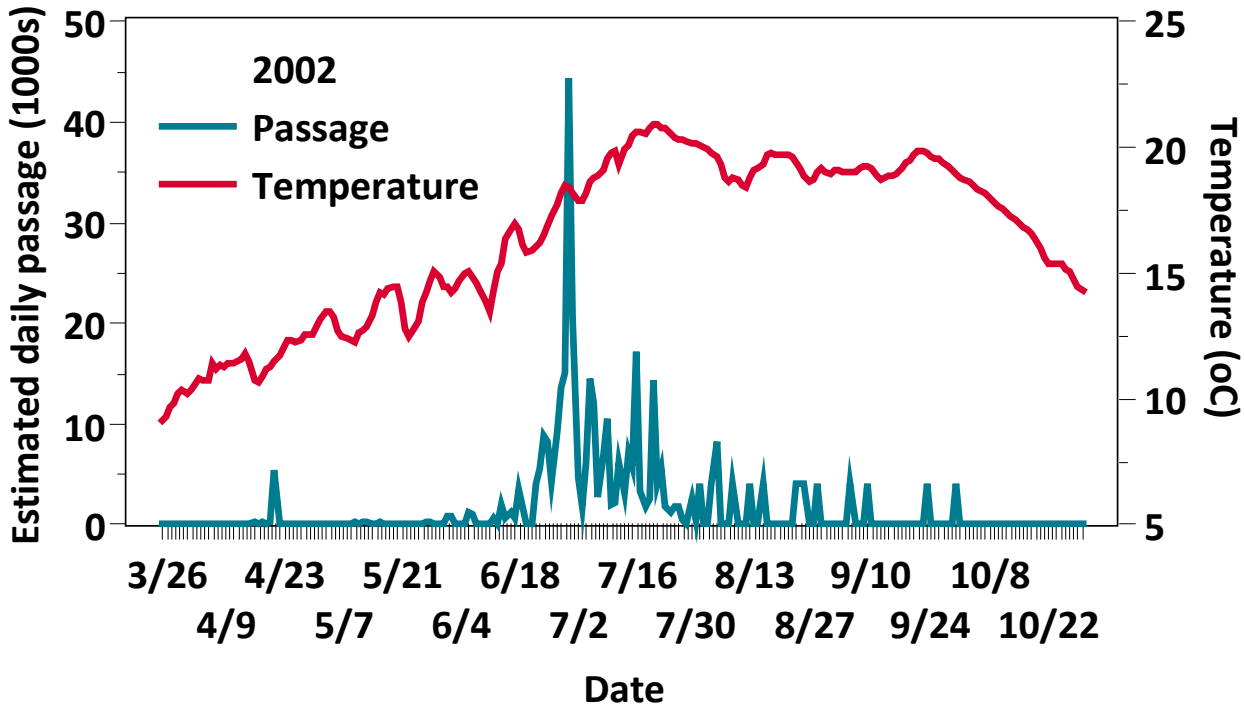

Figure 5.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2002.

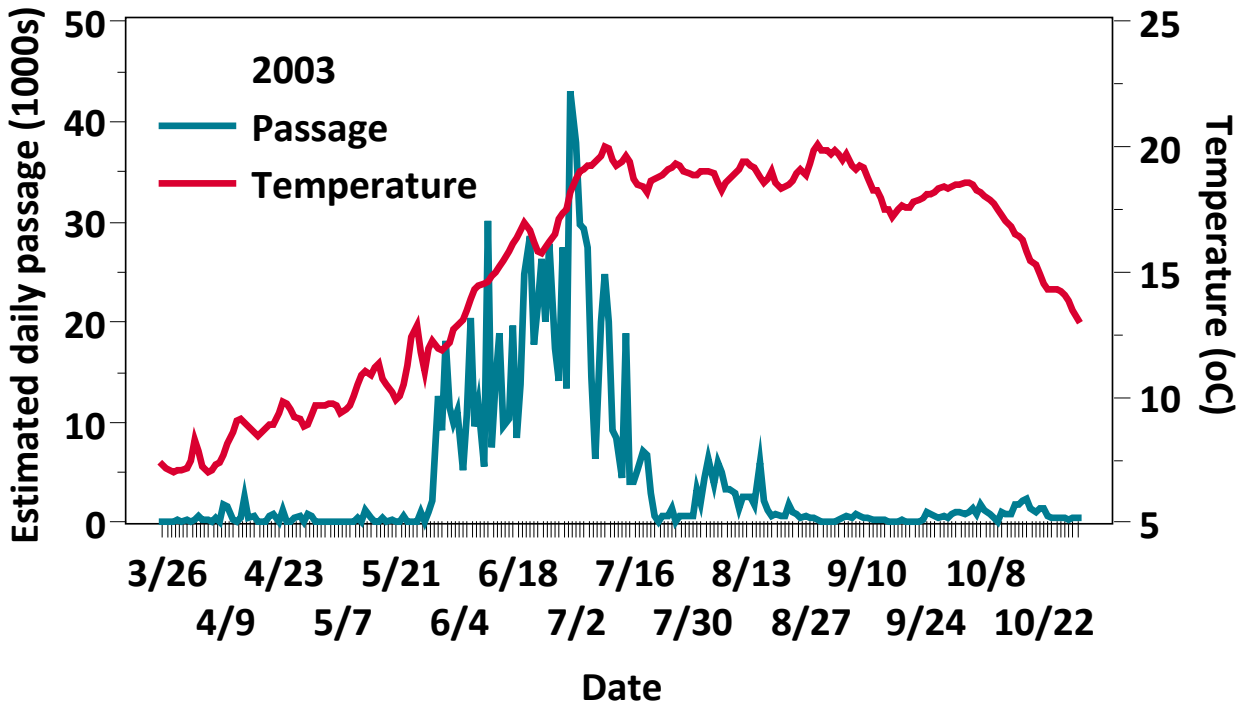

Figure 6.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2003.

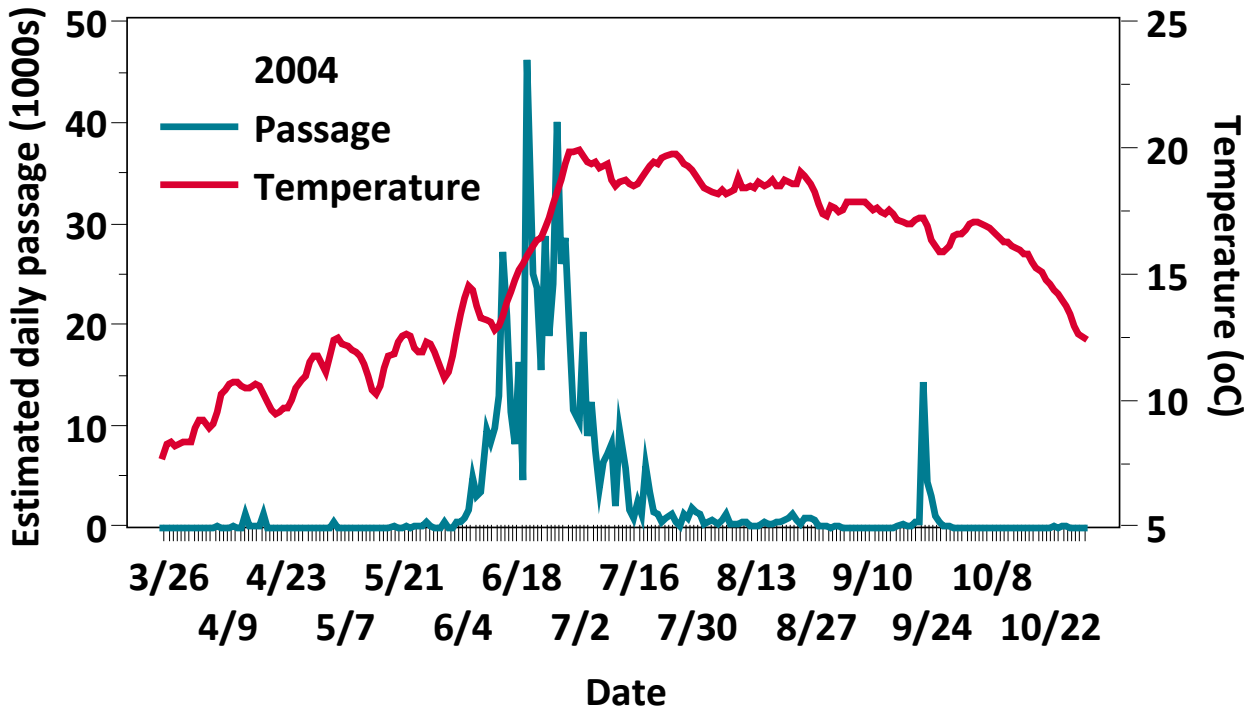

Figure 7.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2004.

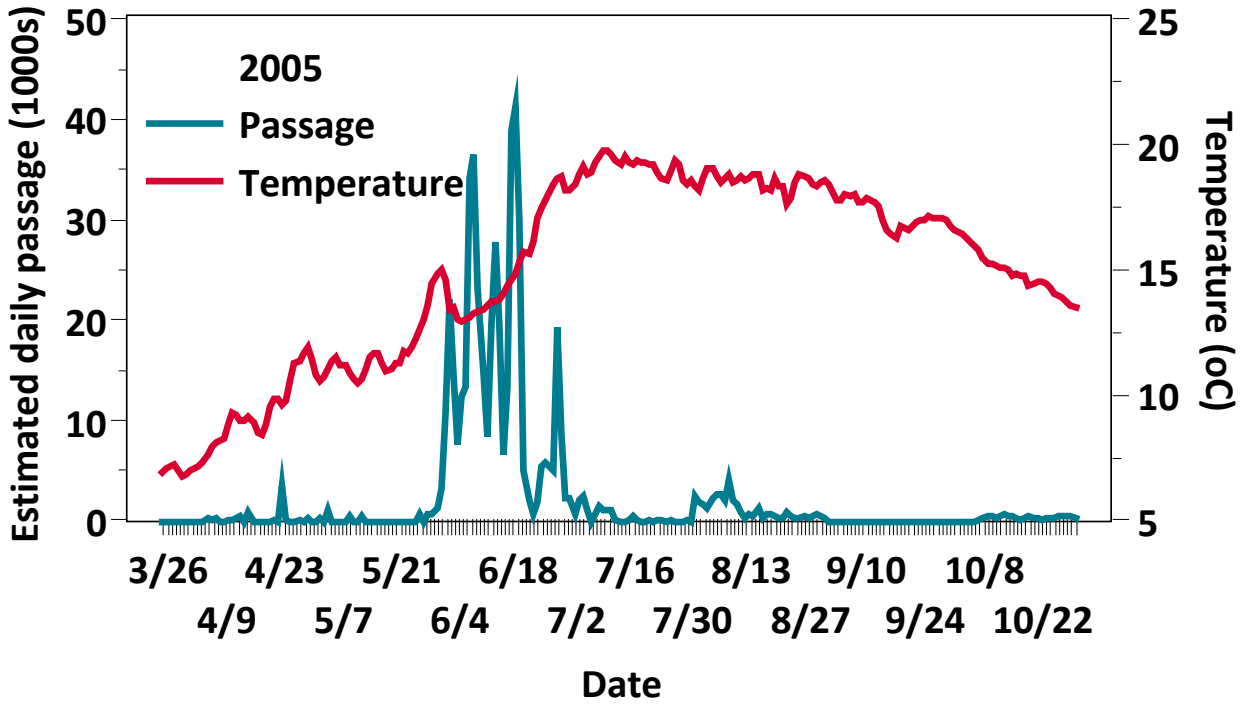

Figure 8.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2005.

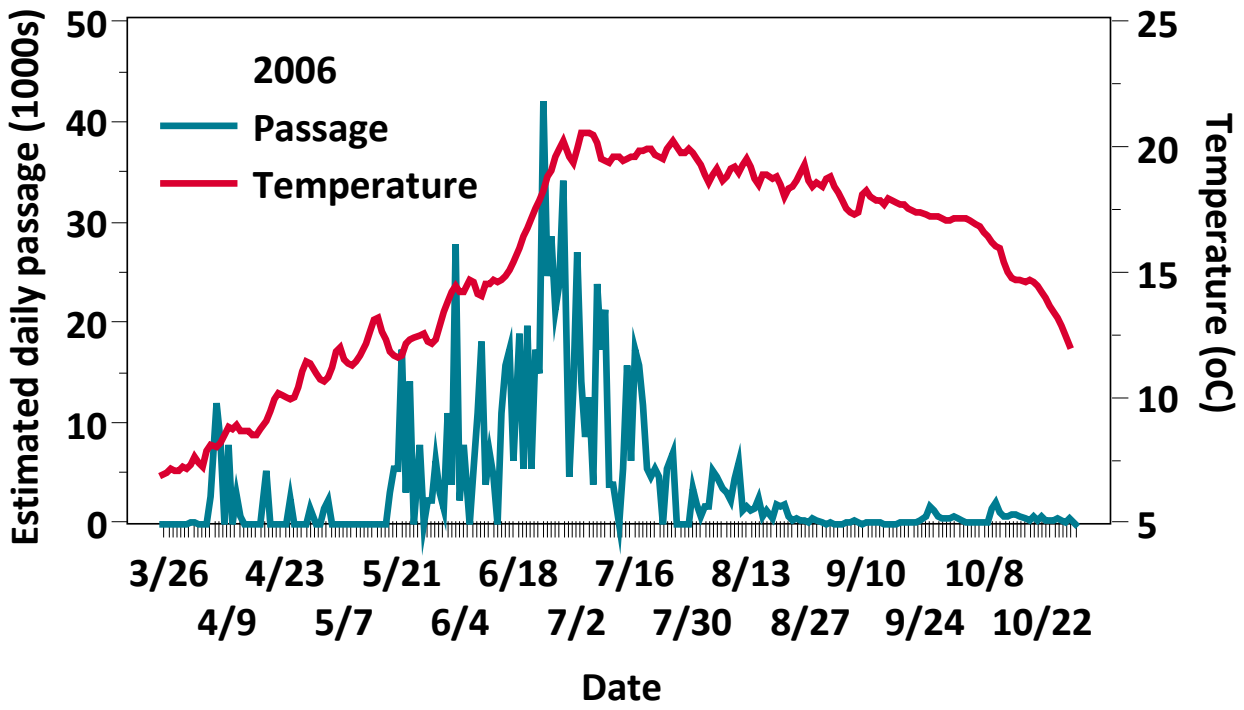

Figure 9.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2006.

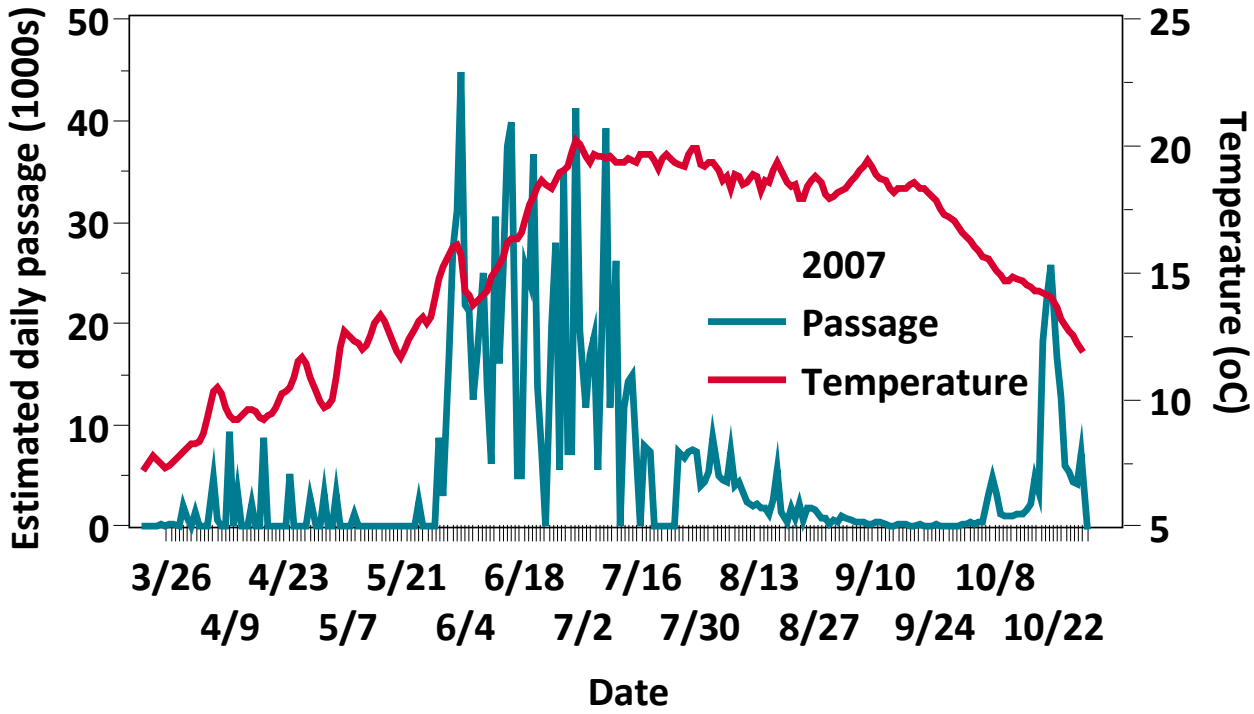

Figure10.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2007.

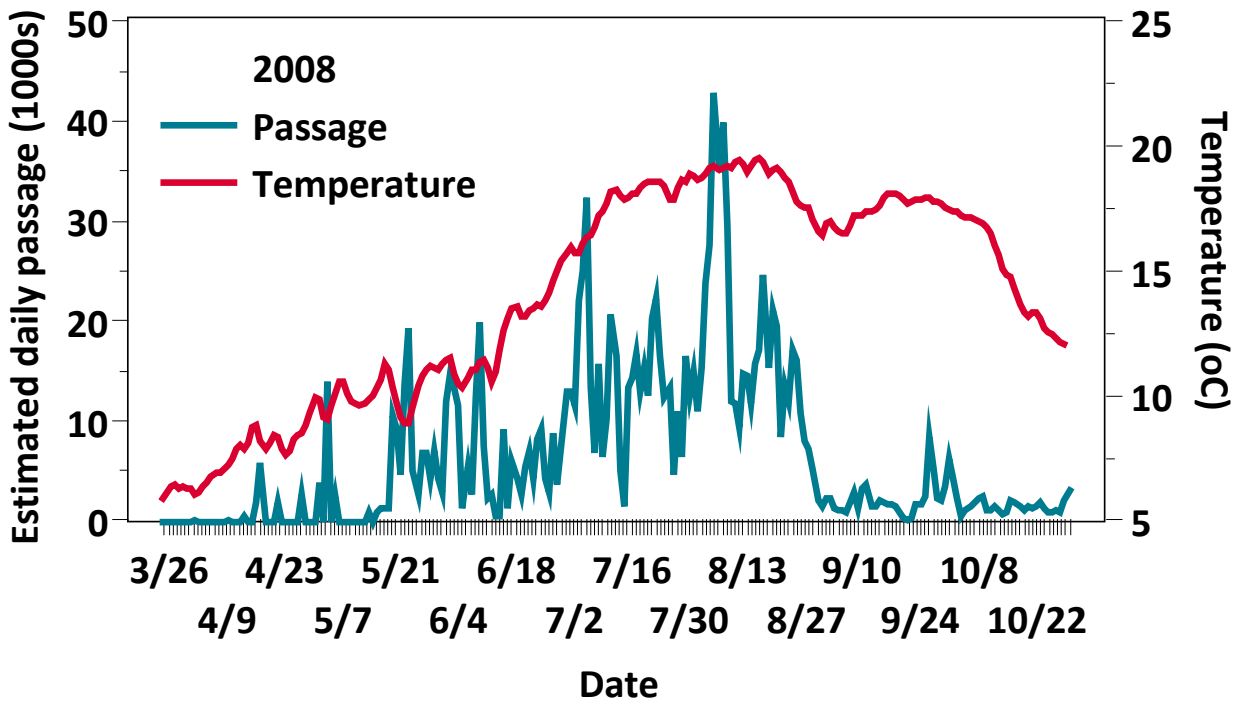

Figure11.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2008.

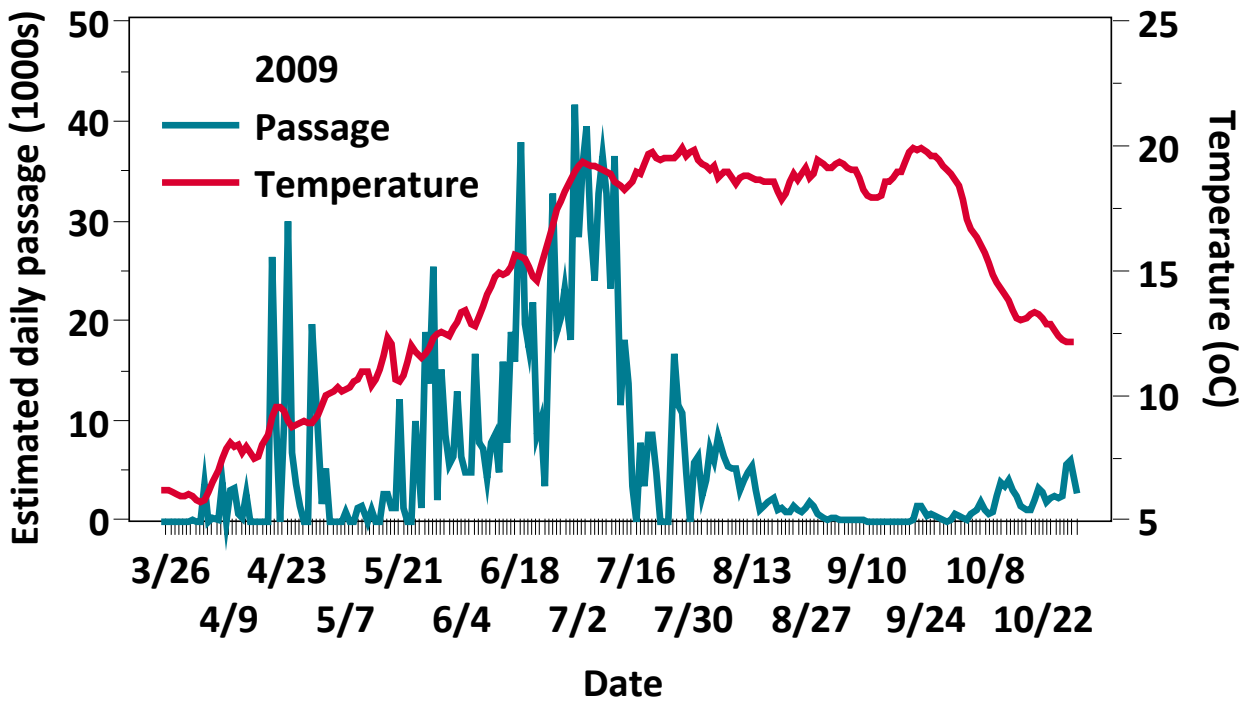

Figure12.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2009.

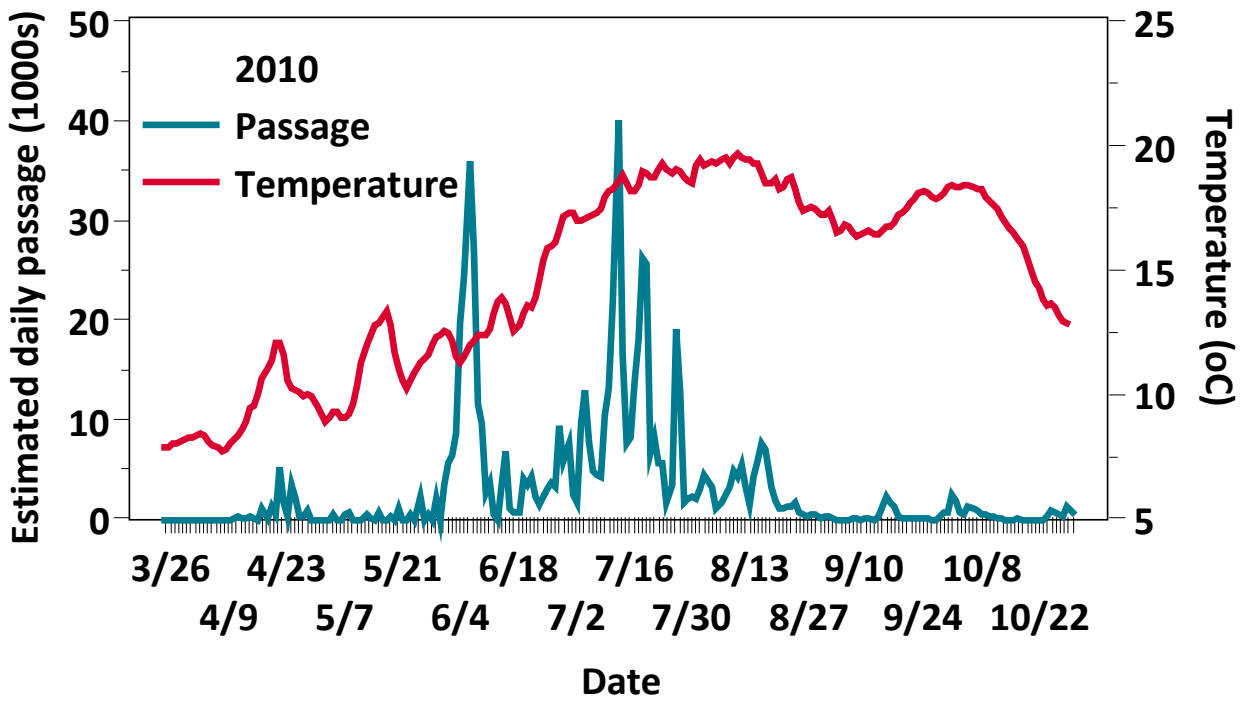

Figure13.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2010.

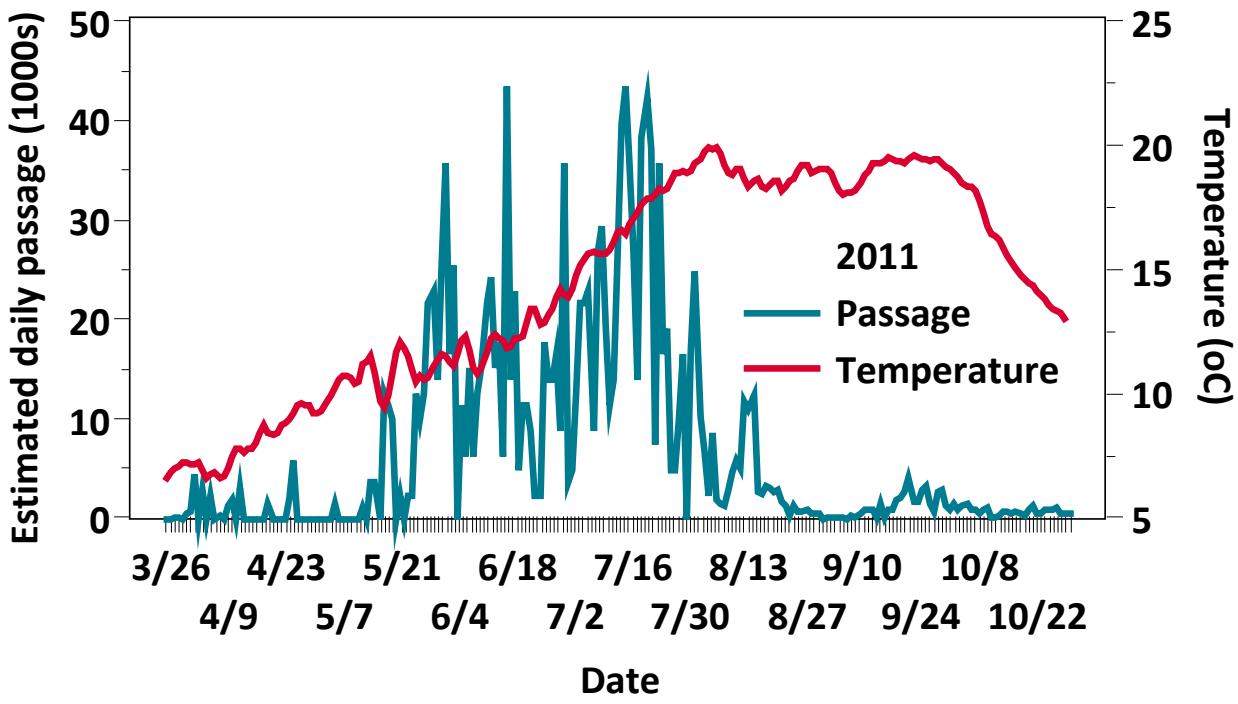

Figure14.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2011.

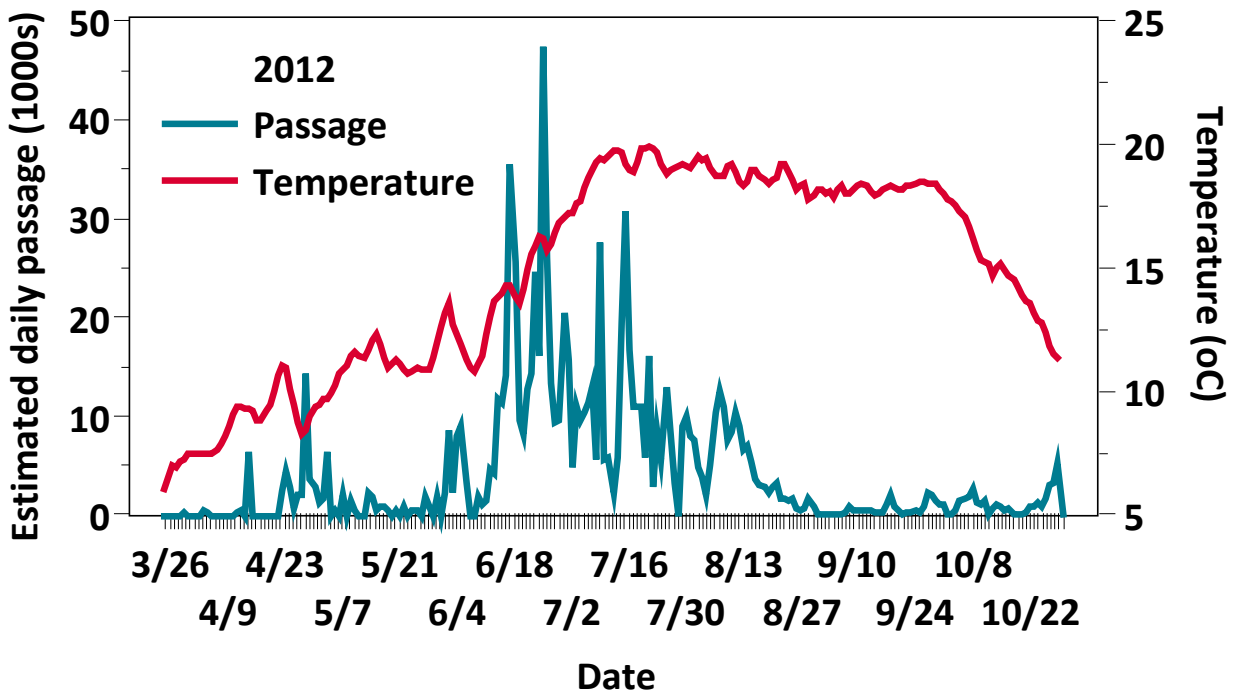

Figure15.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2012.

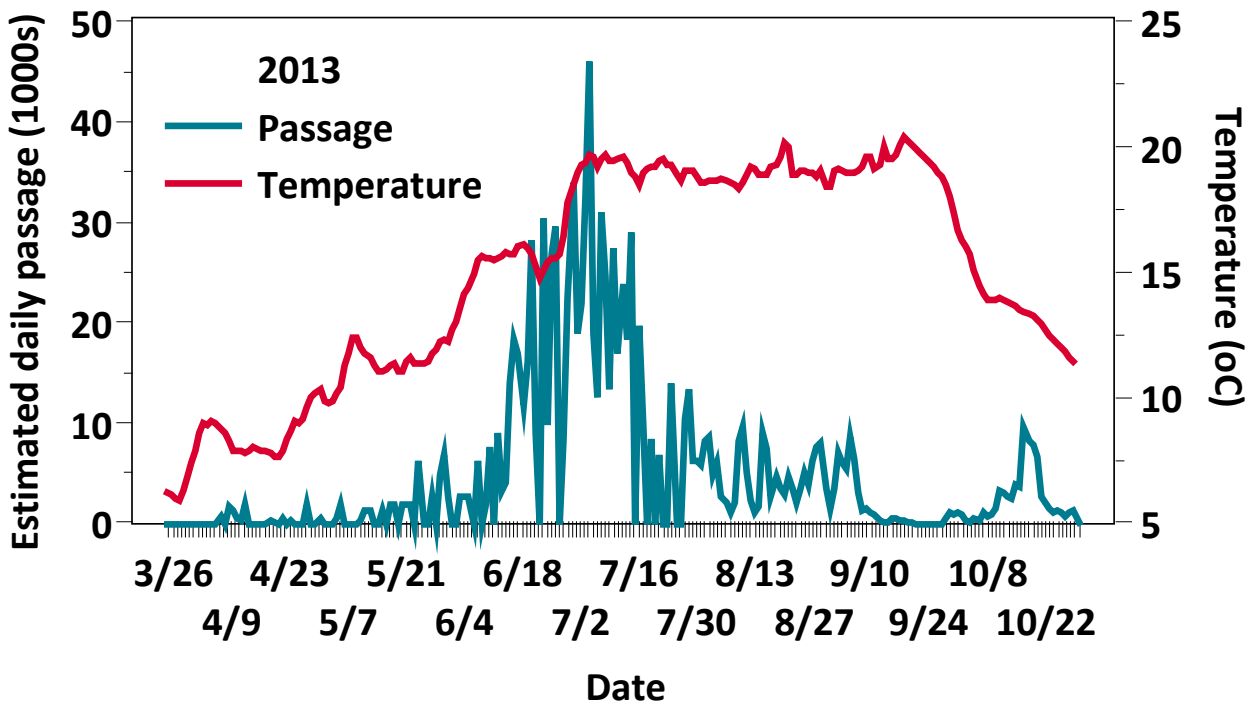

Figure16.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2013.

Acknowledgements

Jim Chandler provided invaluable insight to the influence of the Hells Canyon Complex of Dams on temperature. Phillip Groves was the principal investigator during temperature data collection and redd surveys along the lower Snake River. Funding for this report was provided under project 199102900 funded by the Bonneville Power Administration.

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