2015-2016 Chinook Salmon Dewatered Redd Monitoring on the Sacramento River

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Abstract

California's extensive water delivery system requires elevated Sacramento River flows during summer months and a reduction of flows starting in late summer to conserve storage for the following year. California's unprecedented drought has severely limited stored water in Shasta Reservoir, further emphasizing the importance of conserving stored water. As a result, Chinook salmon spawning downstream of Keswick Dam are subject to redd dewatering as flows are reduced. Overlapping winter-run incubation times and fall-run spawning periods allowed fall-run redds to be built before flows were reduced, increasing dewatering potential. Our monitoring effort marked and revisited redds which were deemed vulnerable to dewatering, re-measuring depth as flows out of Keswick Dam were reduced. Additionally, marked redds were categorized by the degree and duration of dewatering, indicating effect on juveniles. We observed 291 dewatered fall-run redds and one spring -run redd during the 2015-2016 survey period, a dewatering rate of 2.14%. Assuming a fecundity of 5,407 eggs per female (USFWS, 2012), 100% potential egg to fry survival, and 100% mortality, dewatering is theoretically responsible for a reduction in recruitment of 1,573,437 juvenile fall-run Chinook and 5,407 juvenile spring -run Chinook. It is unclear whether 100% mortality can be assumed, therefore additional research should be conducted to further clarify exactly what impact different degrees of dewatering have on Chinook redds in the Sacramento River.

Introduction

Since 2010, the California Department of Fish and Wildlife (CDFW), in partnership with Pacific States Marine Fisheries Commission (PSMFC), has conducted dewatered redd monitoring on the Sacramento River, between Tehama bridge (river mile 229) and Keswick Dam (river mile 302). The objective of this monitoring is to (1) determine the total number of redds dewatered and (2) provide real-time data for flow management purposes. Chinook salmon (*Oncorhynchus tshawytscha*) is the focal species in this monitoring effort.

Monitoring of dewatered redds is necessary on the Sacramento River to determine the impact of flow reductions from Keswick Dam. Flow is kept high throughout the summer to meet the demand of downstream water users. The agency that operates Keswick and Shasta Dams, the United States Bureau of Reclamation (Reclamation), reduces flows in the fall and early winter in order to maintain sufficient water storage for the following year. While this reduction in flow during 2015 did not negatively impact many redds below the first two major tributaries due to supplemental flow, the portion of the Sacramento River between Keswick Dam and Clear Creek (river mile 289) experienced significant redd dewatering as a result of these flow reductions. Negligible tributary flow during the fall-run Chinook salmon (fall-run) incubation period on this portion of river meant that any reduction in flow out of Keswick Dam was quickly evident as reduced water level.

Reclamation contracts with water users throughout the Central Valley, resulting in elevated Sacramento River flows in the summer for diversion out of the Sacramento-San Joaquin Delta through the Central Valley Project pumps. Since flows are elevated during the summer and early fall months, high quality spawning gravel that would otherwise be above the water line is made accessible to spawning Sacramento River winter-run Chinook salmon (winter-run). Due to the winter-run's endangered status under the federal and California Endangered Species Acts, Reclamation maintains high flows through October to provide winter-run alevins time to emerge. This presents a problem for the more numerous fall-run, which peak in spawning between late October and early November. The subsequent reduction(s) in flow for water conservation after winter-run alevins have emerged has the potential to dewater a large number of fall-run, spring-run, and potentially even late fall-run redds before alevins emerge.

Monitoring was conducted in an effort to document percent redds dewatered and provide fisheries and water resource managers with the data necessary to effectively manage the system for multiple beneficial uses. We were able to provide nearly real-time dewatering data to managers which allowed them to operate quickly, and is responsible for keeping at least 20 shallow winter-run redds from being dewatered.

It is important to note that the objective of this monitoring effort is to document the number of redds dewatered, not the overall abundance of redds. Determining dewatering percentage is possible because newly constructed shallow redds can be readily identified by their lack of algae and presence of fish, whereas deep water redds cannot be distinguished in river sections without annual bed mobilization.

Life History

The Sacramento River is unique in that it has four distinct spawning runs of Chinook salmon. These include winter-run, spring-run, fall-run, and late fall-run. Of these winter-run are state and federally listed as endangered, spring-run are state and federally listed as threatened, and late-fall and fall-run are federally listed as species of concern (NOAA, 2016).

Winter-run enter the river between December and August (CDFW, n.d.) in immature reproductive state (Reclamation, 2008), move up river quickly, and hold below Keswick Dam until spring and mid-summer. Due to water temperature requirements they then generally spawn in the 10 miles below Keswick Dam and the majority of redds emerge by mid to late October. Once emerged, fry hold in freshwater and estuaries for an additional five to nine months before moving in to the ocean (Reclamation, 2008).

Historically, winter-run spawned in the highest reaches of the Pitt, Sacramento, and McCloud Rivers as well as Hat Creek and Battle Creek (Reclamation, 2008). They would travel to these headwaters in order to spawn in creeks fed by cold-water springs, which contained the only water of suitable temperature for successful spawning during hot summer months. This is the source of the largest problem for winter-run spawning in the highly engineered Sacramento River system. Since winter-run cannot access their historic spawning grounds, sufficient cold water must be released out of Keswick Dam in order to allow for successful summer spawning. Winter-run are endemic to the Sacramento River system as well, further complicating and emphasizing the importance of conservation efforts.

Central Valley spring-run Chinook salmon (spring-run) are the next group to enter the river, between March and September. Like winter-run, spring-run enter in sexually immature form and hold for a period of several months before spawning. They are more commonly found in tributaries to the Sacramento River such as Butte, Deer, Mill, and Antelope creeks. Once in the tributaries they migrate to high elevations and hold through the summer in deep cold-water pools, before spawning in the fall, slightly ahead of fall-run. Spring-run juveniles exhibit inconsistent juvenile rearing and emigration strategies, functioning as either stream-type or ocean-type. The stream-type juveniles will generally rear in natal streams and emigrate as yearlings, whereas ocean-type juveniles will rear in the main channel and emigrate as sub-yearlings (NOAA, 2016).

Fall-run is the largest of the four runs and during 2015-2016 was the run most impacted by redd dewatering. Fall-run enter the Sacramento River as sexually mature adults between June and December and spawn between late September and December (CDFW, 2010). Juveniles emigrate within several months after hatching, although a small percentage may emigrate as yearlings. Because of its importance as a commercial and sport fish, the fall-run is also supported by numerous hatchery programs in the Central Valley. Approximately 32 million smolts are released from five central valley hatcheries annually (CDFW, n.d.).

Late-fall run Chinook have a similar life history to fall-run other than a run timing which is later and lower utilization of tributaries for spawning. Late-fall run enter the river between October and April and spawn between January and April (CDFW, 2010). They also enter the river as sexually mature adults and the majority of their juveniles exhibit an ocean-type emigration strategy. A portion of late-fall juveniles may be stream-type as well, remaining in the river until they emigrate as yearlings (CDFW, 2010).

Monitoring Area

The Sacramento River and its tributaries make up California's largest river system at a watershed size of approximately 27,000 square miles (69,930 square kilometers) and 31% of the state's total surface water runoff (Heiman and Lee Knecht, 2010). The Pit, McCloud, and Sacramento rivers all drain into Lake Shasta which is the state's largest reservoir at a capacity of 4.5 million acre-feet (Heiman and Lee Knecht, 2010). The Sacramento River flows out of Shasta Dam and in to Keswick reservoir, a forebay of Lake Shasta in place mainly for flood control and power generation purposes. Reclamation operates both Shasta and Keswick Dams and as such is responsible for flow related environmental impacts which may occur downstream.

Keswick Dam is the limit of anadromy on the Sacramento River and therefore is the northern edge of our monitoring area. From Keswick Dam the river flows another 302 miles (486 kilometers) to the Sacramento-San Joaquin Delta. For practical purposes we set the southern border of the monitoring area at the Tehama Bridge, a distance of approximately 73 miles (117 kilometers; See Figure 1). The area between Keswick and Tehama Bridge contains numerous habitat types, water velocities, and water quality values. Substrate types include mud/silt, sand, clay, hardpan, bedrock, gravel, cobble, and boulders. Because Chinook salmon have specific water quality and gravel size requirements for spawning, redds are often observed in predictable areas. These areas include gradually sloping gravel bars and laterals with 0.11 to 5.9 inch (0.3 to 15 centimeter) diameter gravel (California Department of Water Resources, 2003). Once these traits were identified it became easier to locate areas which had a high probability of containing new redds.

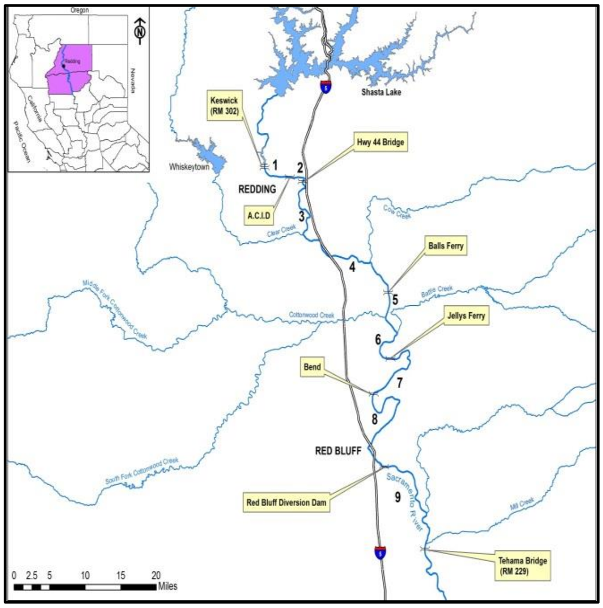

Figure 1.–Map of Upper Sacramento River Basin and study area including survey sections and major tributaries.

One major constraint on identifying redds in the Sacramento River is the lack of bed mobilization above Clear Creek. Since the river is dam operated and no major tributaries flow in between Keswick Dam and Clear Creek, flows only reach high enough levels to mobilize the river bed when Reclamation releases water for flood control or when Keswick Dam spills. Due to the severe California drought and the resulting low level of Shasta Reservoir, there has not been a spill or pulse flow event out of Keswick Dam since 2011 (California Department of Water Resources, 2015). A lack of bed mobilization means that redd morphology often remains intact between salmon runs and spawning years, requiring the surveyor to identify redds based off of algae growth and salmon presence. Below Clear Creek the river generally experiences flows high enough to mobilize bedload on a yearly basis, simplifying the monitoring effort.

Methods

The dewatered redd monitoring was conducted by jet boat and on foot. Survey crews consisted of at least two staff members from CDFW and/or PSMFC. Crews marked and collected data on underwater or dewatered redds. Redds were marked with a Trimble® Geo7x handheld unit and with physical markers (flagged and weighted disk tags). The Trimble® unit utilized a highly accurate global navigation satellite system (GNSS) which allowed redds to be pinpointed to an observed accuracy of nine to 32 inches (23 to 81 centimeters). A minimum of 15 points were taken at each redd and were then differentially corrected in Trimble's GPS Pathfinder Office® software. Differential correction corrects the handheld unit's points based off of a fixed and well surveyed station, further increasing accuracy. This high level of accuracy allowed us to differentiate individual redds upon revisiting sites and to accurately recognize redd superimposition. The Trimble® unit also contained a digital data sheet which allowed for analyzation of data in Microsoft® Access® and ESRI®'s suite of mapping software.

Pertinent data collected for each redd included date, water temperature, crew members, river section, water clarity, weather conditions, redd number, what time the redd was marked or updated, whether a salmon was present, dewatering status, and sampling action. In addition, pictures were taken of all redds throughout the winter-run, and part of the fall-run survey. Pictures were eliminated from sampling procedure part way through fall-run due to time constraints.

In order to standardize the depth measured at each redd, it was always measured at the shallowest point of the tailspill using a stadia rod and recorded to the nearest inch. Measuring shallow winter-run redds proved problematic. Since these redds were of such extreme concern, small changes in depth due to rock movement were deemed unacceptable. To mitigate this, we implemented standardized points of measurement by placing flat painted rocks on the top of each tailspill. This strategy proved successful, allowing us to relay accurate depth information during minor changes in flow.

Water temperature and clarity were sourced from the California Data Exchange Center (cdec.water.ca.gov) and carcass survey data, respectively. The carcass survey crew determined clarity with the use of a secchi disk mounted to a rigid graduated pole so as to reduce drift of the disk in the current. Measuring clarity allowed us to determine the effectiveness of redd surveys on individual days, as poor clarity made spotting redds difficult.

Redd number was determined by the unique disc tag number of the physical marker placed on the redd. Towards the end of the survey, redds were no longer physically marked as it was deemed unnecessary with the high accuracy and reliability of the Trimble® unit. At this point, redd numbers were assigned chronologically without the use of physical disc tags.

The next data point, whether or not a salmon was present, was recorded to indicate confidence in the validity of a given redd. Redds above Clear Creek were often hard to distinguish due to the carryover of redd morphology from previous runs and years, therefore a salmon nearby or actively digging increased confidence in the age of the redd.

The dewatering status included the options of not dewatered, top only, mostly, pot still wet, and pot dry. This was done in order to differentiate potential impact on the eggs and/or alevin in the redd.

Finally, the sampling action was taken to determine what actions were done at the site. The options used were "depth and photo" and "measured," indicating whether or not a picture was taken. Previous years monitoring efforts utilized additional sampling actions, such as "redd modified," however they were not used during the 2015-2016 monitoring effort.

In addition to the data collected for all redds, local water velocity was measured at winter-run redds as flows were reduced. Lower levels of velocity across redds is detrimental to juvenile development as it does not replenish dissolved oxygen or remove waste products as effectively (Bjornn, Reiser, 1991). Water velocity was measured using a SonTek® digital flow meter placed at a point upstream of the redd to reduce hydraulic influence caused by the shape of the redd. To further increase certainty that flow was being measured at the same point every time, painted rocks were once again deployed. Since flow was not reduced appreciably during the winter-run incubation period local water velocity did not significantly differ between measurements.

To locate new redds crews of two would drive specific sections of the river, with one crew member on the front of the boat looking for redds. We would frequent redd "hot spots" based on previous surveys and aerial redd survey results. Once identified, redds were checked for previous marking by using the map function on the Trimble® unit. If unmarked, data was taken and the redd was marked in the Trimble® unit.

Aerial redd surveys were also extensively utilized throughout the winter-run and part of the spring and fall-runs. During the winter-run spawning period the surveys were conducted once a week using a R44 four seat helicopter. The use of a helicopter allowed lower flying elevations, the ability to quickly return and hover over possible redds, and slower travel speeds. This proved effective for spotting potential winter-run redds which were marked on a map of the river and revisited via jet boat to confirm. Due to funding constraints, aerial redd surveys were transitioned to fixed wing flights once every two weeks for the spring and fall-run survey periods. The advantage gained by using the helicopter was not necessary for fall-run due to the high number of redds. These flights were only conducted a few times during the 2015 spring and fall-run spawning period due to environmental factors that required the survey to be cancelled.

At the beginning of the winter-run, spring-run, and fall-run redd dewatering survey all observed redds were marked regardless of depth due to unpredictable future flow reductions. Once flows were scheduled to reduce to the Biological Opinion minimum flow level of 3,250 cfs (USFWS, 2008; see Figure 2 for flow schedule) it became clear which redds were at risk of dewatering. At this point, redds were only marked if they were in two feet of water or less.

Redds were monitored until their projected emergence date. This date was calculated using accumulated thermal units (ATUs). Thermal units are accumulated based on water temperature, with warmer water contributing more ATUs per day than colder water. Chinook alevins will emerge from redds between 1,650 and 1,850 ATUs (Buccola, Rounds, Sullican, Risley, 2013), which takes approximately 72-90 days from the date of fertilization in the Sacramento River. In an effort to ensure emergence at the time of dewatering, the most conservative figure of 1850 ATUs was used.

Data was downloaded from the Trimble® and transferred into a Microsoft Access® and ArcGIS® database where it was used to develop maps and run queries. Queries proved useful in determining which redds were vulnerable to dewatering or had already been dewatered by altering the depth column requirements. This was especially important during the winter-run incubation period when Reclamation wanted to reduce flows and real time forecasting of dewatering was needed to inform management decisions. Thanks to our monitoring, we were able to provide accurate redd depth data that allowed management of flows to prevent dewatering.

Results

Reclamation started reducing flows out of Keswick Dam between September 15 and September 24, 2015, from 7,250 cfs to 6,850 cfs. This flow reduction had the potential to affect 49 active winter-run redds. Because of our monitoring efforts we were able to provide depth data to fisheries managers, avoiding any winter-run dewatering, although one fall-run redd was dewatered. The next flow reduction did not start until October 19, 2015, at which time there were four winter-run redds which had not yet emerged. These redds were once again monitored for depth, with information conveyed to managers which prevented

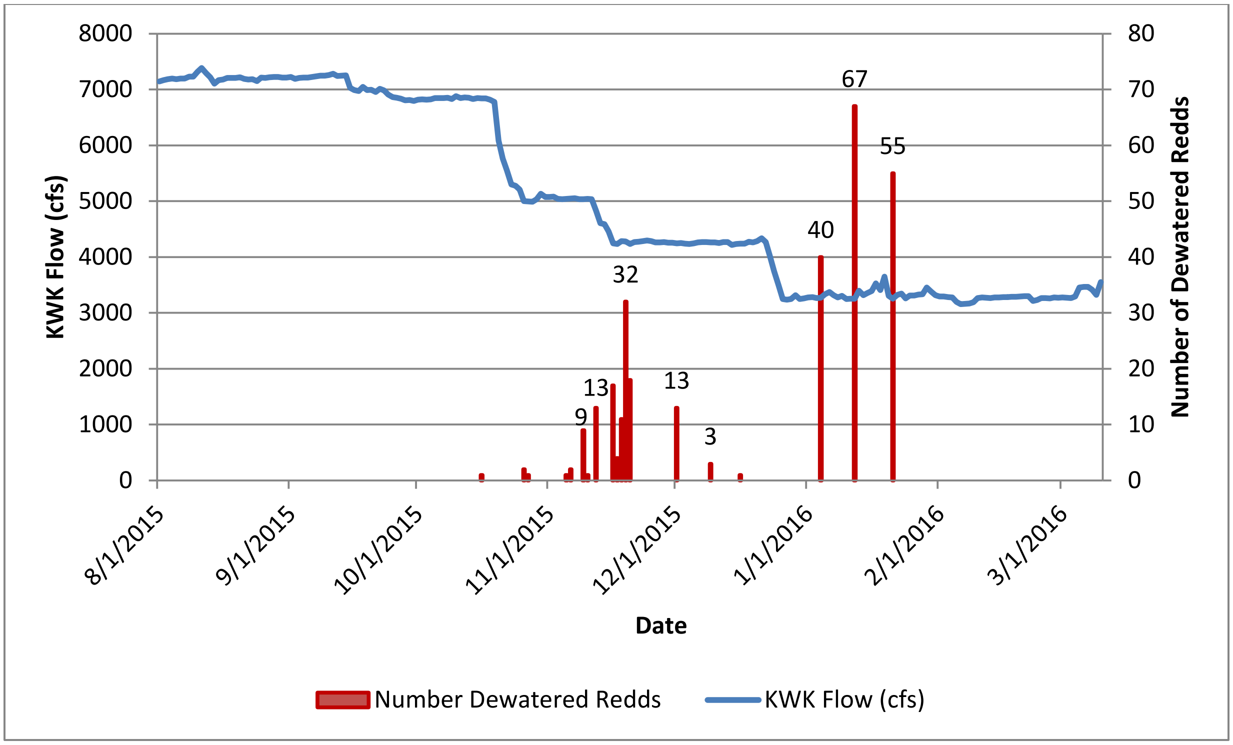

Figure 2.– Flow out of Keswick Dam (KWK) in cubic feet per second compared to the number of dewatered redds, by date observed.

dewatering.

The flow reduction which occurred between October 19 and October 26, 2015 reduced flows by approximately 1,850 cfs over an eight day period, stabilizing at 5,000 cfs. Surprisingly, this substantial flow event was only responsible for dewatering 16 fall-run redds. The next flow reduction to 4,250 cfs occurred between November 12 and November 16, 2015. This flow reduction had a more profound effect on dewatering than the previous reduction, presumably due to the increased abundance of fall-run redds. This flow reduction dewatered an additional 112 fall-run redds and one spring-run redd, bringing the overall dewatered redd count to 129.

The final flow reduction of 1,000 cfs occurred between December 23 and December 26, 2015 and brought the river down to its minimum level of 3,250 cfs (USFWS, 2008). This reduction in flow impacted many more redds than previous reductions, resulting in 162 additional dewatered fall-run redds (Figure 2).

Overall there were 291 observed dewatered redds during the 2015-2016 Chinook spawning season (May 2015 through April 2016). Of these redds, we believe that every one was a fall-run redd besides one which was built in September, and may have been a spring-run redd. Late-fall may have experienced dewatering as well, however due to environmental constraints, limited resources, and the priority of conducting stranding surveys and fish rescues, they were not surveyed. Turbid water and frequent storm events made marking late-fall redds problematic. As such, the observed number of dewatered redds is almost certainly lower than the actual number.

The majority of redd dewatering occurred between Clear Creek and Keswick Dam. Of the 291 dewatered redds observed, 248 were located at or above Clear Creek (Figure 3). The section of river between Clear Creek and the Highway 44 Bridge contained 135 dewatered redds, Highway 44 Bridge to Anderson-Cottonwood Irrigation District (ACID) diversion dam contained 106 dewatered redds, and ACID diversion dam to Keswick Dam contained seven dewatered redds. Of the remaining 43 dewatered redds below Clear Creek, 11 were located between Balls Ferry Bridge and Clear Creek, 17 were located between Bend District Bridge and Balls Ferry Bridge, two were located between Jellys Ferry Bridge and Bend District Bridge, and 13 were located between Red Bluff diversion dam and Jellys Ferry Bridge. No dewatered redds were observed south of Red Bluff diversion dam.

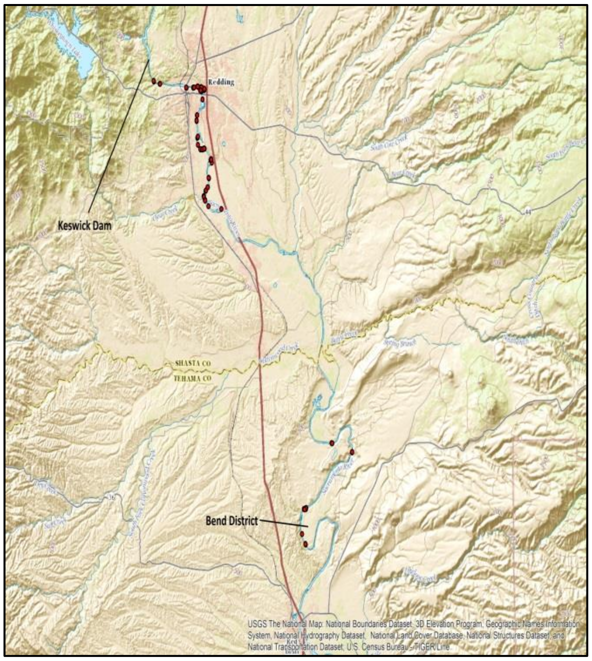

Figure 3.- Map of Sacramento River from Red Bluff to Keswick Dam (KWK). Red icons denote dewatered redds.

CDFW estimated 14,650 spawning spring and fall-run females in the Sacramento River during the 2015 spawning period. Of these females, 94% are thought to have spawned above Tehama Bridge (dewatered redd monitoring reach) and 1.4% did not spawn (Killam, 2015 Annual report – In progress)., The estimate for the number of spawning females in our monitoring reach is 13,578. Each spawning female counts for one redd, therefore the total number of redds is also estimated at 13,578. With this number we calculated the total dewatering percentage at 2.14%. Spring-run was included in the dewatered percentage due to a high degree of overlap and ambiguity between the two runs.

Assuming a fecundity of 5,407 eggs per female (USFWS, 2012), 100% potential egg to fry survival, and 100% mortality upon dewatering , dewatering is theoretically responsible for a reduction in recruitment of 1,573,437 juvenile fall-run Chinook and 5,407 juvenile spring -run Chinook.

When compared to the two previous years monitoring efforts, 2015-2016 saw more dewatering than 2014-2015, but less than 2013-2014 (Figure 4). 2014-2015 saw 47 dewatered redds and 2013-2014 saw 577 dewatered redds. Of the redds dewatered, one was from winter-run in 2014-2015, and five were winter-run in 2013-2014. Summer flows were significantly higher during 2013-2014 and 2014-2015, which may have contributed to the higher numbers of dewatered winter-run redds.

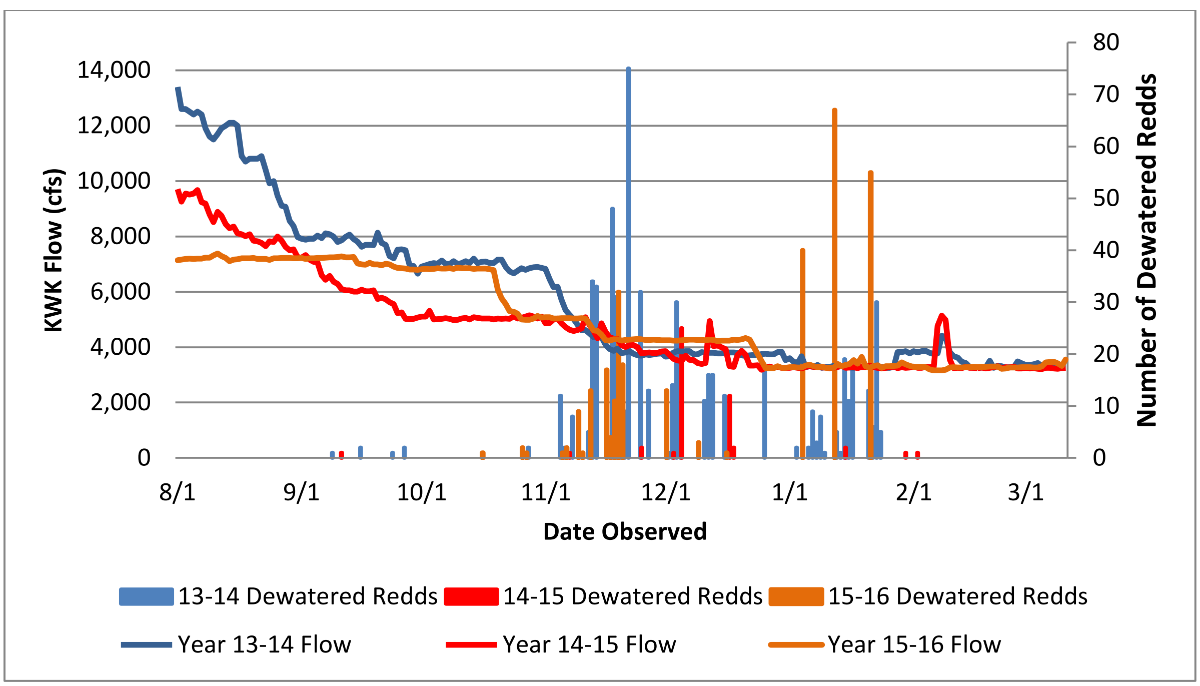

Figure 4. – Flow out of Keswick Dam (KWK) in cubic feet per second compared to the number of dewatered redds, by date observed. Figure compares water years 2013-2014, 2014-2015, and 2015-2016.

Discussion

This monitoring effort should be continued in the future to provide managers real-time data to help guide water management strategies that are protective of Chinook salmon populations. It is important to note that redd dewatering was not proportional to flow reductions. The largest flow reduction during the survey period (6,850 cfs to 5,000 cfs) resulted in 16 dewatered redds, while a much smaller reduction in flow (4,250 cfs to 3,250 cfs) dewatered 162 redds. While severe flow reductions can dewater channelized portions of the river, the majority of dewatering observed occurred on gradually sloping, shallow, gravel bars located next to the thalweg. These gravel bars remain inundated, yet shallow, at higher flows, allowing for extensive spawning.

The results of our dewatered redd monitoring between 4,250 cfs and 3,250 cfs should be considered when developing new management plans. If flows had been reduced to 4,250 cfs on November 1, 2015 and held constant, after all of the winter-run juveniles had emerged, a large percentage of dewatering would not have occurred. Had flows been held at 4,250 cfs the total fall-run and spring-run dewatered redd count would have been 129 redds, a reduction in redd dewatering of 56 percent. From a fall-run fisheries perspective, flows should have been lowered to 4,250 cfs immediately after winter-run emergence and held constant until Keswick releases increased for downstream water users. This should be considered in tandem with winter-run, spring-run, and late-fall run needs, as drought conditions may limit total water availability.

While every effort to mark all dewatered redds was made, it is almost certain that this monitoring effort produced an under-estimate of fall and late fall-run redd dewatering. For fall-run, time and staff constraints had the largest impact on the amount of redds that could be marked. Time had to be split between redd dewatering, water quality, and juvenile stranding monitoring. As such, it was not possible to monitor all productive spawning sites as often as necessary, lending to the probable under estimate of dewatering. Not visiting sites as often as necessary meant some redds were superimposed by other spawning females and previously fresh redds were given time to accumulate sediment and algae. This made identifying all unmarked redds extremely difficult. This issue could be alleviated by hiring additional staff. Late-fall monitoring was mainly limited by environmental constraints, as water clarity was poor for the majority of late-fall spawning.

For future consideration, more research regarding the effects of partial dewatering on Chinook juveniles in the Sacramento River Basin should be completed. It is unclear whether 100% mortality can be assumed for all degrees of dewatering, therefore a study on the effects of partial dewatering would increase confidence in the reduction in juvenile recruitment estimate.

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Previous years reports can be found at:
http://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring.aspx

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