LOWER MOKELUMNE RIVER
UPSTREAM FISH MIGRATION MONITORING
Conducted at Woodbridge Irrigation District Dam
August 2016 through January 2017

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***Abstract*: This report summarizes data collected below Woodbridge Irrigation District Dam (WIDD) on the lower Mokelumne River (LMR) from August 1, 2016 through January 6, 2017. An estimated 8,871 fall-run Chinook salmon (*Oncorhynchus tshawytscha*) passed the WIDD fish ladder between October 1, 2016 and January 6, 2017. Fifty percent of the run passed WIDD by November 9, 2016. Ninety percent of the run passed WIDD by December 8, 2016. Highest daily passage was 324 Chinook salmon on November 9, 2016. The sex and life stage was positively determined for 8,865 fish including 2,366 (27%) adult females, 2,226 (25%) adult males, 1,404 (16%) grilse females, and 2,869 (32%) grilse males. Managed pulse flows were followed by peaks in daily passage and contributed to the high overall returns. Sixty percent of Chinook salmon passage occurred during pulse flow events.**

INTRODUCTION

East Bay Municipal Utility District (EBMUD) has been monitoring adult fall-run Chinook salmon (*Oncorhynchus tshawytscha*) escapement in the lower Mokelumne River (LMR) using video monitoring and trapping at the Woodbridge Irrigation District Dam (WIDD) at river kilometer (Rkm) 64 since fall 1990. Beginning in 2010, through coordination between EBMUD and Woodbridge Irrigation District, Lodi Lake remained full of water throughout the Chinook salmon run. This facilitated continuous video monitoring of Chinook salmon passage in the high stage ladder at WIDD. WIDD operations remained the same during the upstream migration of fall-run Chinook salmon from 2010/2011 through 2016/2017. Therefore, total Mokelumne River fall-run Chinook salmon escapement during these years was based on video monitoring of fish passage at WIDD.

OBJECTIVES

The objectives of this study are to 1) develop an escapement estimate for fall-run Chinook salmon in the LMR, 2) summarize sex and age composition, run timing, and coded wire tag component of the 2016 LMR fall-run Chinook salmon population, 3) describe the relationship of fall-run Chinook salmon movements to environmental conditions and management actions in the LMR and Sacramento-San Joaquin Delta and 4) monitor presence of native and non-native fishes in the WIDD high stage fish ladder.

METHODS

Video

EBMUD's video monitoring in the high stage ladder at WIDD is typically conducted year round, with the exception of a short period of time when the dam is lowered for annual maintenance. This year video monitoring ended on January 6, 2017 when flows exceeded 3,000 cubic feet per second (cfs) and river elevations allowed free passage over the entire dam without the need of the fish ladder. As a result of the forced termination of video monitoring in January during the 2016 run, we estimate that unrecorded Chinook salmon passage was less than 1% of the total escapement based on the run timing and passage counts of adult Chinook salmon migration since 2010.

All other monitoring, data collection, and storage methods for video monitoring were consistent with prior years' monitoring efforts (Marine and Vogel 2000, Workman 2004). For day and night passage designations, the NOAA Solar Calculator (NOAA n.d.) was used to estimate apparent sunrise and sunset. Apparent sunrise and sunset are a result of atmospheric refraction. Atmospheric refraction causes apparent sunrise to occur shortly before the sun crests the horizon and apparent sunset to extend beyond the actual sunset.

Migration Response

Generalized additive models (GAM) were used to identify the influential variables that promote fish passage in the LMR at WIDD. GAMs allow flexibility in the dependency of a response to the covariates by defining the model in terms of smooth functions and not detailed parametric models (Wood 2017). This allows the linear predictor to predict a smooth monotonic function while the response can follow any exponential family distribution.

Covariates used to investigate the relationship between daily salmon counts were average daily flow below WIDD, change in average daily flow below WIDD, positive average daily flow within the North and South Forks of the LMR, proportion of LMR flow below WIDD to positive flow with the North and South Forks, water temperature, and precipitation. In addition, pulse flows and Delta Cross Channel (DCC) operations were categorized as binary variables and treated as factors with the GAMs in order to denote pulse flow events and DCC closures. Covariates were lagged up to seven days in order to investigate delayed responses to each variable. Akaike Information Criterion (AIC) was used to select the best models. Covariates that were not significant were removed from the model if the AIC was improved. All data analyses were performed in the R programming package mgcv.

RESULTS AND DISCUSSION

Fall-Run Chinook Salmon

The fall-run Chinook salmon escapement estimate in the LMR for 2016/2017 is 8,871 spawners entering the river between October 2016 and January 2017 (Figure 1). The highest daily passage of 324 salmon occurred on November 9, 2016. Based on years with continuous salmon passage monitoring at WIDD, fifty percent of Chinook salmon migrated past WIDD between October 24th and November 23th. During the 2016 run, 10% of Chinook salmon passed WIDD by October 18th, 50% passed WIDD by November 9th, and 90% passed WIDD by December 8th (Figure 2).

Sex and life stage were positively determined for 8,865 fish. This includes 2,366 (27%) adult (≥70 cm FL) females, 2,226 (25%) adult males, 1,404 (16%) grilse (<70 cm FL) females, and 2,869 (32%) grilse males (Figure 3). In 2016, approximately a 1:1 grilse to adult ratio was observed on the LMR (48% GR; 52% AD) (Figure 4).

In the 2016/2017 monitoring season, 63% of fish passed the video monitor during the day and 37% during the night. Following relatively consistent hourly passage rates at night, Chinook salmon passage spiked with the onset of sunrise (Figure 5). Peak passage occurred between 0700 hrs and 0900 hrs. Passage continued throughout the day, but decreased following sunset. This trend is consistent with historic passage rates with daytime passage on the Mokelumne River consistently higher than nighttime passage.

Clipped adipose fins were evident on 2,198 (25%) of the observed fall-run Chinook salmon. The sex and life stage were positively determined for 2,195 (1,127 adult and 1,068 grilse) adipose fin clipped fish. Of the fish identified with an adipose fin clip, 616 (28%) were adult (≥70 cm FL) females, 511 (23%) were adult males, 395 (18%) were grilse (<70 cm FL) females, and 673 (31%) were grilse males. Twenty-six percent of the returning adult females were adipose fin clipped, 23% of the adult males were adipose fin clipped, 28% of the grilse females were adipose fin clipped, and 23% of the grilse males were adipose fin clipped. Between 2011 and 2014, approximately 25% of hatchery reared Chinook salmon at the Mokelumne River Fish Hatchery were coded wire tagged and adclipped.

<u>Mokelumne River Flow, Water Temperature, and Rainfall</u>

During the 2016/2017 Chinook salmon migration period, Camanche Dam daily average releases ranged from 274 – 4,926 cfs (Figure 6). Average daily flow was 717 cfs. Average daily flow below WIDD ranged from 105 – 3,327 cfs and averaged 573 cfs (Figure 6). Daily average water temperatures from October through January ranged from 11.4 – 14 C° below Camanche Dam (Figure 7) and 11.3 – 18.7 C° below WIDD (Figure 8). Total rainfall, collected at the Camp Pardee station, was 13.2 inches (Figure 9). Peak daily rainfall was 1.74 inches.

Management Actions and Migration Response

Expected flow below WIDD during August and September was based on the Joint Settlement Agreement (JSA) Below Normal water year type. The water year designation for October through March was Normal and Above. In accordance with the October through March JSA water year designation, flow was increased below WIDD on September 30, 2016 in order to maintain the minimum JSA flow requirement of 100 cfs. This increase in flow corresponded with the first Chinook salmon observed moving passed WIDD on October 1, 2016.

EBMUD conducted 10 planned pulse flow events from October through December, through increased releases from Camanche Reservoir. This was the seventh year in a row that EBMUD released fall attraction flows in the LMR. Sixty percent of Chinook salmon passage occurred during pulse flow events. Woodbridge Irrigation District also supported the implementation of fall attraction flows by the re-regulation of Camanche Reservoir releases. Woodbridge Irrigation District was able to surcharge Lodi Lake by building up the lake elevation to approximately 40 feet and then dropping the lake level by 1 - 2 feet thereby augmenting EBMUD planned pulses. EBMUD did not release any additional water above and beyond typical flow releases in order to surcharge Lodi Lake. In addition to the pulse flow events, multiple DCC closures occurred during the Chinook salmon run in order to reduce mortality of emigrating juvenile salmonids and green sturgeon from the Sacramento River pursuant with the NMFS RPA Action IV.1.2 (NMFS 2009).

As in previous years, peaks in Chinook salmon passage corresponded with pulse flow events (Figure 6). Table 1 summarizes each pulse flow event and concurrent DCC closure conducted during the migration of fall-run Chinook salmon to the Mokelumne River.

Table 1 Summary of management actions, including pulse flow events and corresponding DCC closures, implemented during the 2016/2017 Mokelumne River Chinook salmon run.

Pulse Flow	Date of Peak Flow	Peak Flow (cfs)[1]	Peak Passage Event	Daily CS Passage Total[2]	DCC Operations
1	10/4/2016	574 cfs	10/6/2016	39 CS	Open
2	10/12/2016	453 cfs	10/13/2016	153 CS	Open
3	10/20/2016	786 cfs	10/20/2016	247 CS	Open
4	10/26/2016	989 cfs	10/26/2016	285 CS	Open
5	11/2/2016	1030 cfs	11/2/2016	301 CS	Open
6	11/9/2016	895 cfs	11/9/2016	324 CS[3]	Open
7	11/16/2016	979 cfs	11/16/2016	320 CS	Open
8	11/22/2016	968 cfs	11/22/2016	223 CS	Open
9	11/30/2016	997 cfs	12/2/2016	102 CS	Closed
10	12/7/2016	946 cfs	12/11/2016	154 CS	Closed

[1]Flow is based on raw 15 minute instantaneous measurements recorded at the Golf gauge located downstream of WIDD. Flow data are preliminary and subject to change.
[2] CS = Chinook salmon.
[3]Highest daily passage of fall-run Chinook salmon recorded during the 2016/2017 monitoring period.

GAMs with smooth main effects plus interactions and a poisson distribution performed the best. Pulse flow events, DCC operations, North and South Fork flows, proportion of LMR to North and South Fork flows (lagged 6 days), precipitation (lagged 3 days), and the interactions between flow below WIDD and temperature (lagged 6 days) significantly influenced Chinook salmon passage counts at WIDD (Table 2).

Table 2 Final GAM for Chinook salmon passage counts at WIDD based on environmental and management variables on the lower Mokelumne River during the 2016 salmon run.

Covariates	df	edf	Chi.sq	p-value
Pulse	1	-	18.17	<0.0001
DCC	1	-	11.14	0.0008
North and South Fork Flows	-	8.76	269.9	<0.0001
LMR Flow Proportion (6 days)	-	8.709	112.2	<0.0001
Precipitation (3 days)	-	9	148.9	<0.0001
Flow Below WIDD & Temp (6 days): No Pulse	-	22.666	672	<0.0001
Flow Below WIDD & Temp (6 days): Pulse Event	-	23.916	747.6	<0.0001

Incidental Species

Steelhead (*O. mykiss*) have been observed since monitoring began in 1990. Spawning, typically occurs between January and March for winter steelhead in the Central Valley (IEP Steelhead PWT 1999). However, steelhead were observed in the ladder at WIDD from August through January. Yearling steelhead (FL <20 cm) and subadult steelhead (FL ≤35 cm) were not counted due to their ability to pass through the bars which guide fish in front of the video monitoring vault and their tendency to hold within the high stage ladder. Due to extended residency times of subadult steelhead within the ladder this year and the difficulty in documenting upstream passage, only steelhead presence is reported.

Presence and absence data of native and non-native species are presented in Table 3. Native fishes observed using the ladder include steelhead, Pacific lamprey, Sacramento sucker, and tule perch. Non-native fish using the fish ladders at WIDD include black bass, brown bullhead, goldfish, largemouth bass, redear sunfish, striped bass, and unidentified centrarchids.

Table 3. Native and non-native fish observed in the Woodbridge Irrigation District Dam fish ladder, August 1, 2016 – January 6, 2017. Species names in bold represent native species.

	August	September	October	November	December	January
Steelhead	X	X	X	X	X	X
Pacific Lamprey			X		X	X
Sacramento Sucker			X	X	X	
Tule Perch	X					
Black Bass		X				
Brown Bullhead		X				
Goldfish	X					
Largemouth Bass	X		X			
Redear Sunfish	X				X	
Striped Bass	X	X				

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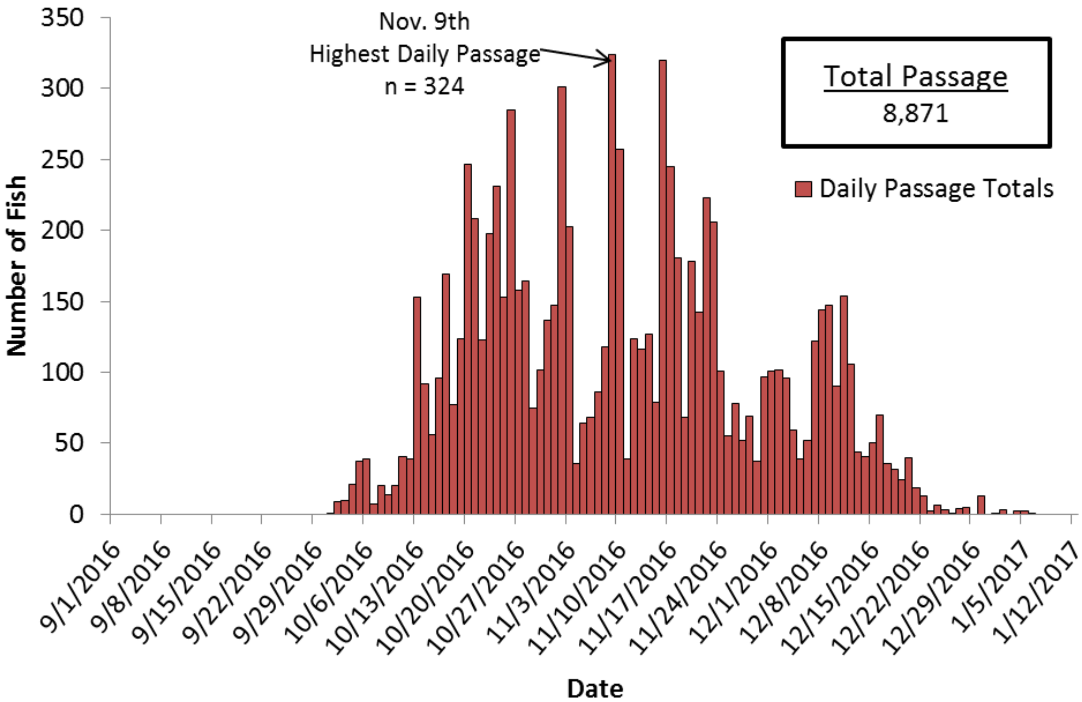

Figure 1. Daily abundance and timing of fall-run Chinook salmon migrating past WIDD.

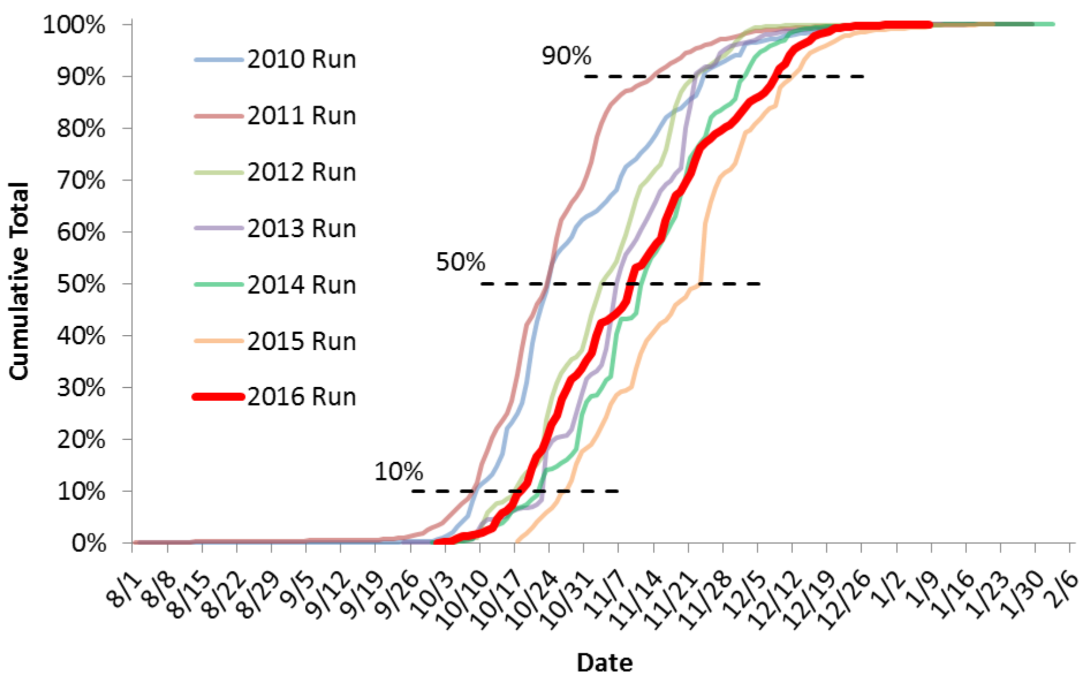

Figure 2. Run time of Chinook salmon migrating to the LMR. Dashed lines represent 10%, 50%, and 90% of fall-run Chinook salmon passed the Woodbridge Irrigation District Dam, 2010-2015. Run years were limited to 2010 – present as this period encompasses the range of identified 50% passage dates on the LMR since monitoring began in 1990.

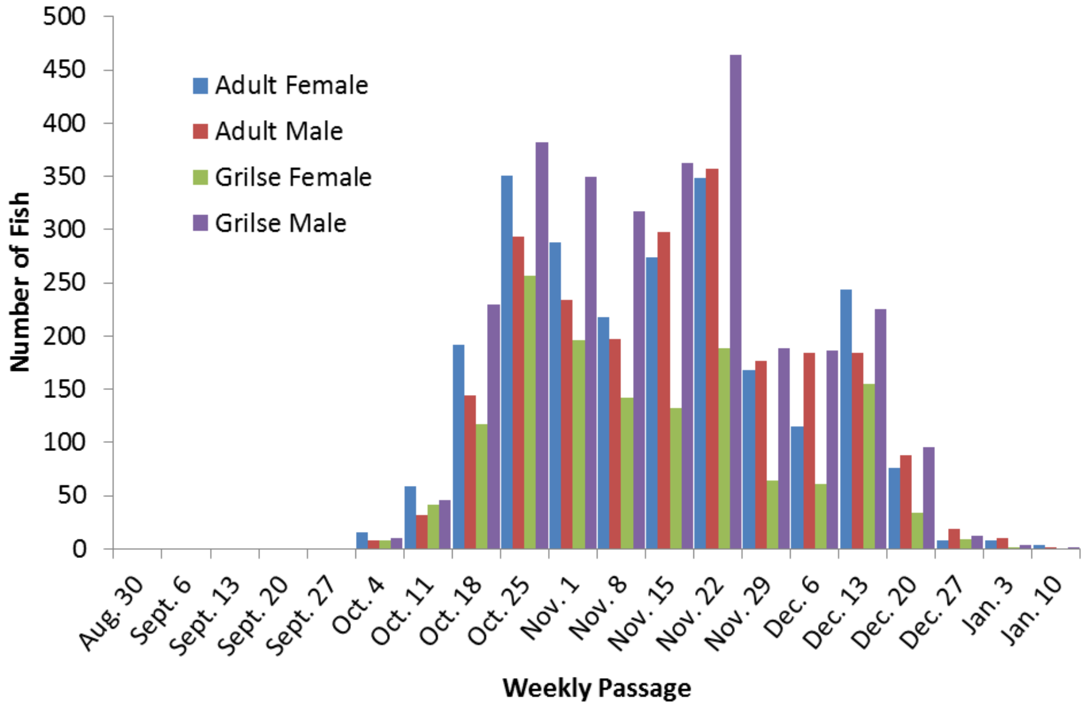

Figure 3. Weekly sex/age composition of fall-run Chinook salmon passing WIDD.

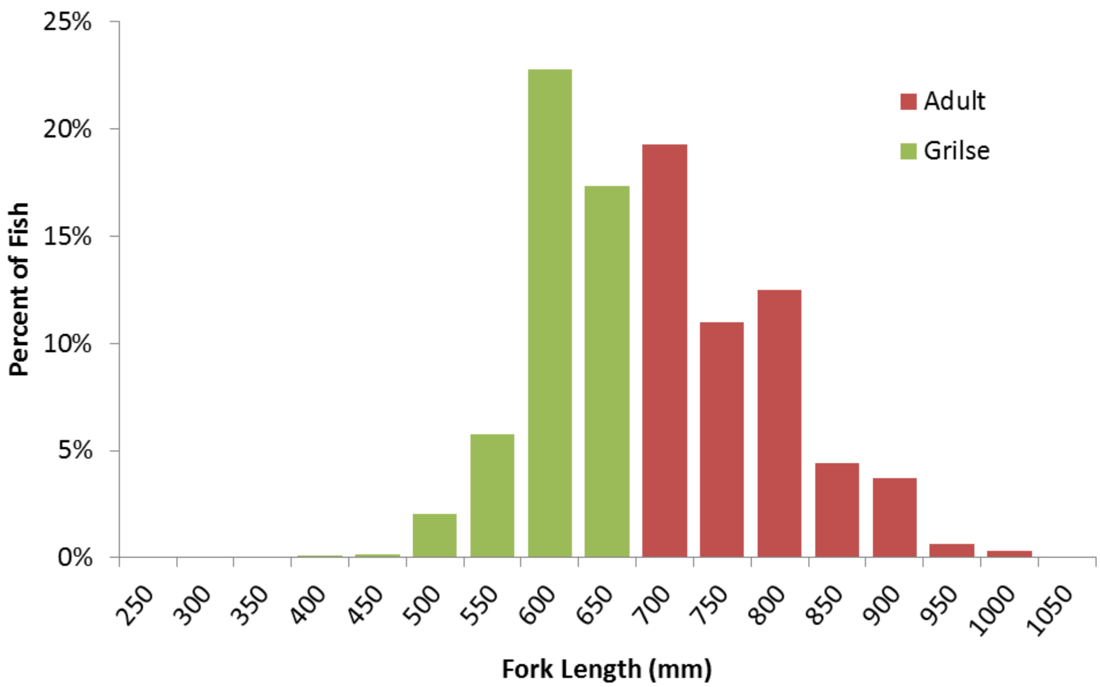

Figure 4. Length frequency of adult and grilse Chinook salmon (% by size class) passing WIDD.

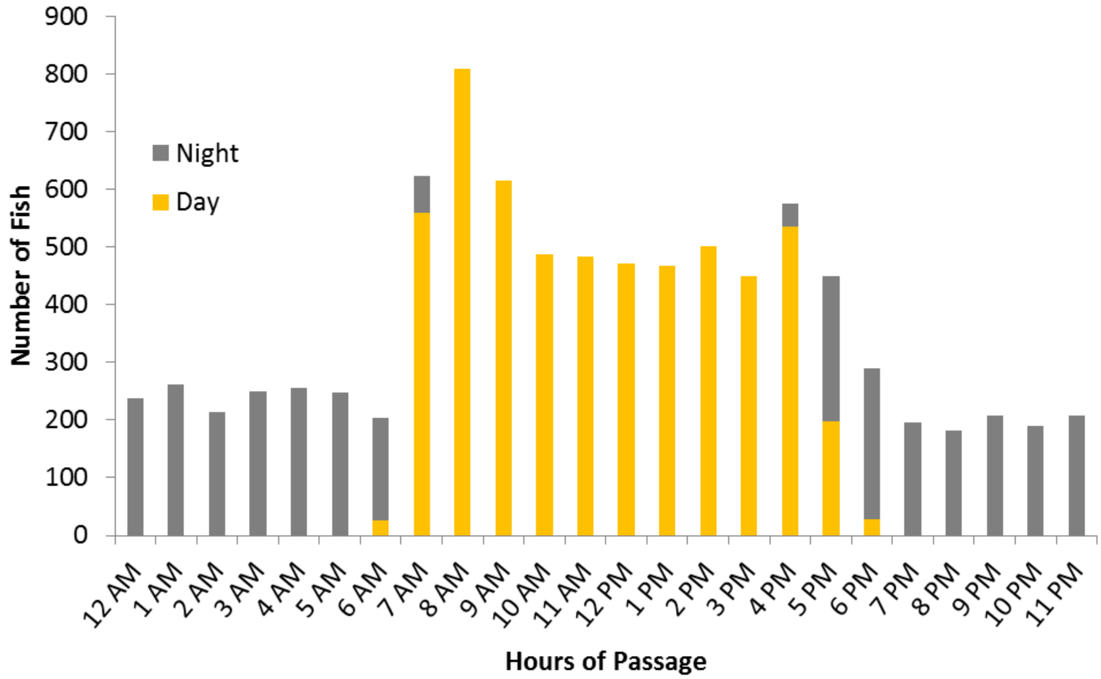

Figure 5. Hourly Chinook salmon passage recorded from video monitoring at WIDD.

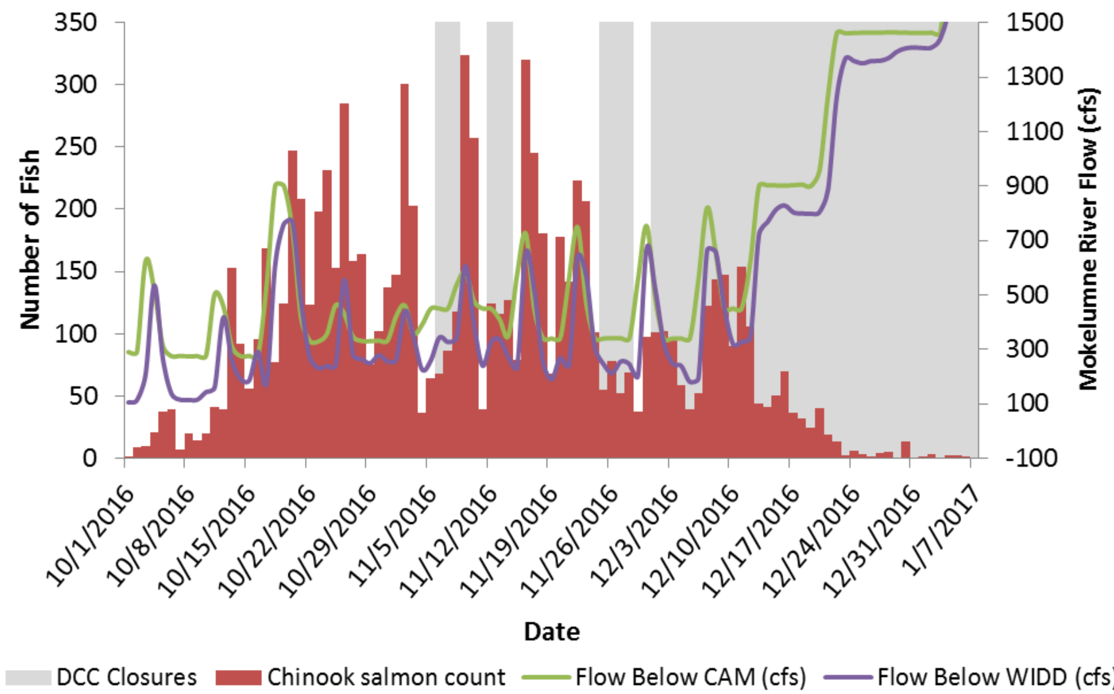

Figure 6. Daily abundance and timing of fall-run Chinook salmon migrating past WIDD compared to flow below WIDD, discharge from Camanche Reservoir, and DCC closures. Flow data are preliminary and subject to change.

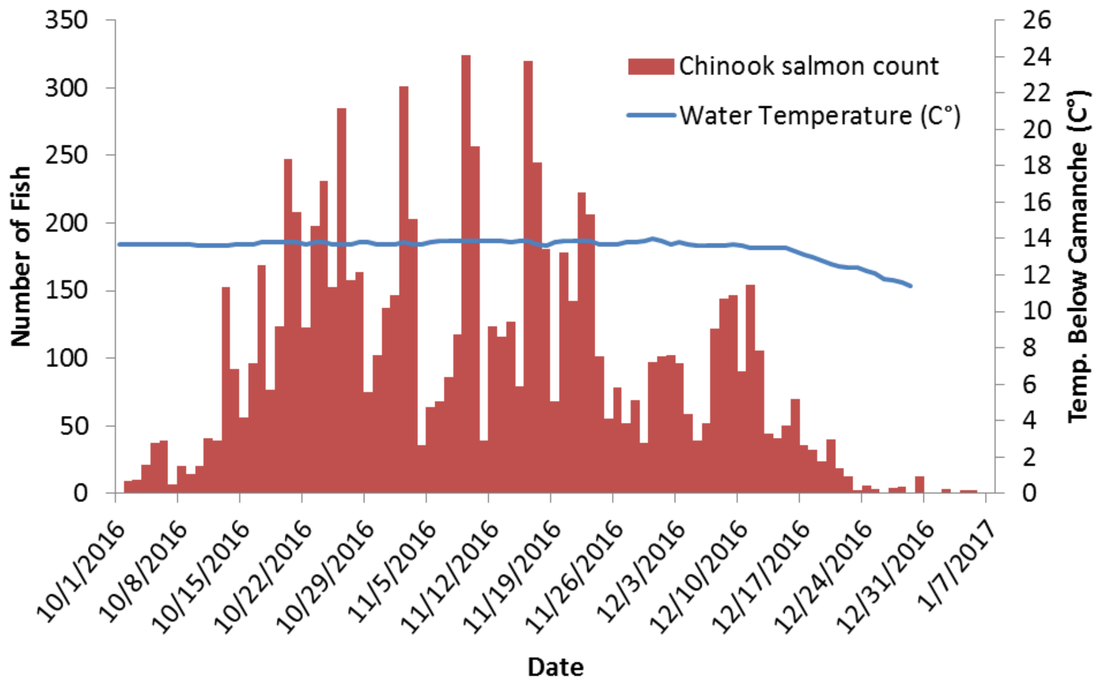

Figure 7. Daily abundance and timing of fall-run Chinook salmon migrating past WIDD compared to temperature below Camanche Reservoir. Temperature data are preliminary and subject to change.

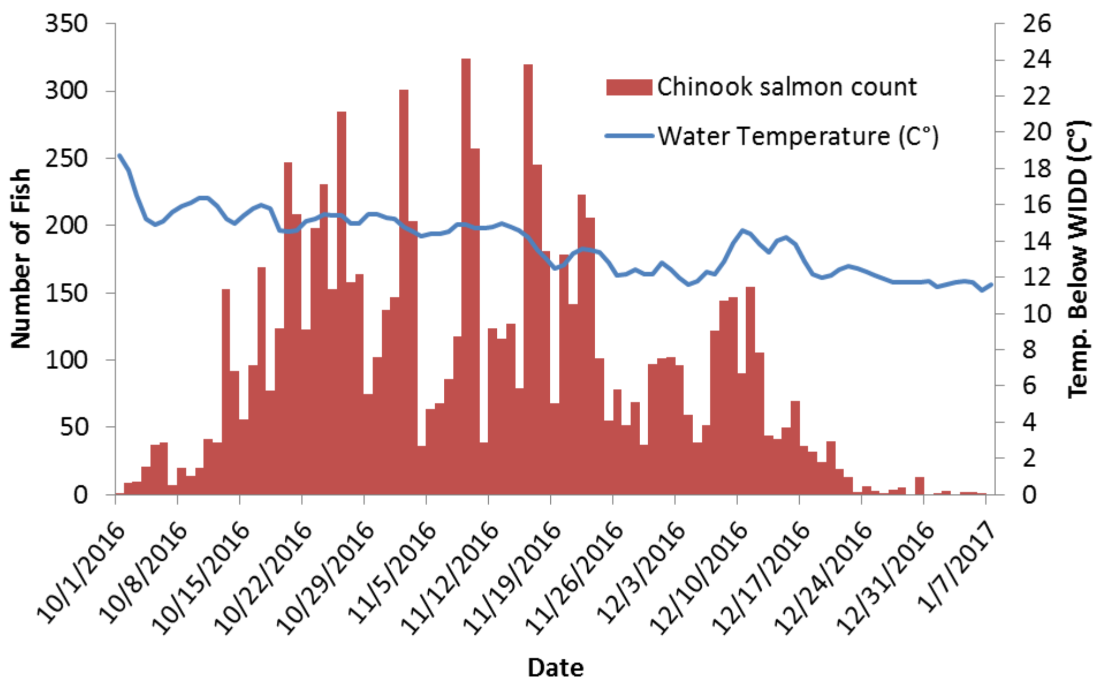

Figure 8. Daily abundance and timing of fall-run Chinook salmon migrating past WIDD compared to temperature below WIDD. Temperature data are preliminary and subject to change.

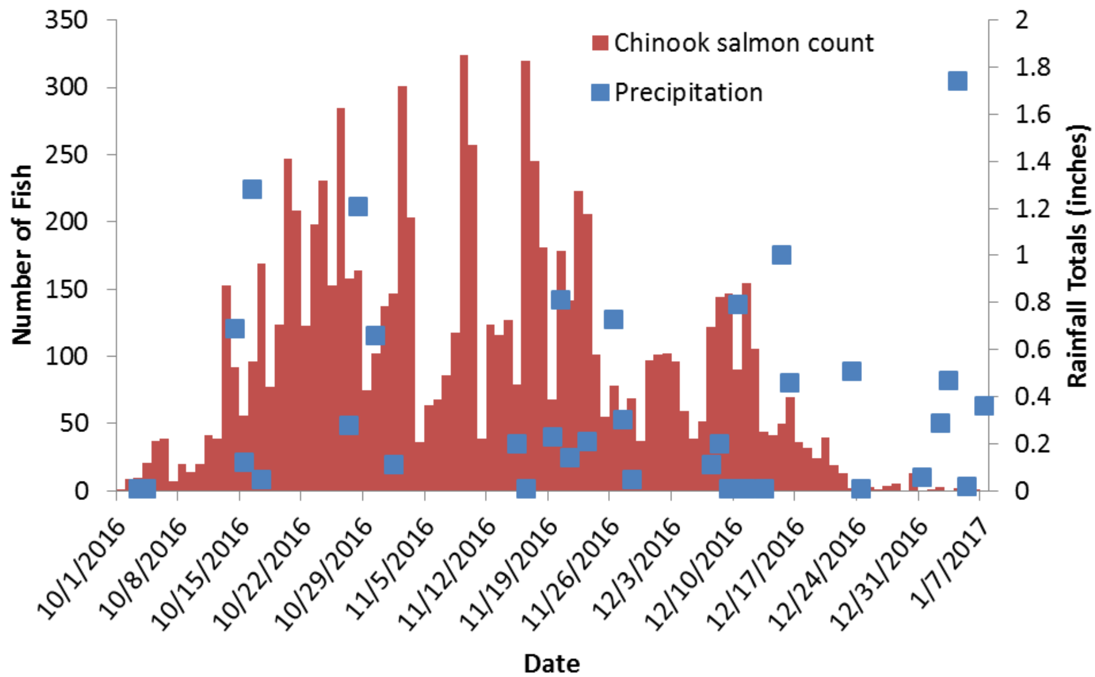

Figure 9. Daily abundance and timing of fall-run Chinook salmon migrating past WIDD compared to rainfall recorded near Pardee Reservoir. Precipitation data are preliminary and subject to change.

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