Monitoring and Evaluation of the Modified Fish Ladder and Barrier Weir at the Coleman National Fish Hatchery

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Abstract

In 2008, the U.S. Fish and Wildlife Service (Service), working cooperatively with The U.S. Bureau of Reclamation (Reclamation), modified the Coleman National Fish Hatchery (NFH) barrier weir and constructed a new fish ladder on Battle Creek at the Coleman NFH. The primary objective was to improve fish passage management capability at that site including providing for rapid fish passage into habitats that will be newly available or improved by the Battle Creek Salmon and Steelhead Restoration Project. Overall, the modified barrier weir and newly constructed fish ladders at the Coleman NFH show the capabilities to support improved fish passage management for Battle Creek. Chinook salmon quickly located the entrance and ascended the fish ladder at the Coleman NFH Barrier Weir. We believe that fish ladders are achieving the desired fish passage goals. We found no evidence to suggest that the Barrier Weir or fish ladders were causing injury to fish entering the Coleman NFH. Five fishes were observed escaping past the Coleman NFH barrier weir; four escaped over the overshot gate and one escaped over the main (i.e., lipped) portion of the barrier weir. The fishes migrating past the overshot gate likely included rainbow trout, steelhead, and Chinook salmon. The single fish that escaped past the main portion of the weir was likely a rainbow trout or steelhead. The main lipped section of the weir was successful at blocking Chinook salmon from migrating upstream. However, the overshot gate failed to meet the desired goal of completely blocking salmon from migrating over the weir. The low number of successful jump attempts suggest a high degree of effectiveness at blocking upstream passage of hatchery-origin fall Chinook, which is a primary concern because of their potential effects on ESA-listed spring Chinook. The barrier weir was less effective at blocking steelhead/rainbow trout. Fish that migrated over sections of the weir did so at flows as low as 203 CFS, well below the design target of 800 CFS. Remedial action to improve the design of the overshot gate is necessary to preclude all fall Chinook salmon from habitat in Battle Creek above the Coleman NFH.

Introduction

In 2008, the U.S. Fish and Wildlife Service (Service), working cooperatively with The U.S. Bureau of Reclamation (Reclamation), modified the Coleman National Fish Hatchery (NFH) barrier weir and constructed a new fish ladder on Battle Creek at the Coleman NFH. The primary objective is to support the restoration of anadromous salmon in Battle Creek by enhancing fish passage management capability (i.e., increased blockage or increased passage capability) at that site. This report details monitoring conducted to assess effectiveness of the barrier weir at blocking salmon and the effectiveness of the fish ladders of attracting and passing salmon.

Monitoring of the Coleman NFH barrier weir and fish ladder was conducted during the 2008-2009 and 2009-2010 spawning seasons to assess whether the facility met the objectives of enhancing fish passage management capability at that site in Battle Creek. Four specific questions were investigated, as identified in the original proposal, to evaluate the effectiveness of the facility:

1) Are migrating anadromous salmonids effectively locating the entrance of the modified fish ladder?
2) Do fish effectively ascend the modified fish ladder?
3) Are migrating anadromous salmonids sustaining injuries or mortality as a result of the modifications to the weir?
4) Can migrating anadromous salmonids circumvent the barrier weir at times when the fish ladder is closed?

Background

The Coleman NFH is located on Battle Creek, 11 miles southeast of Anderson, California and 5.8 miles upstream from the Sacramento River. Battle Creek forms the boundary between Shasta and Tehama counties in north central California. Battle Creek flows into the Sacramento River at river mile 272, approximately 20 miles southeast of the city of Redding. Coleman NFH was built in 1942 as part of a program to mitigate for the construction and operation of Shasta Dam. Fish production programs at the Coleman NFH, one of the nation's largest fish hatcheries, support economically and socially important commercial and recreational salmon fisheries in the Pacific Ocean and the Sacramento River.

A permanent barrier weir has been in place at the Coleman NFH since 1950 to assist in the congregation and collection of salmon and steelhead broodstock. Congregation and collection of broodstock at the Coleman NFH, including fall and late-fall Chinook and steelhead, occurs from

September through February. At times when broodstock are not being congregated and collected, a fish ladder at the Coleman NFH barrier weir is managed to afford passage to upper Battle Creek. During recent years, salmonids have been allowed to ascend Battle Creek upstream of the barrier weir from March through July. The fish ladder is currently closed during the month of August to exclude fall Chinook from the upper portions of the watershed where they could negatively impact ESA-listed (threatened) spring Chinook salmon.

Prior to modification, the Coleman NFH barrier weir was effective at meeting the hatchery's needs for congregating broodstock; however, the weir did not completely block salmonids from ascending Battle Creek upstream of the Coleman NFH. Of particular concern was blocking the migration of fall Chinook, which return to Battle Creek in large numbers and have the potential to interbreed with or destroy redds of ESA-listed spring Chinook, one of the priority species of a large-scale habitat restoration project (Battle Creek Salmon and Steelhead Restoration Project) being implemented in the upper watershed. While most fall Chinook salmon adults were confined below the barrier weir, past observations demonstrated some salmon were able to jump past the weir, particularly as creek flows increased above 350 cfs.

In 1999, the Service, working with a subcommittee of the Battle Creek Working Group, secured initial funding from CALFED[1] to modify the Coleman NFH barrier weir to control fish migration and construct a new fish ladder that would meet the standards of fish ladders associated with the Battle Creek Salmon and Steelhead Restoration Project. Design details were developed and refined by project technical teams over the next several years, and construction activities associated with the Coleman NFH barrier weir and fish ladder improvement project were completed in 2008. Modifications to the Coleman NFH barrier weir are intended to block fish passage at flows up to 800 cubic feet per second (cfs). The new fish ladder is intended to efficiently attract and pass salmonids upstream, with design criteria equivalent to those designed for the Battle Creek Salmon and Steelhead Restoration Project.

[1] In June 1994, four federal agencies -- the Environmental Protection Agency, Bureau of Reclamation, National Marine Fisheries Service and Fish and Wildlife Service along with the State of California signed an agreement to coordinate activities in the Delta, particularly for water quality standards. This was the beginning of CALFED. State and federal agencies, along with stakeholders, developed a science-based proposal for water quality standards, which then led to the signing of a document titled "Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government." This agreement is known as the Bay-Delta Accord, and it initiated a long-term planning process to improve the Delta and increase the reliability of its water supply. The Coleman National Fish Hatchery's Barrier Weir and Ladder modification project was one of the early CALFED Ecosystem Restoration Program projects approved by the Secretary of the Interior as a Fish and Wildlife Service Directed Action as this project needed to be completed prior to the larger Battle Creek Salmon and Steelhead Restoration Project. Total project funding in the amount of $11,276,820 was provided by CALFED through the Bureau of Reclamation. The original 1999 Agreement provided $1,663,400. Subsequent funding was secured/awarded as follows: $6,553,420, and $1,110,000 both in 2006, and $1,950,000 in 2007.

Methods

Monitoring of the Coleman NFH barrier weir and fish ladder was conducted using radio telemetry, Floy® anchor tags, and videography. Radio telemetry was used to evaluate if salmonids effectively locate, enter, and ascend the new fish ladder. Radio telemetry data also provided secondary information regarding the effectiveness of the weir at blocking salmonids from migrating past the weir during times when the fish ladder was closed. Effectiveness of the Coleman NFH barrier weir at blocking salmonids from migrating upstream was primarily assessed using video. To evaluate whether the Coleman NFH barrier weir or ladder caused injuries, fish were tagged with Floy® anchor tags and then released downstream of the weir.

Fish Attraction and Passage Effectiveness

Radio telemetry was used to determine if anadromous salmonids were effectively locating and ascending the fish ladder at the Coleman NFH barrier weir. The fish ladder is configured roughly in the shape of a "Y", with a single downstream entrance that splits into two upstream legs (Figure 1). Entering from downstream, fish pass into the "Entrance Ladder," which is a dual vertical slot fishway with three baffles (steps). Traveling upstream, fish then pass through the "Middle Ladder," which is a rectangular space containing no baffles. At the upper end of the Middle Ladder, fish can be directed either into the "Hatchery Ladder" or the "River Ladder." The Hatchery Ladder is used to divert fish into the hatchery during collection of brood stock. The River Ladder facilitates passage upstream of the Coleman NFH barrier weir. Both the Hatchery Ladder and River Ladder are single vertical slot fishways with similar cross-sectional dimensions; however, the two ladders differ in length. The Hatchery Ladder is approximately 120 feet in length and has a series of eight baffles and the River Ladder is approximately 55 feet in length and has a series of four baffles. Direct monitoring of the River Ladder was not possible during our study because fish migration was blocked to facilitate broodstock collection and to prevent hatchery-origin salmonids from entering the upper watershed. Because the Hatchery and River Ladders are similarly constructed, we monitored fish migration through the Hatchery Ladder to make inferences to rates of passage through the River Ladder.

Hatchery-origin late-fall Chinook were used to assess whether salmonids could locate and ascend the fish ladder. Adult late-fall Chinook salmon were collected during broodstock collection and spawning activities at the Coleman NFH. Fish were anesthetized with carbon dioxide, measured for fork length, and gender was identified. A radio transmitter was intragastrically inserted (radio tagged) as described in Keefer et al. (2004). We used LOTEK® coded radio transmitter tags (model MCFT-3A) with a frequency of 164.480 MHz and a burst rate of 3.0 to 4.0 sec. One hundred and thirty-five hatchery-origin late-fall Chinook salmon were radio tagged over two seasons of study, including 76 in 2009 and 59 in 2010. Fish were allowed to recover in captivity and then transported and released 0.5 miles downstream of the Coleman NFH barrier weir and fish ladder. Following release, a series of four fixed-site antenna arrays logged the movement of the tagged fish upstream to the barrier weir and through the fish ladder.

Four fixed-site antenna arrays (Figure 1) recorded the movements of tagged fish. Each array had a data-logging telemetry receiver (LOTEK® SRX400) and an antenna switch control port (LOTEK® ASP_8). Array A was located at the release site and had two directional yagi antennas pointed upstream and downstream. Array B was located at the Coleman NFH barrier weir and consisted of two "H" short-range directional yagi antennas pointed upstream and downstream. The downstream antenna of Array B was positioned to detect fish as they approached and arrived in the immediate vicinity of the Coleman NFH barrier weir (i.e., tailrace). The upstream antenna of Array B was positioned to detect fish that jumped past the weir. Array C consisted of four underwater antennas located in the Entrance Ladder and Middle Ladder. Array C was intended to detect fish as they approached, entered, and migrated through the Entrance Ladder. Array D was added in 2010 and consisted of three underwater antennas located in the Hatchery Ladder. Array D detected salmon as they migrated through the Hatchery Ladder.

Injuries

One hundred seven adult Chinook salmon were collected from 7 October through 21 October 2008 during fall Chinook spawning activities. Date of capture was recorded. Fish were anesthetized with carbon dioxide, measured for length, identified to gender, photographed on both sides, and tagged with sequentially numbered plastic anchor tags (i.e. Floy® tags) into the musculature near the posterior of the caudal fin. The physical condition of each fish was evaluated and documented, including type, location, and size of external injuries (e.g. length, width and locations of abrasions, contusions, punctures, etc.). Fish were transported in aerated tanks to a release site approximately 300 ft. downstream of the Barrier Weir and fish ladder, where they were allowed to recover from anesthesia prior to release into Battle Creek. Floy® tagged fish that re-entered the Coleman NFH were reevaluated as described above, documenting the date of reentry and external injuries. Fish were again photographed on both sides. A qualitative assessment of injuries was completed to determine whether fish that were exposed to the Coleman NFH barrier weir and fish ladder a second time had an increased rate of injury.

Blocking Fish Passage

We monitored the Coleman NFH barrier weir using a three-camera color video surveillance system [ARM Electronics, Camera Model C520HDCVFIR280DC (NTSC)] from 15 October 2008 through 28 February 2009 and from 15 September 2009 through 19 January 2010. Video cameras were installed in an outdoor housing and recorded to a Honeywell Fusion digital video recorder (DVR; 16 channel, 120 GB hard drive, and 120 images per second [ips]) connected to an uninterrupted power source (UPS; SmartUPS APC 750VA). The DVR and UPS were housed in a metal cabinet (Knaack, Model 99) to protect electronic equipment from water and vandalism. Coaxial and power cables were routed into the cabinet through a weather-proof fitting on the cabinet. A 4.5" hole was drilled into each end of the cabinet and a 110 volt fan and vent were installed to circulate air inside the metal cabinet to prevent electronics from overheating. Two halogen work lights (150W) were used to illuminate the Barrier Weir.

Cameras were positioned to view different expanses of the barrier weir; including: the overshot gate (Camera 1), the north section of the Barrier Weir (Camera 2), and the south section of the Barrier Weir (Camera 3; Figure 2). All portions of the barrier weir that could conceivably be compromised by fishes were encompassed within the view of the cameras and some redundancy existed between the viewing areas of Camera's 2 and 3. Several times each week, video was transferred to external hard drives and brought to the Red Bluff Fish and Wildlife Office. Video recordings were viewed and numbers of jump attempts and successful jumps were recorded for each day. A jump attempt was recorded when a fish reached the velocity barrier (horizontal section) of the weir and a successful jump was recorded when a fish ascended past the upstream vertical wall of the weir. Fish jumping in the area covered by both Camera 2 and Camera 3 were only counted on Camera 3 totals.

For successful jumps, total length of fish was estimated by creating a relationship between recorded images of the fish and parts of the Barrier Weir with known measurements. Images of fish jumping over the barrier weir were projected onto a 226 cm x 173 cm screen. Total fish length, weir plate width, and overshot gate length was measured by three different individuals. Measurements were averaged and the following formula was used to estimate fish length:

$$Total\ Fish\ Length\ = \frac{Fish\ Length_{(Video)}\ \cdot\ Weir\ Structure\ Measurement_{(Actual)}}{Weir\ Structure\ Measurement_{(Video)}}$$

For fish that jumped over the overshot gate, the weir structure measurement used in the formula above was the width of the overshot gate. For the fish that jumped over primary section of the Barrier Weir, the width of the weir plate was used for the calculation.

Results

<u>Fish Attraction and Passage Effectiveness</u>

One hundred thirty-five hatchery-origin late-fall Chinook salmon were radio tagged: 76 in 2009 and 59 in 2010. Fish were tagged and released between 3 February and 6 March during both years. Of the 135 radio tagged fish, 108 moved upstream and re-entered the fish ladder a second time. Zero radio tagged salmon were detected upstream of the Coleman NFH barrier weir.

The median time required for radio tagged fish to move upstream 0.5 miles to the barrier weir tailrace was 55.7 h (Table 1). Once at the tailrace, the median and mean time required for fish to enter the fish ladder was 1.7 h and 11.4 h, respectively (Table 1). The relatively large difference between the median and mean indicates the presence of outliers (Figure 3). For example, a few salmon moved downstream after arriving at the tailrace but before entering the fish ladder. The maximum amount of time to move from the tailrace into the fish ladder was 116.8 hours. A "mean" is highly influenced by outliers in which case the "median" is the more robust and accurate measure of central tendency. Removing data associated with fish that moved downstream prior to re-entering the fish ladder yielded a median and mean time of 0.8 h and 2.2 h, respectively (Table 1).

Once inside the fish ladder, the median time required for salmon to ascend the Entrance Ladder (three baffles) was 0.1 h. The median time to ascend the Hatchery Ladder (8 baffles) was 0.2 h. Some fish tended to hold in the Middle Ladder prior to ascending the Hatchery Ladder or exited downstream prior to ascending the Hatchery Ladder. Including these delays, the median time required to ascend both ladders was 0.6 h (Table 1). There was no significant difference between males and females regarding the median time required to locate and enter the fish ladder or to ascend the ladder (Kruskal-Wallis tests, $P \geq 0.22$). Also, there was no significant correlation between the release date and passage delays linear regressions, $P \geq 0.59$).

Radio tagged salmon exhibited a clear diel pattern with regard to time of first arrival at the tailrace and time of first entry into the fish ladder. Salmon entered the fish ladder primarily during daylight hours and peak movement into the ladder occurred during the 14:00-16:00 PST period (Figure 4). Some salmon arriving at the tailrace at night delayed entry into the fish ladder until daylight hours. This behavior is illustrated in Figure 4 by showing a moderate spike in movement to the tailrace during the period 22:00-24:00 but no corresponding spike in movement into the ladder.

Individual salmon entered the ladder from 1 to 8 times. Fifty four percent of the salmon that entered the fish ladder entered the hatchery pond and 46% returned downstream of the Coleman NFH barrier weir without entering the hatchery pond.

Injuries

Fifty Floy® tagged fall Chinook salmon reentered the hatchery and 57 fish were not observed after release. Of the re-captured fish, three fish had sustained injuries that were not present when they were released. One fish had a small cut on the left side below the lateral line and midway between the pectoral and anal fins, one fish had abrasions on the left operculum near the eye, and on the anterior portion of the snout, and one fish had lacerations in the head above the left eye.

Blocking Fish Passage

We observed 8,433 jump attempts at the Coleman NFH barrier weir; 657 in 2008-2009 and 7,776 in 2009-2010. Most jump attempts occurred prior to the end of fall Chinook spawning (i.e. the end of November; Figure 5). More jump attempts were made in 2009-2010 compared to 2008-2009, even when accounting for the later start date in 2008-2009 (Figure 5). The south end of the weir received more jump attempts in both years (Table 2). Zero of the 135 radio tagged fish were detected upstream of the Coleman NFH barrier weir. Zero fish were observed on recorded video ascending over the Coleman NFH barrier weir in 2008-2009 and five fish migrated past the weir in 2009-2010. All successful jumps over the Coleman NFH barrier weir occurred in the late-afternoon to early-evening, between 3:38 pm and 7:20 pm, and most successful jump attempts occurred early in the fall Chinook migration period (Table 3). The first successful jump occurred on 9/21/2009, three successful jumps occurred on 9/24/2010, and one successful jump occurred on 10/17/2009 (Table 3). Four of the fish ascended over the overshot gate (Figure 2; Camera 1) and one fish ascended over the primary weir near the north wall that separates the primary weir from the overshot gate (Figure 2; Camera 2). Estimated lengths of fish that successfully ascended over the Barrier Weir ranged from 342 mm to 594 mm total length (Table 3).

Flows ranged from 200 to 1,387 cubic feet per second (cfs) in 2008-2009 and 199 to 1,806 in 2009-2010 (Figure 5). All successful jumps over the Barrier Weir occurred at low flows (i.e. 203 – 205 cfs; Table 3; Figure 5). We were not confident in our abilities to observe fish that may have passed over the weir at flows exceeding approximately 800 cfs.

Discussion

<u>Fish Attraction and Passage Effectiveness</u>

The median time for radio tagged late-fall Chinook salmon to locate the ladder entrance was 1.7 h and the median time to ascend the ladder was 0.6 h. We did not monitor passage through the River Ladder leg but its design and dimensions are similar to the Hatchery Ladder except that it is approximately half the length. Therefore, we believe it is likely that passage through the River Ladder would likely occur more quickly than the Hatchery Ladder. Design criteria for the Coleman NFH barrier weir fish ladder specified a maximum allowable delay of three days. In 2010, we monitored a total of 44 fish that moved up through the entire fish ladder and all but one passed in under three days (98%).

We radio tagged Coleman NFH-origin late-fall Chinook salmon to make inferences of passage efficiency for all anadromous salmonids in Battle Creek, including other races of Chinook salmon and steelhead. Hatchery-origin late-fall Chinook were used as surrogates to avoid adverse impacts to threatened Central Valley spring Chinook salmon and steelhead, as well as natural-origin stocks of fall and late-fall Chinook salmon. Collecting study fish in the Coleman NFH spawning building had the advantage of avoiding impacts to the naturally spawning populations in Battle Creek but had the disadvantage of using study subjects that had previously located and ascended the fish ladder prior to radio tagging. This may have led to either a negative or positive bias in passage delay measurements. Familiarity with the site may have led to a reduction in passage delay times. Conversely, avoidance behavior due to the stressful tagging procedure may have led to an increase in passage delay times.

We feel that late-fall Chinook salmon were a sufficient proxy population for other runs of Chinook salmon and steelhead. For example, spring Chinook salmon generally enter Battle Creek in better physical condition than late-fall Chinook because, unlike late-fall Chinook, they must be able to reside in freshwater for several months prior to spawning. Adult steelhead also enter Battle Creek in prior to complete maturation and are capable of faster burst movements and higher sustained swimming speeds than Chinook salmon (Bell 1986). Steelhead would therefore also likely navigate the fish ladder at least as quickly as late-fall Chinook salmon.

Injuries

The injury rate from release after tagging until reentry into the hatchery was 6%. Observed injuries were dissimilar, suggesting that there was not a common cause, as might be expected with a design flaw. The injuries observed were minor and could not be unambiguously attributed to the Coleman NFH barrier weir and fish ladder.

We believe that some fish failed to reenter the hatchery because they spawned naturally in Battle Creek. At the time when fish were Floy® tagged in the hatchery, many were close to being "ripe", or ready to spawn. Upon reentry into the hatchery, all of the fish recovered were very dark in coloration and in advanced stages of maturation. Based on our observances, we believe that the likelihood of injuries to fall Chinook salmon resulting in or around the Coleman NFH barrier weir and fish ladder are low and pose a small risk to anadromous salmonids in Battle Creek.

Blocking Fish Passage

Five fish were observed passing over the Coleman NFH barrier weir; four passed over the overshot gate and one passed over the main barrier weir lip. Based on the recorded video images, we could not identify with certainty the species that successfully escaped past the weir. Three of the fish were unlikely to be salmon due to their small size (e.g., fork lengths: 342 mm, 441 mm, 455 mm). The smallest salmon measured at the Coleman NFH in 2009-2010 was 500 mm fork length. We speculate these fish were steelhead trout or resident rainbow trout (*Oncorhynchus mykiss*) based on their size and morphology. The lengths of the two larger fish (575mm and 594mm) that jumped past the weir were within the length ranges typical of both Chinook and steelhead in Battle Creek. Based on morphological features, particularly body thickness, we believe that the two larger fish that jumped over the weir were likely Chinook salmon.

The Coleman NFH barrier weir and fish ladder modification project was designed to support the restoration of anadromous salmonid populations in Battle Creek by allowing the ability to selectively control access upstream of the Coleman NFH. The ability to control upstream passage enables the fishery managers to focus first on restoration of ESA-listed "priority species". To accomplish this necessitates the ability to block fall Chinook salmon from jumping past the weir. The primary section of the Coleman NFH barrier weir was successful at preventing upstream migration of fall Chinook salmon. Only one fish was observed jumping past this section of the weir and, based on the small size of that fish, it was likely a rainbow trout. Four fish successfully migrated over the weir at the overshot gate and we consider it likely that two of these fish were Chinook salmon. The overshot gate did not meet the design criteria that was specified in the design criteria and should be modified if blocking all fall Chinook from migrating above the weir is a desired goal of the facility.

All five of the successful jumps occurred prior to or early during the collection of fall Chinook brood stock. We believe the likelihood of successfully jumping over the weir is reduced as fish approach sexual maturity. Fish are generally in the best physical condition during the early portion of the run and there is a general deterioration of physical abilities as salmon approach maturation.

We recorded substantially more jump attempts in 2009-2010 compared to 2008-2009 (Figure 5) despite smaller run sizes of both fall and late-fall Chinook salmon in Battle Creek (Fall Chinook in Battle Creek: 10,639 in 2008-2009 and 6,152 in 2009-2010; Late-fall Chinook in Battle Creek: 6,429 in 2008-2009 and 5,505 in 2009-2010). It is likely that environmental conditions, such as water temperature and stream flow, influence the numbers of jump attempts. Particularly noteworthy is the flow increase in Battle Creek that occurred after a rainstorm in mid-October 2009 and the corresponding increase in jump attempts. Chinook salmon migration typically increases during the period of increasing flows and turbidity associated with rainstorms, which would be expected to increase the number of fish encountering the weir resulting in more jump attempts. It is also possible that operation of the fish ladders may have affected jumping attempts. We speculate that salmonids that do not have access to a fish ladder may demonstrate increased attempts to circumvent the weir by jumping; however, we were not able to demonstrate this during this study. Ladder operations during the fall and late-fall Chinook spawning periods are shown for 2008-2009 and 2009-2010 in figures 6 and 7.

We speculate that the reduced jumping activity in late-November through February was a result of fewer fish in the vicinity of the Barrier Weir and lower water temperature in Battle Creek (figure 8). The relative abundance of Chinook salmon in the vicinity of the Barrier Weir is typically highest during the peak of migration of fall Chinook (October) and declines markedly thereafter, typically remaining relatively low throughout the late-fall Chinook migration season. Warmer water temperatures earlier during the years also likely contributed to more successful jumps. Although we could not conclusively relate jumping activity to water temperatures in this study, we consider it likely that fewer jump attempts are made when the water temperature in Battle Creek is lower. It is important to note that video monitoring early during the monitoring period, when we believe fish are most likely to successfully jump over the Coleman NFH barrier weir, did not occur in 2008-2009. Therefore, some successful jumps may not have been observed.

Four of the five fish that were able to jump over the Coleman NFH barrier weir passed over the overshot gate. The overshot gate is designed to be raised or lowered to adjust the flow of water near the entrance of the fish ladder to attract fish to that location. The overshot gate does not have an overhanging lip at the crest and, therefore, does not appear to afford the same level of success at blocking passage as the main portion of the weir. The position of the overshot gate was not recorded during this study; however, based on the position of the gate as shown in the recorded video, we believe that the gate was at or near the upright (fully closed) position when fish escaped past the structure.

Conclusions

Chinook salmon quickly located the entrance and ascended the fish ladder at the Coleman NFH Barrier Weir. Based on the results of this study, we believe that fish ladders are achieving the desired fish passage goals.

We found no evidence to suggest that the Barrier Weir or fish ladders were causing injury to fish entering the Coleman NFH. The rate of injury incurred in the vicinity of the Coleman NFH barrier weir and fish ladder were low, observed injuries were minor, and could not be directly attributable to the barrier weir or fish ladders.

Throughout two seasons of monitoring, five fishes were observed escaping past the Coleman NFH barrier weir; four escaped over the overshot gate and one jumped over the main portion of the barrier weir. The main section of the barrier weir was successful at blocking Chinook salmon from migrating upstream of the hatchery. The single fish that escaped past the main portion of the weir was likely a rainbow trout/steelhead. However, the overshot gate failed to meet the desired goal of completely blocking salmon from migrating over the weir. The fishes migrating past the overshot gate likely included rainbow trout/steelhead and Chinook salmon.

The low number of successful jump attempts suggests a high degree of effectiveness at blocking upstream passage of fall Chinook, which is a primary concern because of their potential effects on ESA-listed spring Chinook. The barrier weir was less effective at blocking steelhead/rainbow trout. Fish that migrated over sections of the weir did so at flows as low as 203 CFS, well below the design target of 800 CFS. Remedial actions to improve the design of the overshot gate are necessary to improve the capability of blocking fall Chinook salmon from accessing habitat in Battle Creek upstream of the Coleman NFH.

Recommendations

1.) The overshot gate is an area of particular vulnerability for fish jumping over the weir. We recommend the Service work with Reclamation[2] to develop a design modification that will remedy this area of weakness. Further monitoring in this area should occur after completion of modifications.

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[2] As of the writing of this report, Reclamation engineers have completed 30% design for developing a remedy for the deficiency in the overshot gate area. Design modifications are anticipated to be finalized and physical modification to overshot gate is expected be complete in 2011 or 2012.

2.) The position of the overshot gate should be recorded in the future, particularly, if additional monitoring of the Coleman NFH barrier weir is scheduled.

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Table 1. Travel time of adult late-fall Chinook salmon as they encounter and pass through the improved fish ladder at Coleman National Fish Hatchery on Battle Creek. Salmon were tagged with radio transmitters and monitored using fixed-site antenna arrays and radio receivers. From downstream to upstream, antenna locations include the following: P1=release site, P2=barrier weir tailrace, P4=inside ladder entrance, P6=top of Entrance Ladder, P7=bottom of Hatchery Ladder, and P9=top of Hatchery Ladder. Movement "P2 to P4" is the time taken to locate and enter the ladder and "P4 to P9" is the time taken to ascend the entire fish ladder (i.e., Entrance and Hatchery Ladders). Included is the total number of fish observed (n).

	Travel Time (hours)					
	P1 to P2	**P2 to P4**	P2 to P4[a]	P4 to P6	P7 to P9[b]	**P4 to P9[b]**
Median	55.7	**1.7**	0.8	0.1	0.2	**0.6**
Average	60.1	**11.4**	2.2	0.2	0.8	**1.9**
Minimum	2.1	**0.1**	0.1	0.0	0.0	**0.1**
Maximum	199.3	**116.8**	29.2	2.2	16.9	**31.9**
n	113	**108**	75	104	44	**44**

[a] Does not include fish that moved upstream to P2, back downstream to P1, then upstream to P4
[b] Data are only available from 2010

Table 2. Number of jumps per meter of weir monitored, by camera, during the 2008-2009 and 2009-2010 periods.

Year	Camera 1	Camera 2	Camera 3
2008-2009	7.7	11.8	35.1
2009-2010	59.1	110.8	432.4

Table 3. Date and time of each successful fish jump over the Coleman National Fish Hatchery Barrier Weir. Also included are the Battle Creek flow (cfs) at the time of the jump, the camera where the jump was observed, and the estimated length of the fish that ascended the weir.

Date	Time	Flow (CFS)	Estimated Total Length (mm)	Camera
9/21/2009	6:35 PM	204	342	2
9/24/2009	4:31 PM	203	455	1
9/24/2009	4:45 PM	203	594	1
9/24/2009	7:20 PM	203	441	1
10/17/2009	3:38 PM	205	575	1

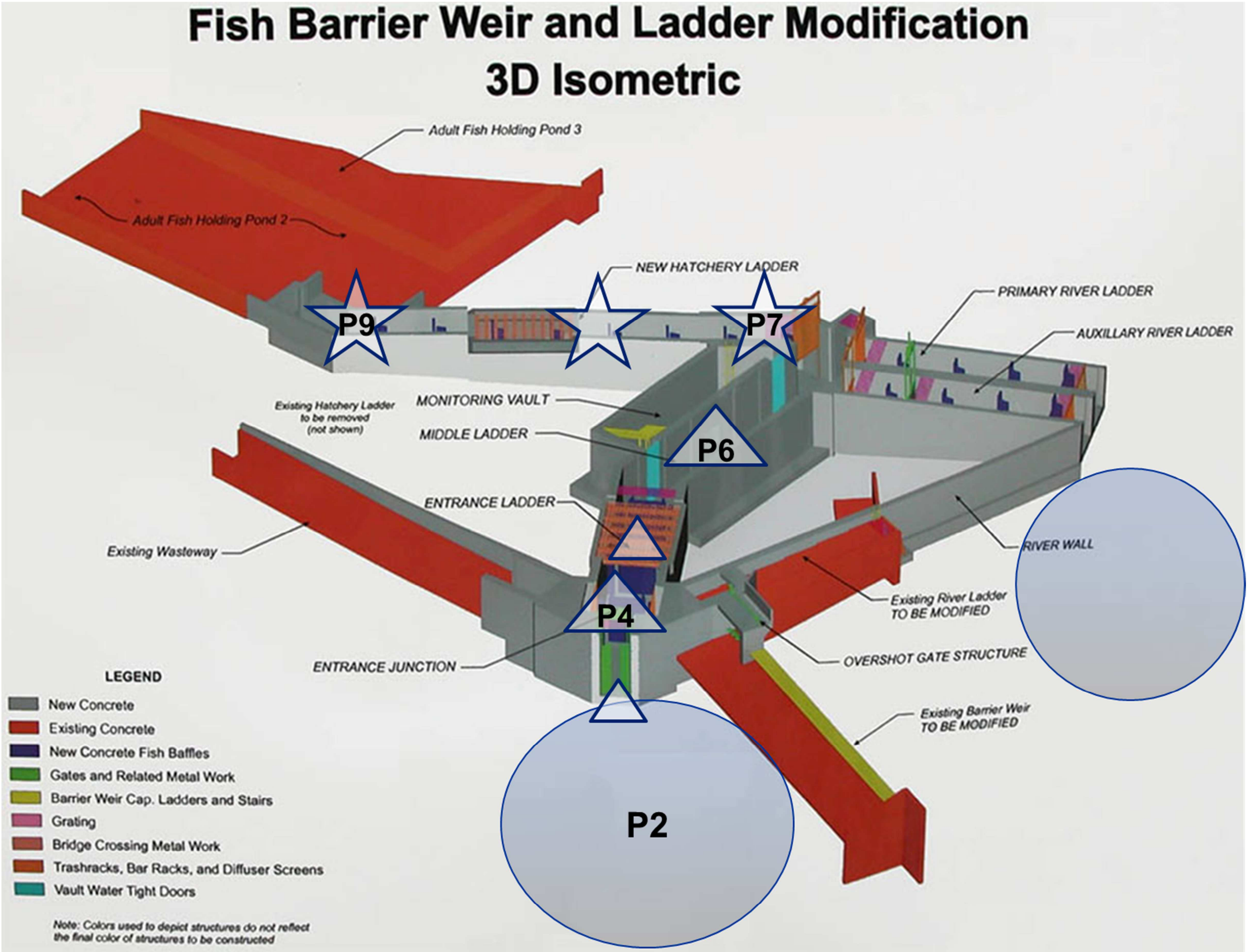
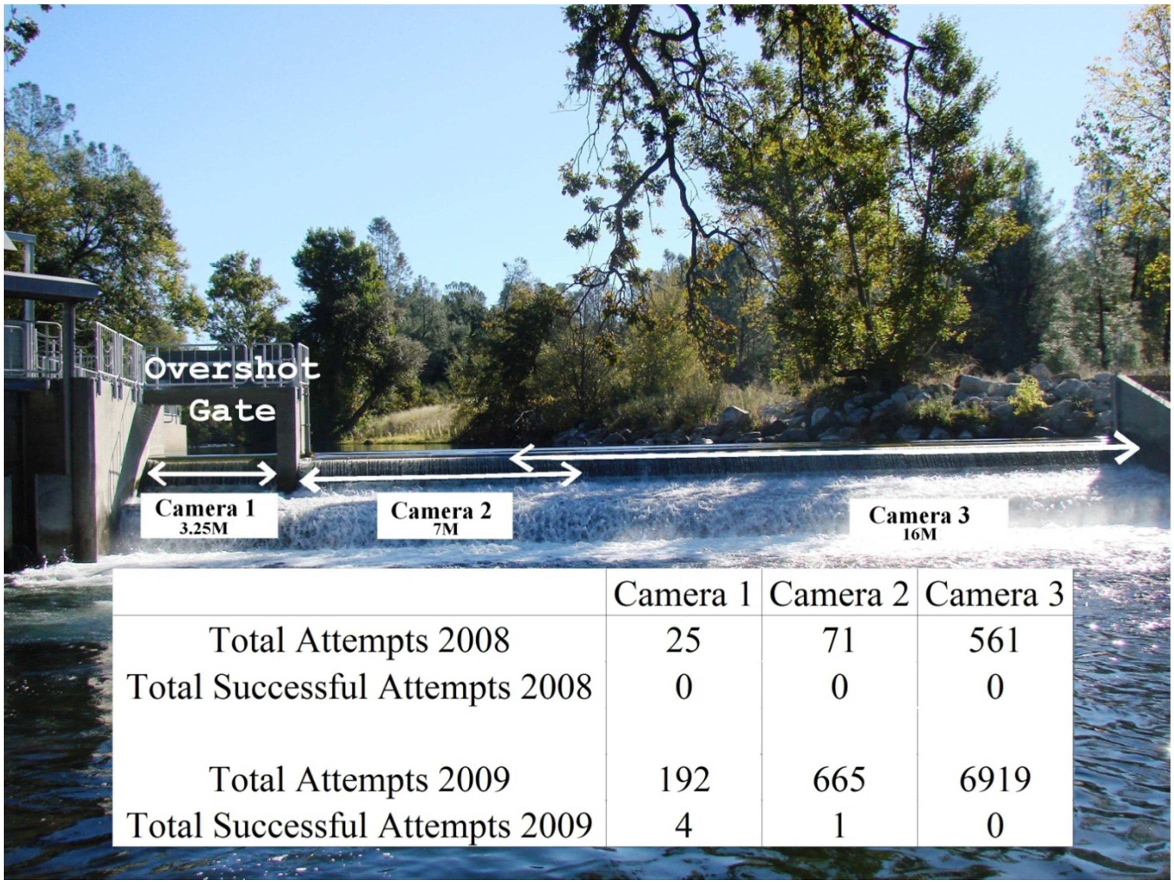


Figure 1. Illustration of the improved fish ladder and barrier weir at Coleman National Fish Hatchery on Battle Creek. Radio telemetry antenna arrays are represented as follows: ovals = aerial Array B, triangles = underwater Array C, and stars = underwater Array D. Key locations are labeled as P2, P4, P6, P7, and P9.



	Camera 1	Camera 2	Camera 3
Total Attempts 2008	25	71	561
Total Successful Attempts 2008	0	0	0
Total Attempts 2009	192	665	6919
Total Successful Attempts 2009	4	1	0

Figure 2. Photograph of the Coleman National Fish Hatchery Barrier Weir, fish ladder, and overshot gate. Also shown are the areas covered by the three camera's during the video monitoring aspect of this study and the distance that each camera view covered. Total attempts and successful attempts made by fish to jump over the weir are shown for two periods: 1.) from 15 October 2008 through 28 February 2009 (2008); and, 2.) from 15 September 2009 through 19 January 2010 (2009).

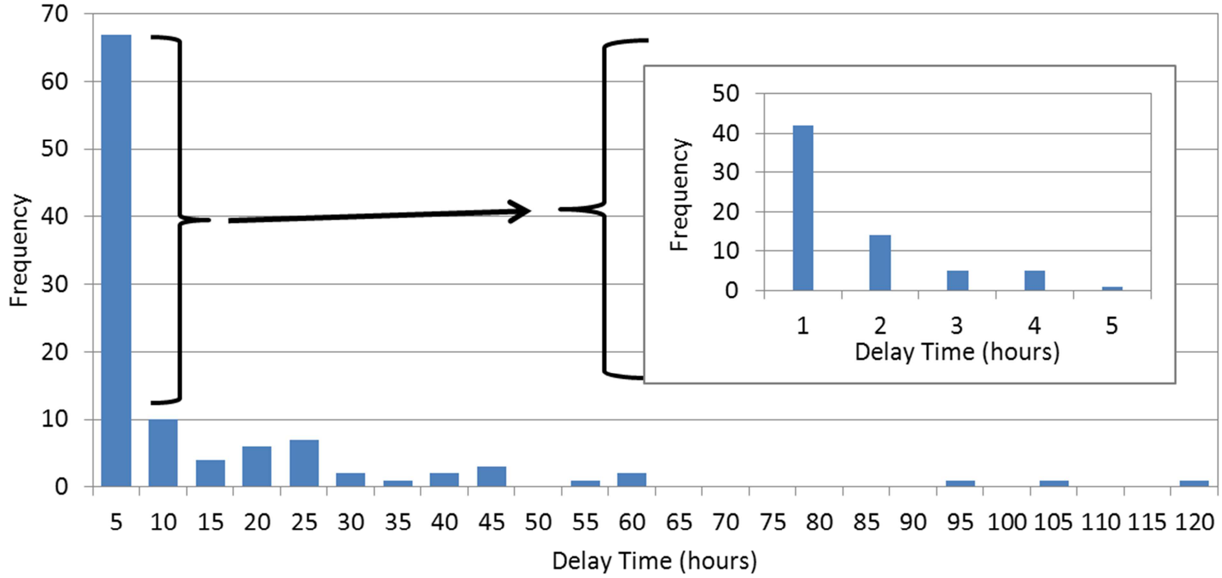


Figure 3. The delay-frequency distribution for radio tagged Chinook salmon entering the improved fish ladder at Coleman National Fish Hatchery. Delay time is the time duration from arrival at the barrier weir tailrace to entrance into the fish ladder.

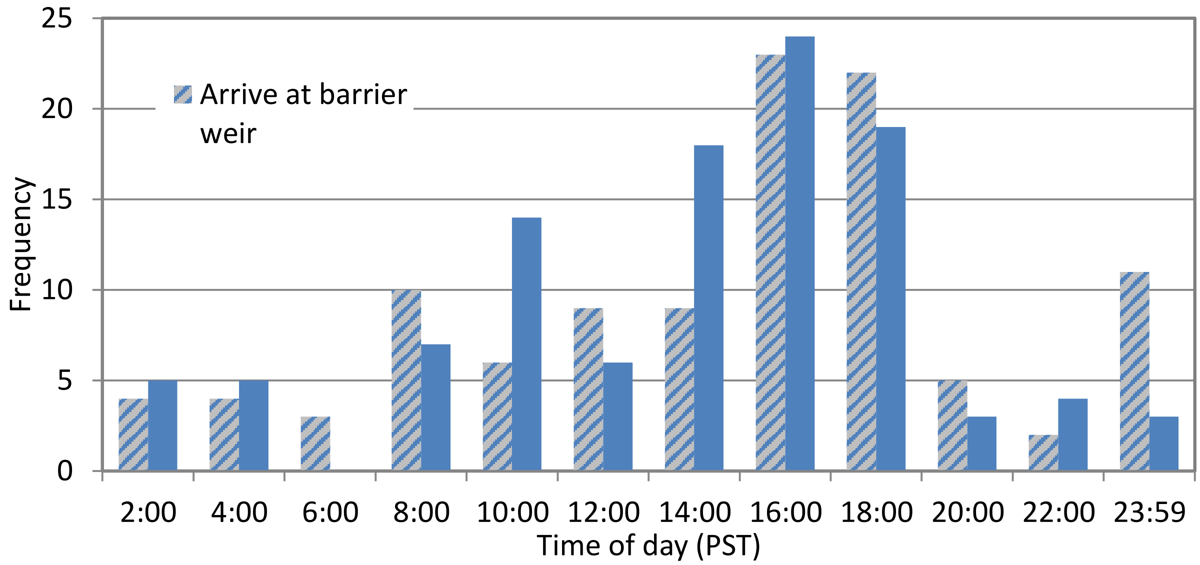


Figure 4. Diel time-frequency distribution for first detection (1) at the barrier weir tailrace and (2) immediately inside the entrance to the fish ladder.

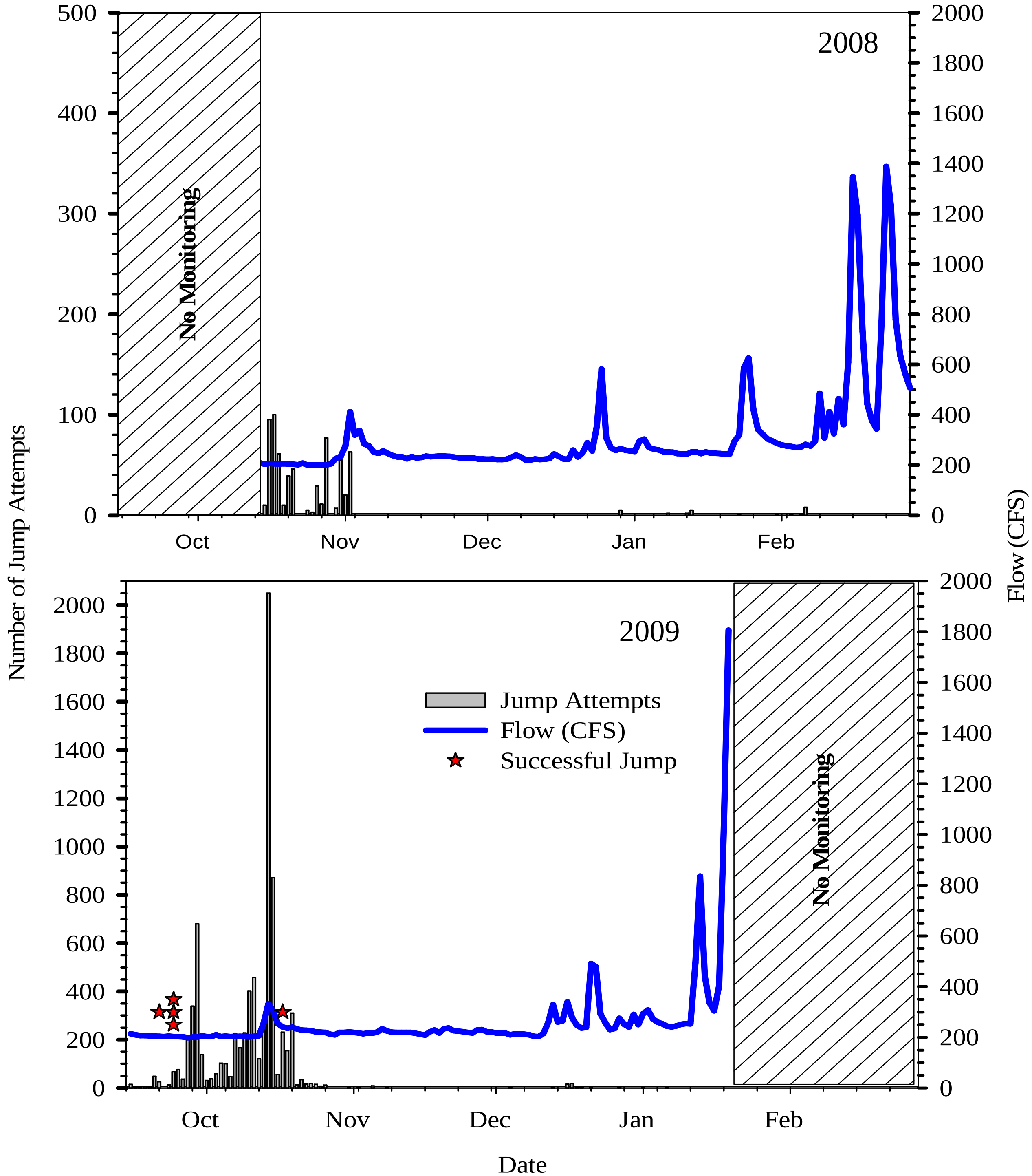


Figure 5. Number of jump attempts and number of fish that successfully jumped over the Battle Creek Barrier Weir. The line shows the amounof Battle Creek flow in cubic feet per second (CFS).

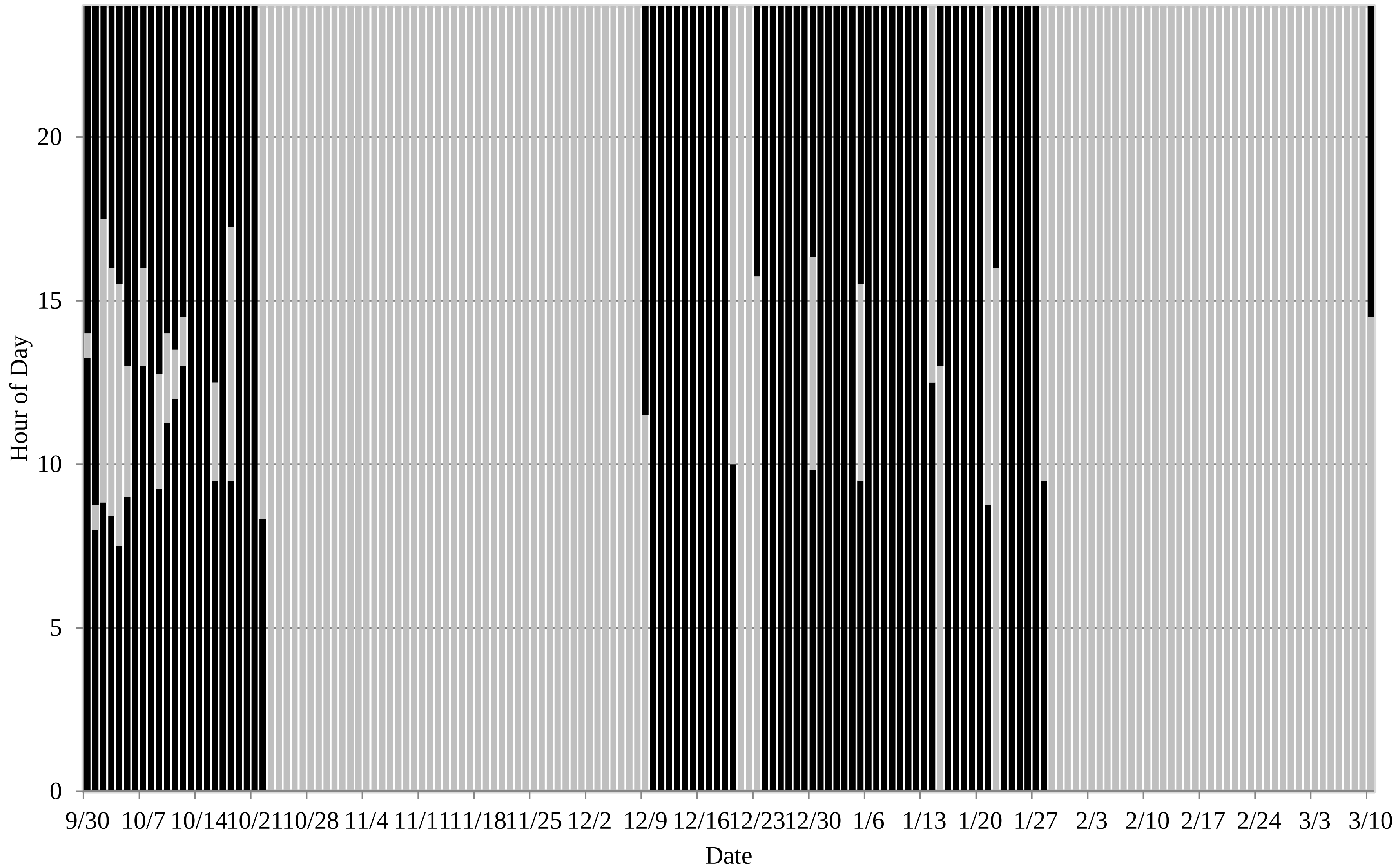


Figure 6. Daily operation of the Coleman NFH barrier weir fish ladder during fall and late-fall Chinook salmon broodstock collection, 2008-2009. Black bars indicate that the fish ladder was closed and gray bars indicate fish ladder was open.

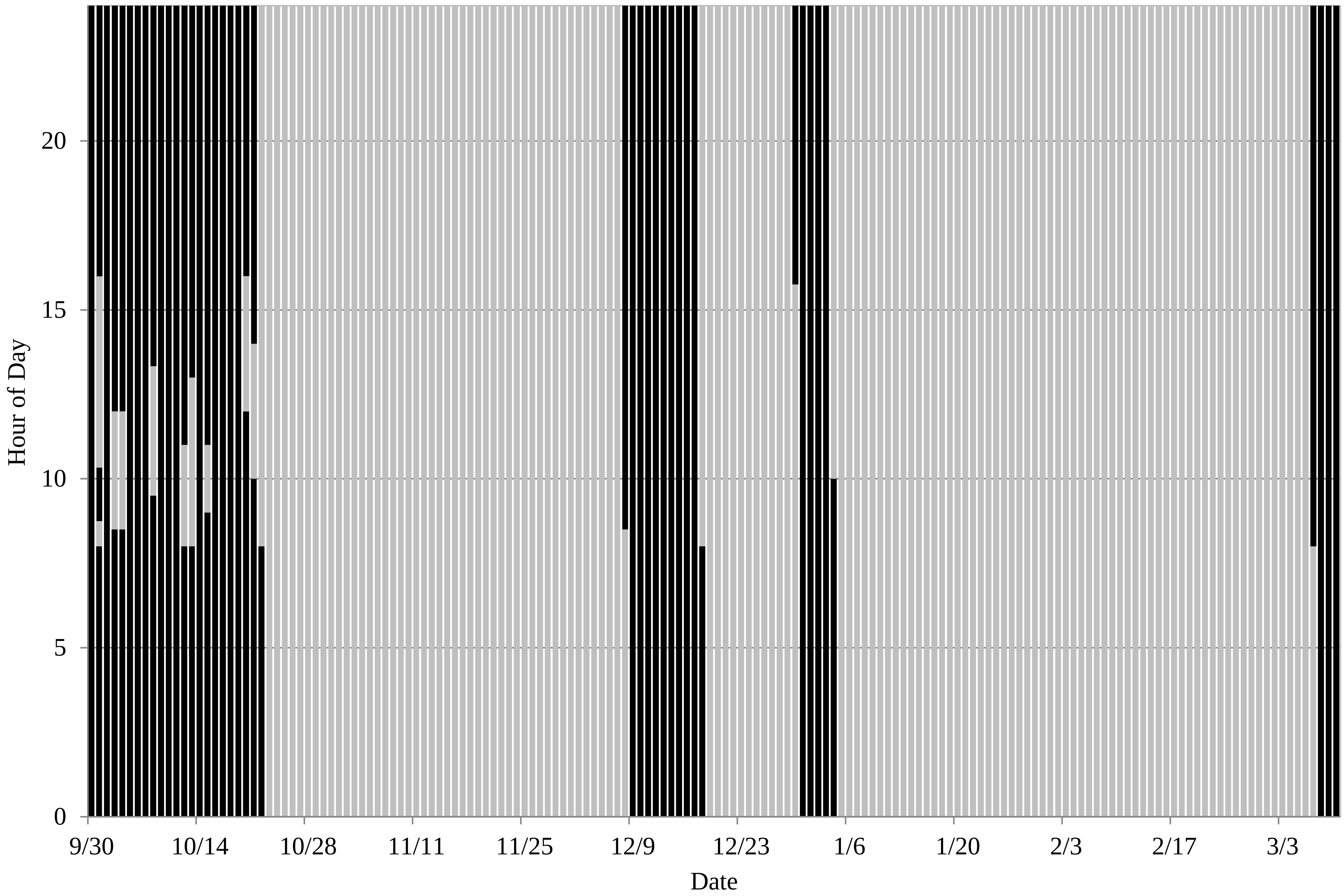


Figure 7. Daily operation of the Coleman NFH barrier weir fish ladder during fall and late-fall Chinook salmon broodstock collection, 2009-2010. Black bars indicate that the fish ladder was closed and gray bars indicate fish ladder was open.

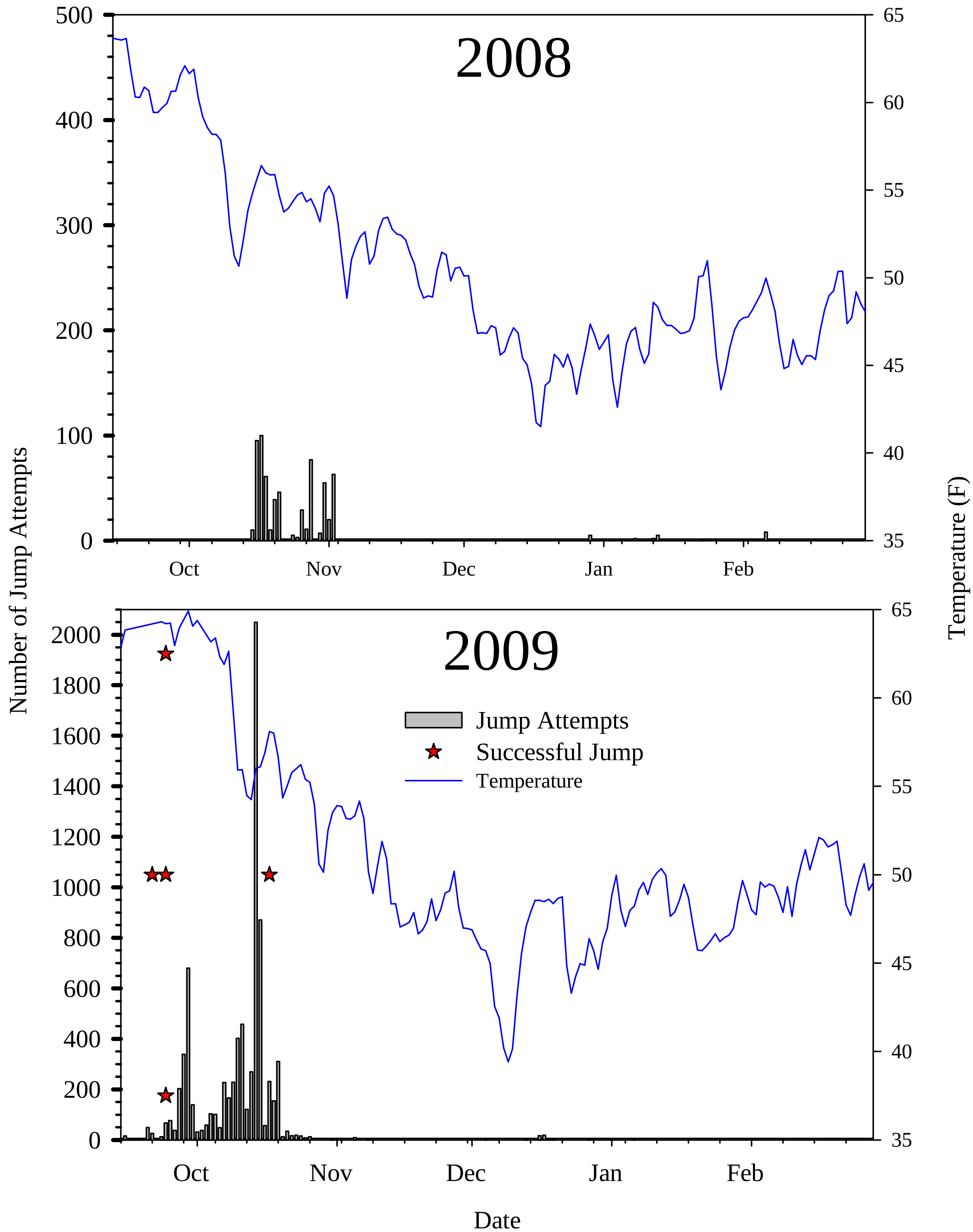


Figure 8. Number of jump attempts and number of fish that successfully jumped over the Battle Creek Barrier Weir. The line shows the temperature of Battle Creek flow in degrees Farenheit.