2018/2019 MOKELUMNE RIVER HATCHERY CHINOOK SALMON SPAWNING AND RELEASE PROTOCOL

Background

The Mokelumne River supports Central Valley fall-run Chinook salmon (*Oncorhynchus tshawytscha*) (fall-run), which is the only salmon run known to naturally occur in this waterway (Clark 1929). Fall-run are listed as a Species of Concern under the federal Endangered Species Act (NMFS 2004).The Mokelumne River Hatchery (MOK) conducts artificial propagation of fall-run to enhance economically important commercial fisheries and popular sport fisheries in the ocean and rivers of California.

Camanche Dam, which impounds Camanche Reservoir is the upper limit of anadromous fish migration in the Mokelumne River. East Bay Municipal Utility District (EBMUD) initiated construction of Camanche Reservoir in 1963. As mitigation for blocking access to spawning grounds for salmonids, EBMUD provided funding for the original construction of the MOK in 1964.The MOK is located on the south bank of the Mokelumne River at the base of Camanche Dam. While EBMUD provides funding for fall-run production, the California Department of Fish and Wildlife (CDFW) administers and operates the hatchery. The Commercial Salmon Stamp Fund provided funding for an additional MOK building built in 2002 and continues to financially support the MOK. On an annual basis the MOK produces fall-run for mitigation (Mitigation Element) and for ocean salmon enhancement (Ocean Enhancement Element). The annual MOK production goal is 5,400,000 fall-run smolts (3,400,000 for Mitigation Element and 2,000,000 for Ocean Enhancement Element). The MOK receives requests from researchers to produce small numbers of fall-run smolts for special studies (Special Studies Element). Special Studies Element production is separate from Mitigation and Ocean Enhancement elements and varies in quantity annually or may not occur.

1.0 Central Valley Fall-run Chinook Salmon Production Release Size Goals

The 2018-2019 spawning season fall-run Chinook salmon production prioritized goals for MOK are as follows:

Fall-run Chinook salmon Mitigation Element: Up to 3,400,000 smolts, at 27.2 fish per kilogram (60 fish per pound)

Fall-run Chinook salmon Mitigation Element, Maturation Study: 400,000 smolts, to a variable size due to experimental rearing conditions

Fall-run Chinook salmon Special Studies Element, In-River Release Study: 400,000 smolts, at 27.2 fish per kilogram (60 fish per pound)

Fall-run Chinook salmon Ocean Enhancement Element: Up to 2,000,000 smolts, at 20.4 per fish kilogram (45 fish per pound)

The MOK is expected to produce and release 6,200,000 juvenile Chinook salmon this season. To meet this goal a total of 6,820,000 eggs will be needed. Based on past performance of eggs taken at the MOK, survival from the green to eyed egg stage is approximately 95 percent. Survival from the eyed egg stage to release is also approximately 95 percent. An approximate ten percent buffer of 620,000 eggs will account for mortality during incubation phases.

2.0 Central Valley Fall-run Chinook Salmon Broodstock Collection and Spawning

2.1 Gathering Broodstock

A fish weir will be installed on the first Monday in October, in the Mokelumne River directly below the MOK by CDFW staff. The weir will be placed perpendicular from bank to bank to span the entire river channel. The fish weir will encourage migrating adult fall-run toward a permanent fish ladder on the south bank of the river which then guides fish toward the MOK. Once fish ascend the ladder, they enter a fish trap on the MOK premises near the holding ponds. The fish trap allows for the enumeration of potential broodstock fish as they arrive and for staff to distribute migrants to holding ponds. Broodstock collection is guided by an egg-take model to reduce the need for excessing production and to allow fish not needed for the hatchery program to spawn in the river. The fish ladder may be closed periodically through the spawning season to avoid losses in holding ponds due to overcrowding, and as guided by the weekly egg-take model. Salmon will be enumerated during distribution to holding ponds to ensure that enough fish will be available to meet egg take goals throughout the spawning season. Broodstock will be selected from those fish that enter the MOK when the hatchery ladder is open. The ladder will be open during the historical adult fall-run Chinook salmon migration period of early October through December (Yoshiyama et al. 1998).

2.2 Brood Stock Identification

Three fish ladders have been constructed to provide for fish passage over Woodbridge Irrigation Dam (WID), which is an irrigation impoundment in the Mokelumne River 39 river kilometers (24 river miles) downstream of MOK. Two ladders provide passage during the WID dam-out condition under high and low flows, and the other ladder provides passage during the WID dam-in condition. The dam-in ladder has a digital video camera operated by EBMUD that obtains complete migrant counts under nearly all flow and operating conditions during the WID dam-in condition, which encompasses the entire fall-run migration period. During the years of 2010 to present, daily counts of upstream fall-run migrants passing Woodbridge Irrigation Dam had a mean passage completion of 10%, 50%, and 90% occurring October 18, November 4, and November 26, respectively (Del Real and Shillam 2016). Adult tagging studies at WID have shown travel time to the MOK to be one to ten days (Merz 1996), so real time adult migrant counts provided by EBMUD will allow for forecasting migrant arrival timing to the MOK which in turn assist in planning hatchery spawning operations.

The number of two-year-old males (jacks) selected as broodstock will not exceed the lesser of: 1) 50 percent of the total number of jacks to arrive at the hatchery, and 2) five percent of the total males selected as broodstock (California HSRG 2012). If enough males older than two years are not available, then jacks will be used to fulfill production goals. Two-year-old females (jills) will not be excluded from broodstock. However, jills will only be used if they are ripe upon entering the MOK facility. Jills are not held in holding ponds to mature unless there are not enough older females available to meet egg take goals. Coded wire tag (CWT) (see Section 5.0

Marking and Tagging) evaluation from brood years (BY) 2014 and 2015 distribution of known length at age for MOK returns suggests that most jacks are < 68 centimeters (cm) fork length (FL) and the majority of jills are < 65 cm FL (Smith 2018). During the hatchery spawning season, grilse are recognized by hatchery staff and used according to California HSRG recommendations and MOK egg take goals. During the spawning season, CWTs may be read to verify grilse length. If CWT information suggests a different size range for grilse, management will adjust length criteria to maintain contribution rates to broodstock. Grilse contribution to broodstock during the spawning season will be recorded and documented in annual hatchery production reports.

2.3 Broodstock Collection and Spawning Goals

Based on historical migration and spawn timing, it is anticipated that MOK fall-run broodstock collection and spawning will commence mid-October and continue until late December. Broodstock collection will be conducted in a manner that represents fish arriving to spawning grounds in the Mokelumne River throughout the entire natural migration and spawning period. Migrant arrival to spawning grounds in the Mokelumne River is represented by a bell-shaped curve, where few migrants arrive near the tails of the curve and the bulk of the migrants appear in the peak of the curve. Annual hatchery egg take goals will replicate the bell shaped curve of adult spawning in the river (Figure 1).

There may be unforeseeable delays to migrant arrival timing and availability for MOK spawning purposes due to environmental factors in rearing areas or migration corridors. If there are not enough ripe salmon available for spawning as predicted to initiate in mid-October, weekly egg take goals will be shifted according to when migrants start appearing at the MOK while maintaining efforts to gather eggs replicative of the natural fall-run spawning period (bell shaped curve).

Salmon entering the MOK facility will be kept in holding ponds near the hatchery building until they are spawned. Males are held separately from females, and females are sorted by ripeness between holding ponds. Because only ripe fish are spawned, males and females will be checked weekly for ripeness and unripe fish will be allowed to mature further in holding ponds. To meet egg take goals and collect eggs in a fashion that represents the entire adult migrant return period (a bell-shaped curve), MOK staff will need to conduct spawning activities once per week in the beginning of the run in October and tail of the run in December. MOK staff will increase spawning efforts in the peak of the run in November to two or three days per week.

Based on an average of 5,100 eggs per adult female at MOK over the past 10 seasons, an estimated minimum of 1,338 female adult fall-run Chinook salmon and an even number of males are necessary to meet the annual egg take goal of 6,820,000 eggs. Grilse returns to the MOK can occur at a rate of 25 to 30 percent and jills have been observed to have less eggs on average compared to adult females. If jills are used during spawning, more females will be required in order to meet the annual egg take goal.

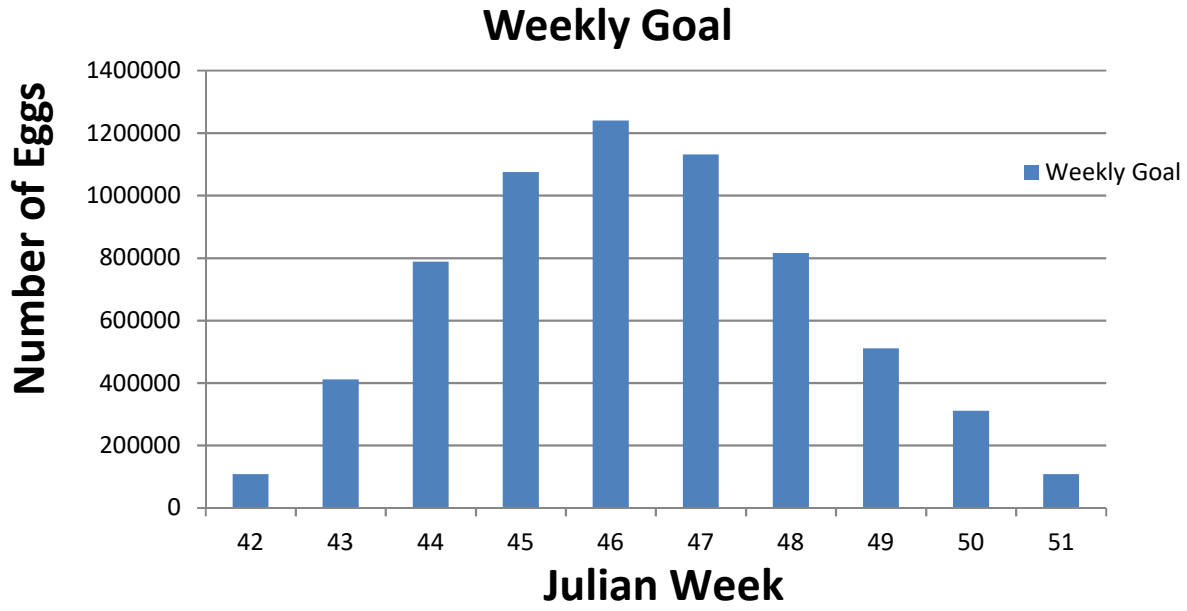
Adult fall-run will be spawned using a true 1 male: 1 female ratio. Every effort will be made to maintain this ratio. However, deviation from this approach may be necessary due to insufficient numbers of male broodstock. In this case fall-run will be spawned by using the milt from one male spawned with no more than two females as suggested in the California HSRG 2012.

Reuse of males will be recorded and documented in annual hatchery production reports along with details justifying such decisions.

Fish will be sorted by sex in the hatchery building prior to being prepared to be spawned. MOK staff will examine every fish for presence or absence of an adipose fin and record those observations. Fish used as broodstock are tallied and recorded while spawning occurs as male or female and grilse or adult.

All fish that enter the MOK during the spawning season will be made available to CDFW Central Valley Coded Wire Tag Project for CWT recovery. Central Valley Coded Wire Tag Project staff will remove heads of salmon with excised adipose fins for CWT extraction. Heads will be removed after fish have been spawned to reduce the potential for blood to interfere with fertilization. Central Valley Coded Wire Tag Project staff may also collect scale samples from fish after they have been spawned for aging by the CDFW Ocean Salmon Project.

Figure 1. Expected egg collection by Julian week (October 17 through December 18) needed to procure 6,820,000 fall-run Chinook salmon eggs.



2.4 Egg Tracking

Up to 6,820,000 Chinook salmon eggs from across the spawning season are needed to meet the release goal of 6,200,000 smolts. The target of 6,820,000 green eggs allows for an approximate ten percent buffer against mortality or disease during incubation phases. Eggs will be gathered and put into inventory according to an egg take model (Figure 1); eggs collected in excess of this model will be culled as green eggs the day they were gathered after fertilized eggs from all parings on that day are mixed. When culling occurs due to excess egg take, excess eggs will be culled in a manner that does not completely eliminate representative families or any temporal segment of the run. There is no anticipated set amount of eggs that will be culled each season; culling will only occur if egg take goals for a given day are exceeded.

2.5 Egg Incubation and Juvenile Rearing

Immediately after spawning, MOK staff will mix a chilled saline solution in with the eggs and milt to extend sperm motility and aid in the fertilization process. Fertilized eggs will then be rinsed of milt, ovarian fluid, and the saline solution with sterilized, ultra violet (UV) treated water. The eggs from seven families will be placed in buckets containing a solution of nine liters of UV treated water to 150 milliliters (mm) iodine for a period of 20 minutes. Eggs will then be placed in pure UV treated water for two hours to allow eggs to become water hardened. Eggs will be inventoried and placed in 800 ounce upwelling jars containing circulating UV treated water. When the eggs reach 310 temperature units (TU), eggs will be gently stirred inside the jars by MOK staff. When the eggs reach 530 TU, they will be addled by manual siphoning. On the following day all of the remaining live eggs will be counted using Jensorters and placed into upwelling jars or vertical stack incubators.

When 60-75% of the eggs have hatched they will be transferred into indoor rearing troughs. When 90% of the fish in incubation stacks have buttoned-up, they will be transferred to outdoor concrete raceways. Fry will be hand fed Bio-Oregon fish feed to satiation every morning and multiple times throughout the work day. Fry will be fed on #0 crumb for the first 10-14 days depending on water temperature and then switched to #1 crumb until they reach 181 juveniles per kilogram (kg). After fry reach 181fish/kg, they will be fed as follows; #2 crumb at 181-91fish/kg, 1.2mm pellet at 90-57 fish/kg, 1.5mm pellet at 56-27 fish/kg and 2.0mm pellet at 26-20/kg. Two weeks prior to release, fish will be fed Bio-Oregon Supreme fish feed which is thought to help smolts transition to brackish or marine release waters.

2.6 Pathology Protocol

The MOK will employ measures to prevent introduction, spread, or amplification of fish pathogens to natural stocks using disease control and prevention techniques (IHOT 1995). During spawning, ovarian fluid samples from adult females will be collected by CDFW Fish Pathology Lab staff to monitor for disease. To reduce the potential for spreading pathogens and to increase survival of fertilized eggs, a standardized process to sterilize eggs will be employed (Wedemeyer, 2001). This process recommends eggs to be drained of ovarian fluid and milt reducing exposure of eggs to coelomic fluids, eggs to be treated for 10-60 minutes in active solution of polyvinylpyrrolidone iodine during egg water hardening and for UV water to be used during throughout the egg taking process and incubation phases.

The Hatchery Building water supply will be manipulated to maintain temperatures between 10 and 12.8° Celsius (50 - 55° Fahrenheit) during the spawning and egg incubation period. This temperature range will minimize egg loss due to coagulated yolk disease, cold water disease bacteria (*Flavobacterium psychrophilum*) infection, and infection by other mixed motile *Aeromonas* bacteria.

No adult salmon that have entered the MOK premises will be allowed to return to the river to avoid issues of properly accounting for in-river escapement totals and to reduce hatchery impacts to natural area (river) spawning fish. National Pollution Discharge Permit (NPDES) conditions prohibit disposal of hatchery spawned salmon carcasses in the river. Hatchery spawned carcasses will be given to local nonprofit organizations and food banks: American Canadian Fisheries, Dignity Alcove and United Chaplin's Association.

3.0 Central Valley Fall-run Chinook Salmon Production Release Strategy

Batches of hatchery produced fish will be released when they reach target size. Projected release timing and location is provided in Table 1. Weight counts will be taken as fish are being loaded into transport trucks and recorded on release receipts following standard hatchery practices. Salt will be added to a level of ten parts per thousand to transport tank trucks prior to loading fish for transport. Transport equipment will not be allowed contact receiving water to prevent the spread of aquatic invasive species, as outlined in the Hazard Analysis and Critical Control Point Plan (Anderson and Smith 2011).

Releases will be coordinated with outgoing tides, acclimation net pen operations and receiving water temperatures <18.5°C (65°F). Salmon will be released into acclimation net pens during slack tide prior to the ebb flow and releases will be scheduled on not more than two consecutive days. Should environmental conditions be poor, CDFW may delay or expedite the release dates to the extent possible when conditions are more conducive to survival. The release timing will be selected depending on weather, availability of net pens, hauling trucks and CDFW management review. Time of plant, temperature of receiving water and transport tank water, and the condition of the fish during release will be recorded on planting receipts.

Table 1. - Production goals, release timing and release location for fall-run Chinook salmon production at the Mokelumne River Hatchery 2018/2019.

Number of Juveniles	Release Site	Average Size	Release Timing	Production Element
3,400,000	Sherman Island	27.2 per kilo	April 15 - June 15	Mitigation
400,000	Maturation Study, Sherman Island	variable*	April 15 - June 15	Mitigation
400,000	In-river Release Study	27.2 per kilo	April 15 - June 15	Mitigation
Up to 1,160,000	Sherman Island	20.4 per kilo	April 15 - June 15	Ocean Enhancement
Up to 720,000	Pillar Point in Half Moon Bay	20.4 per kilo	April 15 - June 15	Ocean Enhancement
Up to 120,000	Santa Cruz Harbor	20.4 per kilo	April 15 - June 15	Ocean Enhancement

*Fish used during the maturation study will be raised using experimental feeding and temperature regimes and average size at release may be variable.

3.1 Central Valley Fall-run Chinook Salmon Release Locations

Release strategies have implications for juvenile survival, fishery contribution and adult stray rates (Palmer-Zwahlen and Kormos 2015). The Mokelumne River Hatchery Coordination Team (HCT) meets regularly throughout the year to discuss specific release strategies including release locations, release logistics, equipment needs and the purchase of CWTs.

The majority of the Mitigation Element (3,400,000) and Ocean Enhancement Element (up to 1,280,000) fall-run smolt production is planned to be release in the San Joaquin River near Sherman Island (38.045600/-121.713500). Several transport truck deliveries will be made to acclimation net pens staged near Sherman Island. At the start of the ebb tide the net pens will be untied from their moorings and allowed to drift with the tide for up to two hours before fish are released. The acclimation pens will be operated by the Fishery Foundation of California. More information can be found at www.fisheryfoundation.org. CWT recovery data indicates that the release location at Sherman Island is the best option for optimizing hatchery broodstock returns, contributions to sport and commercial fisheries, and limiting environmental and predation impacts experienced by fish released in the Sacramento–San Joaquin River Delta (Delta). Supporting data can be found on the Regional Mark Processing Center website www.rmpc.org.

Ocean Enhancement Element fall-run production will also be released in ocean net pens at Pillar Point in Half Moon Bay and in Santa Cruz Harbor. Coast Side Fishing Club will assist CDFW with releases at Pillar Point. Pillar Point will receive three deliveries of 240,000 (720,000 total) fish over a three week period. The fish will be vaccinated for vibriosis prior to delivery and acclimated in holding net pens for five days prior to release. While being acclimated in holding pens at Pillar Point, fish will be fed by solar powered automated feeders. The Monterey Bay Salmon and Trout Project will assist CDFW with a release group of 120,000 in the Santa Cruz Harbor. Fish will be acclimatized in net pens in Santa Cruz Harbor for a period of two hours prior to release.

3.2 Special Studies Central Valley Fall-run Chinook Salmon Production

Occasionally fishery researchers conducting special studies may request MOK produced juvenile Central Valley fall-run Chinook salmon. Requests for numbers of fish or eggs do not change prioritized production goals and are produced in excess of Mitigation and Ocean Enhancement elements. Egg and fish requests for special studies conducted by stakeholders other than CDFW or EBMUD are due to CDFW August 1 of each year. Special studies allocation requests are made to the CDFW statewide hatchery coordinator and if approved are provided for review by regional CDFW fisheries biologists as well as the Mokelumne River HCT.

- Two experimental groups of 200,000 (400,000 total) juvenile salmon should be released simultaneously within the Mokelumne River below Woodbridge Dam and directly below the MOK in 2019. The paired releases of marked and tagged fish will allow CDFW and EBMUD management to assess and compare the behavior, condition, and survival of salmon between release locations. These experimental fish will be produced in excess of Mitigation Element production targets. Each of the two groups will receive a unique CWT at a rate of 100 percent to differentiate them from other release groups and all fish will be externally marked at a rate of 100 percent by excising adipose fins. This will be the fourth consecutive year of this study. As these efforts are experimental in nature, they do not represent a permanent change to MOK release strategies.

- EBMUD fishery biologists will be conducting a special study requiring 400,000 juvenile salmon produced by the MOK this season. These fish will be produced in excess of

Mitigation Element production targets. The study will examine whether reduced feed rates and reduced temperatures during rearing at the hatchery can influence precocious maturation of hatchery fish (Appendix 6.3). Four study groups of 100,000 each will be raised in separate raceways at the MOK to conduct the study. All study fish will be 100 percent marked by the removal of the adipose fin and each of the study groups will receive a unique CWT. The study fish will be released in the same fashion as other Mitigation Element production releases; in the spring at Sherman Island, in the lower San Joaquin River (38.045600/-121.713500).

□ This season a total of 19,865 fall-run Chinook salmon will be produced by the MOK for special studies being conducted by stakeholders other than CDFW or EBMUD. These stakeholders, their respective studies, requested allotments and requested sizes are listed below.

- University of California, Davis; Floodplains, Tidal Wetlands, and Dark Carbon: determining the heterotrophic carbon contribution to higher level consumers (300 salmon; 45-50mm)
- California Department of Water Resources; Ongoing evaluations of SWP export facility losses (4,300 salmon; 75-100mm)
- United States Bureau of Reclamation; Facility Efficiency Evaluation (2,000 salmon; 55-110mm)
- University of California, Santa Cruz; Delta Predation Study (2,000 salmon; 30-40mm)
- University of California, Davis; Analyze the strontium isotope signatures of the otoliths from Chinook to provide “known origin” reference samples for our Central Valley "isoscape" (15 salmon; 80-90mm)
- National Marine Fisheries Service; Identifying Pathogen Hotspots and Modeling Impacts on California Salmonids (2,250 salmon; 60mm)
- National Marine Fisheries Service; Tagging and tether study to improve understanding of the relationship between predation mortality, predator contact points, and survival for out-migrating Chinook (9,000 salmon; 65mm)

4.0 Marking and Tagging

The Constant Fractional Marking Program (CFM) was initiated in 2007 by CDFW, U. S. Fish and Wildlife Service (USFWS) and the Pacific States Marine Fisheries Commission (PSMFC) for fall-run Chinook salmon at Central Valley hatcheries (Allen 2006). Under this program, 25 percent of all fall-run produced in California Central Valley hatcheries will be supplied with an internally planted CWT and externally marked with an adipose fin clip. Mitigation and Enhancement element fish released in net pens near Sherman Island will be marked and tagged with a CWT at 25 percent. All Experimental Mitigation Element groups of juvenile Chinook salmon are 100 percent marked and tagged with a CWT. Ocean Enhancement element fish released in ocean net pens at Pillar Point and Santa Cruz will be marked and tagged with a CWT at 100 percent with each location receiving a unique CWT code.

5.0 References

Allen, S. 2006. ERP Directed Action Implementation of a Constant Fractional Marking/Tagging Program for Central Valley Hatchery Chinook Salmon. Pacific States Marine Fisheries Commission.

Anderson, R. and Smith W. 2011. Mokelumne River Hatchery Hazard Analysis and Critical Control Point Plan. California Department of Fish and Game. Unpublished. 10pp.

California Hatchery Scientific Review Group (California HSRG). 2012. California Hatchery Review Report. Prepared for the US Fish and Wildlife Service and Pacific States Marine Fisheries Commission. June 2012. 100 pgs.

Clark, G. H. 1929. Sacramento-San Joaquin Salmon (*Oncorhynchus tschawytscha*) Fishery of California. Division of Fish and Game of California, Bureau of Commercial Fisheries, Fish Bulletin No. 17. 73 pp., 32 figs.

Del Real, C. and J. Shillam. 2016. Lower Mokelumne River Upstream Fish Migration Monitoring Conducted at Woodbridge Irrigation District Dam August 2015 through May 2016. Unpublished EBMUD report. 14pp.

IHOT (Integrated Hatchery Operations Team). 1995. Policy and Procedures for Columbia Basin Anadromous Salmonid Hatcheries. Annual report to the Bonneville Power Administration, project 92–043, Portland, Oregon.

Marine K.R. 1997. Minutes of the Mokelumne River Technical Advisory Committee. Sacramento, California.

Merz, J. 1996. Peterson Disc Tagging of Adult Chinook Salmon in the Lower Mokelumne River. EBMUD Unpublished Report. 8pp.

NMFS (National Marine Fisheries Service). 2004. Endangered and Threatened Species; Establishment of Species of Concern List, Addition of Species to Species of Concern List, Description of Factors for Identifying Species of Concern, and Revision of Candidate Species List Under the Endangered Species Act. Federal Register / Vol. 69, No. 73 / Thursday, April 15, 2004

Palmer-Zwahlen, M and B. Kormos. 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. California Department of Fish and Wildlife. Fisheries Administrative Report 2015-4. November 2015

Smith, W. 2016. Length versus age evaluation of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) using coded wire tags at Mokelumne River Hatchery. Unpublished data.

Wedemeyer, G. 2001. Fish Hatchery Management. American Fisheries Society; Bethesda, MD.

Yoshiyama, R. M., Fisher F. W., and Moyle, P. B. 1998. Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. North American Journal of Fish Management 18: 487-521.

6.0 Appendix

6.1 California Hatchery Scientific Review Group (California HSRG 2012) Recommendations for the Mokelumne River Hatchery

Mokelumne Fall Chinook Program

The integrated fall Chinook program at MOK has a goal to release up to five million fall-run Chinook salmon smolts that average 60 fpp or larger for harvest purposes. Approximately two million additional Chinook are raised to post-smolt size (45 fpp) each year for an ocean enhancement program. All of the enhancement salmon production is released into San Pablo Bay or reared in net pens on the coast. Remaining Mokelumne-origin salmon smolts are released below Woodbridge Dam, about 10 miles downstream of the hatchery. Juvenile fall Chinook are released between March and June and all fish are marked at a rate of 25 percent (constant fractional marking) with an adipose fin-clip and coded wire tag.

Recommendations for All Mokelumne River Hatchery Programs

- Clear goals should be established for the program. Program production goals should be expressed in terms of the number of age-3 ocean recruits just prior to harvest (Chinook salmon), and the number of adults returning to freshwater (steelhead).

- Broodstock for the program should only come from native, locally adapted stocks. Out-of-subbasin importation of eggs, juveniles or adults should not occur, even if it means juvenile production targets will not be achieved in some years. Work with water managers to improve conditions for migrating juveniles and adults.

- Transporting and releasing juveniles to areas outside of the Mokelumne River should be discontinued. Juvenile fish should be released at the hatchery, or if not possible, as far upstream in the Mokelumne River from the confluence of the Sacramento River as possible to reduce adult straying and increase the number of adult fish returning to the hatchery. Consider necessary facility modifications or equipment purchases that will facilitate on-site releases. Release locations for steelhead may take into consideration ecological and predation effects on other fish populations but should not compromise homing of adults to the hatchery.

- Performance standards for each phase of the fish culture process should be established and tracked annually. Summaries of data collected with comparisons to established targets must be included in annual hatchery reports.

- Managers should investigate the feasibility of collecting natural-origin adult fish at alternate locations. The existing trapping location is very limited in its ability to capture fish representing the entire spectrum of life history diversity. Only fish that migrate to the furthest upstream reaches are susceptible to capture.

- A Monitoring and Evaluation Program should be developed and implemented and a Hatchery Coordination Team formed for the program. Implementation of these processes will inform hatchery decisions and document compliance with best management practices defined in this report.

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review

process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

- CDFG should develop an updated Hatchery Procedure Manual which includes performance criteria and culture techniques presented in IHOT (1995), Fish Hatchery Management (Wedemeyer 2001) or comparable publications. The fish culture manual (Leitritz and Lewis 1976) is outdated and does not reflect current research and advancements in fish culture.

Mokelumne River Fall Chinook Major Program Recommendations
The major recommendations of interest to resource managers for the Mokelumne fall Chinook salmon hatchery program are provided below. Those selected for presentation may represent major changes in operations, changes in approach or outcomes towards achieving harvest or conservation objectives, or will require substantial investment of resources. The California HSRG's evaluation of program compliance with standards and guidelines and the group's comments about this program are presented in their entirety in Appendix VIII.

- Natural-origin fish should be incorporated into broodstock at a minimum rate of 10 percent to prevent divergence of the hatchery and natural components of the integrated population. This may require auxiliary adult collection facilities or alternative collection methods (e.g., seining or trapping).

- Until all off-site releases of Chinook salmon are eliminated in the entire Central Valley, coded-wire tag analysis should be used to identify stray hatchery-origin fish among those fish selected for broodstock. Strays from other hatchery programs should not be used as broodstock, or if eggs are collected from or fertilized by such fish, they should be culled soon after spawning.

- Program fish should be 100 percent coded wire-tagged and 25 percent adipose fin-clipped. "Yearling" releases should receive an additional distinguishing external mark or tag (e.g., a ventral fin clip) allowing real-time discrimination from fingerling releases at the adult stage.

- Returning yearling-origin adults should not be used as broodstock. If eggs are collected from or fertilized by such fish, they should be culled soon after spawning. Adequate numbers of fingerlings should be released each year to meet numerical goals for broodstock. When adult returns from fingerling releases are inadequate to satisfy hatchery egg take needs, yearling returns may be used to reduce the deficit.

6.2 Implementation of 2012 California Hatchery Review Group Report Recommendations at the Mokelumne River Fish Hatchery

The Mokelumne River HCT used the following criteria to rank all of the recommendations presented in the California Hatchery Review Report that pertained to MOK. Prioritization was based on the following criteria applied to each recommendation:

High priority: Would substantially improve program performance in a critical area. Effects would be immediate or may take some time to realize, but have long-term implications to

program success. And/or, implementation is crucial for authorization of HGMP for the program. Implementation is necessary to meet program purpose and goals.

Medium priority: Would moderately improve program performance in an important, if not critical, program area. Effects may be immediate or may take some time to realize, and may or may not have long-term implications to program success. And/or, implementation is not crucial for authorization of HGMP for the program, but would add to program justification. Implementation adds to progress toward program goals, but is not essential to meeting them.

Low priority: Implementation would not substantially improve program performance in any critical or important area, but would add to the program. And/or, implementation is not specifically necessary for authorization of HGMP for program, nor would it add to program justification under the HGMP. And/ or, effect of implementation is very uncertain or logistically difficult or is otherwise infeasible.

The major CA HSRG (2012) recommendations for Mokelumne River Fish Hatchery and programs the Mokelumne River HCT review of those recommendations are listed below.

No.[1]	**CA HSRG Recommendation**	**Priority to Review Recommendation** (high, med, low[2])	**Estimated Timeline (Years)**	**Comment**
All Mokelumne River Hatchery Programs				
1	Clear goals should be established for the program.	High (Implemented)	<1	HCT prepared draft document in 2015
2	Broodstock for the program should only come from native, locally adapted stocks.	High (Current practice)	>5	Fall Chinook salmon broodstock comes from fish trapped at the hatchery. Steelhead broodstock comes from fish trapped at the hatchery. The origin of the broodstock was from eggs transferred from Feather River Hatchery, and hatched at MOK, and reared and released by MOK personnel.
	Out of sub basin importation of eggs, juveniles, or adults should not occur, even if it means juvenile production targets will not be achieved in some years.	Low (Current practice)	<1	
	Work with water managers to improve conditions for migrating juveniles and adults.	High	>5	
3	Transporting and releasing juveniles to areas outside of the Mokelumne River should be discontinued. Juvenile fish should be released at the hatchery, or if not possible, as far upstream in the Mokelumne River from the confluence of the Sacramento River as	High	>5	Juvenile fish are released at locations and methods determined by CDFW and EBMUD personnel and described in an annual operation agreement.

	possible to reduce adult straying and increase the number of adult fish returning to the hatchery. Consider necessary facility modifications or equipment purchases that will facilitate on‐site releases. Release locations for steelhead may take into consideration ecological and predation effects on other fish populations but should not compromise homing of adults to the hatchery.			
4	Performance standards for each phase of the fish culture process should be established and tracked annually. Summaries of data collected with comparisons to established targets must be included in annual hatchery reports.	High/Medium	1-5	Data is collected by hatchery personnel but is not summarized due to lack of staffing.
5	Managers should investigate the feasibility of collecting natural origin adult fish at alternate locations. The existing trapping location is very limited in its ability to capture fish representing the entire spectrum of life history diversity. Only fish that migrate to the furthest upstream reaches are susceptible to capture.	Low	<1	Current spawning habitat is limited to approximately 15 miles downstream from Camanche Dam. There is no evidence to support the thesis that either fall Chinook salmon or steelhead trapped at the hatchery are genetically different from fish that spawn in the river. Look at carcass survey to determine if there is any significant difference below the hatchery
6	A Monitoring and Evaluation Program should be developed and implemented and Hatchery Coordination Team formed for the program. Implementation of these processes will inform	High Low (Implemented) High	1-5 <1 >5	EBMUD personnel conduct monitoring and evaluations of the hatchery and river fish populations. A HCT has been formed to assist with hatchery decisions and document compliance with BMPs. The Constant Fractional

	hatchery decisions and document compliance with best management practices defined in this report.			Marking Program lacks effective monitoring and reporting.
7	CDFW should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.	Low (Implemented)	<1	CDFW personnel have prepared a formal, written fish health policy. A copy is attached (Appendix B).
8	CDFG should develop an updated Hatchery Procedure manual that includes performance criteria and culture techniques presented in IHOT (1995), Fish Hatchery Management (Wedemeyer 2001) or comparable publications. The fish culture manual (Leitritz and Lewis 1976) is outdated and does not reflect current research and advancements in fish culture.	Medium	1-5	Members of the CDFW Hatchery Management Committee are preparing procedure manuals for anadromous fish hatcheries.
		Fall Chinook Salmon Program		
9	Natural origin fish should be incorporated into broodstock at a minimum rate of 10 percent to prevent divergence of the hatchery and natural components of the integrated population. This may require auxiliary adult collection facilities or alternative collection	Medium/Low	>5	Additional information is required to evaluate this recommendation. Increasing natural production would increase the percentage of natural origin fish in the hatchery broodstock.

	methods (e.g., seining or trapping).			
10	Until all off site releases of Chinook salmon are eliminated in the entire Central Valley, coded wire tag analysis should be used to identify stray hatchery origin fish among those fish selected for broodstock. Strays from other hatchery programs should not be used as broodstock, or if eggs are collected from or fertilized by such fish, they should be culled soon after spawning.	Medium/Low	<1 For current 25% tag rate >5 when 100% CWT is implemented	This is a low priority recommendation and supporting information is lacking. Currently, the origin of the hatchery broodstock is evaluated after spawning. Analysis required of the number of strays from Nimbus Fish Hatchery and Coleman National Fish Hatchery as a result of in-river releases
11	Program fish should be 100 percent coded wire tagged and 25 percent adipose fin clipped. "Yearling" releases should receive an additional distinguishing external mark or tag (e.g., a ventral fin clip) allowing real‐time discrimination from fingerling releases at the adult stage.	Medium	>5	This is a "best management" scenario but benefits have not been clearly identified. Monitoring costs would be high and most likely greater than the initial marking and tagging costs.
12	Returning yearling origin adults should not be used as broodstock. If eggs are collected from or fertilized by such fish, they should be culled soon after spawning. Adequate numbers of fingerlings should be released each year to meet numerical goals for broodstock. When adult returns from fingerling releases are inadequate to satisfy hatchery egg take needs, yearling returns may	Not applicable	<1	Yearling fall Chinook salmon are not reared and released at MOK.

	be used to reduce the deficit.			

6.3 Chinook Salmon Maturation Study, East Bay Municipal District, lead researcher: Robyn Bilski

Can alteration of hatchery rearing strategies reduce juvenile growth to lessen precocious maturation of fall Chinook salmon?

Introduction

Freshwater salmon habitat in the California Central Valley is scarce, much of which has been lost as a result of anthropogenic activities, including the construction of dams and water diversions (Yoshiyama et al. 1998). Several anadromous fish hatcheries have been constructed in California to mitigate those losses and to support commercial and recreational fisheries along the Pacific coast. These hatcheries are often located just below the base of large rim dams, most of which delineate the upper limit of anadromy. Because these limits have shifted to much lower elevations in the watershed, the extent of cold water habitat has been dramatically reduced and water temperature is often considered a limiting factor for populations of Chinook salmon and steelhead in the California Central Valley.

The Mokelumne River watershed approaches the southernmost extent of the geographic range for Chinook salmon (Moyle 2002). At the regulating reservoir (Camanche), the hypolimnion is carefully maintained over the summer and water releases from the dam are controlled to optimize cold water for Chinook salmon embryo incubation. Despite this, water temperatures often exceed the range that is considered optimal for the species (Myrick and Cech 2001, Bilski and Rible 2015). Although warmer water temperatures during rearing may be optimal for salmonid growth, they may also promote early maturation. Studies demonstrate that age at maturity is governed by heredity (Hankin et al. 1993), but can also be growth dependent (Foote et al 1991, Beckman et al 2007). Precocious maturation of salmon may cause a financial loss to the fishing industry because many of these fish never reach the minimum allowable size for harvest. In addition, younger salmon have limited reproductive success in the wild and are often excluded from hatchery broodstock. However, several researchers have successfully reduced growth and precocious maturation of spring Chinook salmon through the manipulation of feed rates and decreasing incubation and rearing temperatures (Shearer et al 2006, Adelizi et al 2017).

The Mokelumne River Fish Hatchery (MRFH) has seen variable returns of fall Chinook salmon over the last 25 years (Table 1). The proportion of age-2 females spawned at the hatchery has remained relatively low, although somewhat flexible. Despite this, age-2 salmon often return in large numbers. In fact, over half of the fish trapped in six of the last ten years have consisted of age-2 salmon. The MRFH utilizes a 150 ton air cooled chiller to decrease water temperatures for Chinook salmon embryos during incubation. However, once the majority of salmon embryos have hatched, they are moved to indoor rearing troughs and/or outdoor raceways containing unchilled water from February through the holding period (late April or May). In addition, Chinook salmon fry and early parr are typically fed to satiation.

The objective of this study is to determine if the reduction of feed rates and/or rearing temperatures can effectively decrease growth to constrain precocious maturation of MRFH origin salmon.

Location/Study Area

The MRFH is located just below Camanche Dam, on the south bank of the lower Mokelumne River (Figure 1). The hatchery began operating in 1964, to compensate for the loss spawning and rearing habitat above Camanche Dam by supporting populations of fall-run Chinook salmon and steelhead (Jewett 1974). The current production targets are developed to provide 3.4 million fingerling salmon and 250,000 yearling steelhead for the mitigation program and 2 million fingerling salmon for the enhancement program.

Each year, adult Chinook salmon are guided towards the hatchery by a temporary weir, which is installed in early October. The salmon ascend a fish ladder, which is open during the historical adult fall-run migration period from early October through December. Depending on the arrival times and ripeness of the potential broodstock trapped at the hatchery, salmon spawning may begin as early as mid-October and continue until late December. Adult salmon are typically spawned at a 1:1 ratio and efforts are made to distinguish and generally exclude the use of age-2 fish as broodstock. After the spawning process, eggs are treated and water hardened to maximize survival and then placed into upwelling jars or vertical stack incubators in the hatchery building. The hatchery building water supply is altered through use of an air cooled chiller to maintain temperatures between 10 and 12.8°C during the spawning and egg incubation period.

Salmon are transferred from the upwelling jars to indoor rearing troughs when 60-75% of the eggs have hatched and transferred from the vertical stack incubators to outdoor concrete raceways when 90% of the eggs have hatched and buttoned-up. In both cases, the water supply is no longer chilled. Salmon fry and early parr are fed to satiation every morning and multiple times throughout the work day with Bio-Oregon's BioVita Starter size 0 and size 1 feed, depending on fish weight. Once fish exceed a weight of 350 per pound a feed chart is followed (Table 2), which has been modified from the Feed Size and Feed Rate Guidelines developed by Bio-Oregon. A few weeks prior to release, the feed is changed to Bio-Oregon Supreme fish feed to help salmon smolts with the transition to brackish or marine release water. Daily water temperatures just below the hatchery have ranged from 8.3 to 17.0°C during the months of February through May over the last five years (2013-2017).

Releases of salmon raised for the mitigation program take place between late April and the end of May each year. The salmon are acclimated in net pens and released near Sherman Island, just below the confluence of the lower Mokelumne and the San Joaquin Rivers (Figure 1). The releases are coordinated with outgoing tides and typically take place when the receiving waters are less than 18.5°C.

Methods

Spawning and Incubation

To ensure that the study groups of salmon originate from the same sets of parents, fish will be taken from a lot of salmon spawned on 30 November 2017. This lot will consist of approximately 120 pairs of salmon. In an attempt to exclude age-2 fish from being used as broodstock in this lot, no male salmon will be selected that are less than 71 cm (fork length) and no female salmon will be selected that are less than 65 cm (fork length). These thresholds are developed from preliminary coded wire tag (CWT) data from returning Chinook salmon early in the season.

Shortly after the eggs, milt, and chilled saline solution are mixed, they will be rinsed with sterilized ultra violet (UV) treated water. Eggs from seven females will be treated for 20 minutes with 150 ml of iodine in a 9 L bucket of UV water and then water hardened in pure UV treated water for two hours. The eggs will then be placed in 800 ounce upwelling jars containing circulating UV treated water during incubation. When the eggs reach 530 temperature units (TU), they will be addled by manual siphoning. After this process is complete, the eggs will be divided into four study groups of approximately 100,000 eggs and remain in the indoor rearing troughs until the buttoned-up fry stage. The number of fish in each group will be determined using a count by volume estimate.

Experimental Design

Two of the experimental groups will remain in the indoor rearing troughs through March. The first group (1-FT) will be placed on a reduced feed diet and water temperatures will be lowered to 10-11°C using an air cooled chiller. As the fish grow, this group will be evenly split into six rectangular tanks (4.6 m long x

0.8 m wide x 0.5 m deep) with a water flow of XX L/min. The second experimental group (2-T) will also be split evenly into six tanks having the same dimensions and flow rate. This group will follow the same feeding chart as the control group (4-C, Table 2), but water temperatures will be lowered to 10-11°C using an air cooled chiller through March. The third and fourth groups (3-F, 4-C) will be transferred to separated 6.1 m long x 3 m wide x 0.6 m deep screened sections of an outdoor raceway pond once the salmon reach the buttoned-up fry stage. At the beginning of April groups 1-FT and 2-T will be moved to separated 6.1 m long x 3 m wide x 0.6 m deep screened sections of an outdoor raceway due to indoor spatial constraints. Prior to the transfer, water temperatures will gradually be raised over 24-hours for acclimation. Shade structures will be placed over the sections of the raceway holding study groups 1-FT and 2-T to lower water temperature to the extent possible and limit light in a manner similar to the hatchery building.

All groups of experimental fish and the control fish will be fed Bio-Oregon's BioVita Starter, BioVita Fry, and BioVita Supreme feed. BioVita Starter will be used until the salmon are approximately 2.3 g each. BioVita Fry will then be used until the largest group of salmon reach approximately 3.6 g each. At that time BioVita Supreme will be used until the salmon are released. The quantity and size of the feed will change based on the weight of the fish and the water temperature, as established by the feeding charts. Weight counts will be performed on a weekly basis, every Monday, and coincide with water temperature measurements to establish weekly feed size, feed type, and quantity.

The control fish (4-C) and group 2-T will be fed at the same rate established for standard hatchery operations (Table 2). The other two groups (1-FT, 3-F) will be allocated feed according to the chart established in Table 3. This table was developed using a standard thermal growth coefficient (TGC) for Chinook salmon of 0.00098 to meet the minimum daily requirement of digestible energy and feed based on a bioenergetics model developed by Cho (1992). In comparison, the estimated TGC for standard feeding practices at the MRFH is 0.00182 using historic raceway water temperatures and average fish weight at release.

Naturally produced salmon will be sampled at juvenile traps on the LMR (Figure 1) to make environmental, growth, and physiological comparisons between the hatchery and wild populations of LMR fall Chinook salmon.

Abiotic sampling

Shortly after spawning, hourly water temperatures will be recorded in chilled water adjacent to the upwelling jars inside the hatchery building with TidbiT water temperature loggers. Hourly water temperatures will also be recorded in unchilled water in the outdoor concrete raceways. Once the salmon fry are transferred from the upwelling jars and split into the experimental groups, hourly water temperatures will be recorded in the indoor rearing troughs where each study groups resides. The temperature loggers will be transferred to the outdoor raceways when the study groups are moved near the beginning of April. From the buttoned-up fry stage through the end of the holding period, dissolved oxygen (DO), pH, and turbidity measurements will be recorded on a weekly basis in the indoor rearing troughs and outdoor raceways, where each study groups resides. Water temperature, DO, and turbidity will be sampled daily at the juvenile trapping sites, Monday through Friday.

Biotic sampling

When over 95% of the study fish in an individual study group reach the swim-up stage, 50 fork length (FL), total length (TL) and weight measurements will be recorded for each study group (1-FT, 2-T, 3-F, and 4-C) on a weekly basis through the end of the holding period. These fish will also be examined and characterized by one of the following life stages: alevin, unbuttoned fry, buttoned-up fry, seamed fry,

parr, and smolt. Depending on catch, up to 50 salmon will be weighed and measured (FL) at the juvenile trapping sites throughout the study period.

When salmon from the study groups reach the parr life stage (weeks 10-12), biological samples will be taken from each study group to measure gill Naþ,Kþ-ATPase activity and whole-body triglyceride levels. Fifteen samples will be taken from each study group every three weeks until the salmon are released.Up to fifteen samples will also be taken from naturally produced salmon smolts captured at the traps during weeks 19, 22, and 25.

Tagging

The four groups of study fish will be coded-wire-tagged (CWT) using the AutoFish System™, which can accommodate fish from 57 to 147 mm TL (Vander Haegen and Blankenship 2010). Any Chinook salmon that fall outside of the size range of the individual tagging lines set up for machine processing will be sorted out and manually tagged. Each group will receive a unique tag code. All of the salmon tagged will also be externally marked with an adipose fin clip. The size range (TL) and total number of Chinook salmon successfully coded-wire-tagged for each tagging line will be recorded. In addition, the total number of salmon hand processed and sacrificed for place checks will be recorded.

Overall mortality will be assessed by subtracting the number of fish that are CWTd from each group by the estimated number of salmon in each group at the eyed-egg stage.

Release

Four transport trucks, each containing two 2,721 L holding tanks, will be filled with water from the MRFH, ice, and a recommended concentration of salt (0.1 to 0.3% salt solution). One day prior to loading, the salmon will be mixed in the same outdoor raceway. The trucks will be loaded with salmon from all four study groups at the MRFH using a submersible fish pump and hand nets. The salmon will be transported on the same day and released in the San Joaquin River at Jersey Point (38° 2' 41.97" N, 121° 42' 48.72" W). Consistent with standard hatchery practices, the releases will take place in the spring when receiving water temperatures are less than 18.5°C and there is an outgoing tide. At Jersey Point, the fish will be gravity-released through a planting tube and discharged into net pens measuring 6.1 m long, 2.6 m wide, and 4.6 m deep. The net pens will be allowed to drift horizontally down the deep channel along the north bank for a minimum of 1 hour. The time of release, temperature of the receiving water, salmon mortality, and the condition of the fish during release will be recorded.

Analysis

Fulton's Condition Factor (Bagenal and Tesh 1978) will be calculated to compare fish condition between groups on a weekly basis using the standard formula having metric units: $K = (W/L^3) \times 100{,}000$. Where K is Fulton's Condition factor, W is the weight of the salmon in grams, L is the length of the salmon in millimeters, and 100,000 is the constant used in the equation.

A one-way ANOVA or equivalent nonparametric test will be used to examine the differences in length, weight, condition, gill Naþ,Kþ-ATPase activity and whole body triglyceride levels between study groups. The significance level will be set at $P < 0.05$. The Regional Mark Processing Center (http://www.rmpc.org/) will be queried to estimate the survival and age structure of adult salmon harvested or recovered from each study group.

References

Adelizi, P., B. Erlandsen, and J. McGrath-Castro. 2017. Managing Precocious Maturation in Chinook Salmon (*Oncorhynchus tshawytscha*) Captive Broodstock. Proceedings from the 35th Annual Salmonid Restoration Federation Conference. Davis, CA.

Bagenal, T. B. and F. W. Tesch. 1978. Age and growth. Pages 101-136 *in* T. B. Bagenal (editor). Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook No. 3. Blackwell Scientific Publications. Oxford, England.

Beckman, B.R., B. Gadberry, P. Parkins, K.A. Cooper, and K.D. Arkush. 2007. State-dependent life history plasticity in Sacramento River winter-run chinook salmon (*Oncorhynchus tshawytscha*): interactions among photoperiod and growth modulate smolting and early male maturation. Canadian Journal of Fisheries and Aquatic Sciences. 64: 256-271.

Bilski, R. and E. Rible 2015. Lower Mokelumne River Salmonid Redd Survey Report: October 2014 through February 2015. East Bay Municipal Utility District, Lodi, California.

Cho, C.Y. 1992. Feeding systems for rainbow trout and other salmonids with reference to current estimates of energy and protein requirements. Aquaculture. 121: 95-103.

Foote, C.J., W.C. Clarke, and J. Blackburn. 1991. Inhibition of smolting in precocious male chinook salmon, *Oncorhynchus tshawytscha*. Canadian Journal of Zoology. 69: 1848-1852.

Hankin, D.J., J.W. Nicholas, and T.W. Downey. 1993. Evidence for Inheritance of Age of Maturity in Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences. 50: 347-358.

Jewett, P.F. 1974. Mokelumne River Fish Installation Annual Report for 1972-73 Season. Administrative Report No. 74-14. California Department of Fish and Game, Anadromous Fisheries Branch. Region 2, Inland Fisheries.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkeley, CA, USA.

Myrick, C.A. and J.J. Cech. 2001. Temperature Effects on Chinook Salmon and Steelhead: a Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum, Technical Publication 01-1. http://www.sfei.org/modelingforum/

Shearer, K., P. Parkins, B. Gadberry, B. Beckman, and P. Swanson. 2006. Effects of growth rate/body size and a low lipid diet on the incidence of early sexual maturation in juvenile male spring Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture. 252: 545-556.

Vander Haegen, G. and Blankenship, L. 2010. Advances in Coded Wire Tag Technology: Meeting Changing Fish Management Objectives. Pages 127-140, *In* Wolf, K.S., and O'Neal, J.S., eds., PNAMP Special Publication: Tagging, Telemetry, and Marking Measures for Monitoring Fish Populations. A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002.

Yoshiyama, R.M., Fisher, F.W., and Moyle, P.B. 1998. Historical abundance and decline of Chinook salmon in the central valley region of California. North American Journal of Fisheries Management. 18:487- 521.

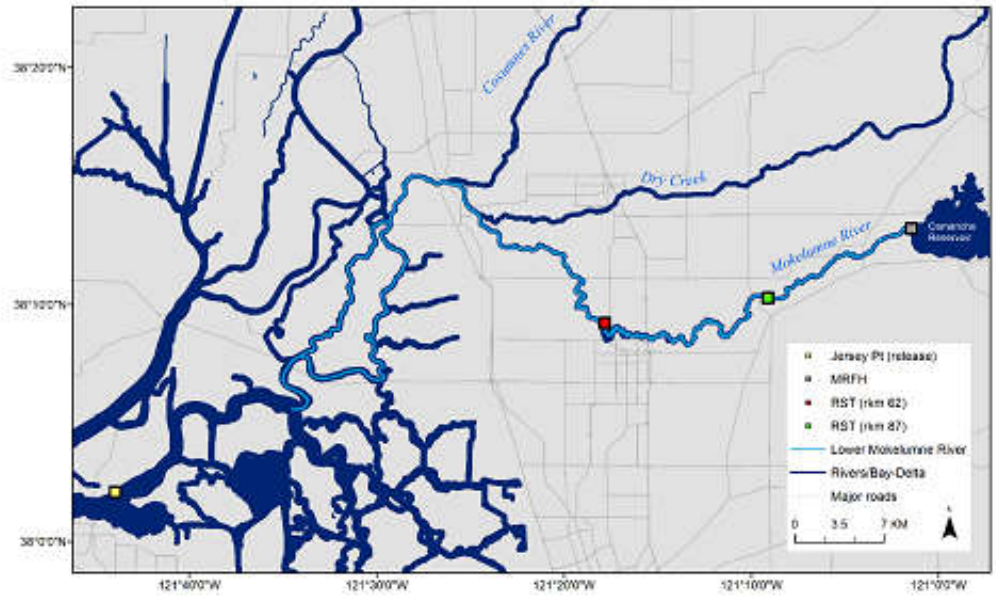


Figure 1. Map of the study area including the Mokelumne River Fish Hatchery (MRFH), juvenile fish trapping locations (RST), and the fish release location (Jersey Point).

Table 1. A summary of fall-run Chinook salmon trapped and females spawned at the Mokelumne River Fish Hatchery by brood year.

Brood Year	Adult Males Trapped	Adult Females Trapped	Total Adults Trapped	Grilse Males Trapped	Grilse Females Trapped	Total Grilse Trapped	Grand Total Trapped	Proportion of Grilse Trapped	Number of Grilse Females Spawned	Number of Adult Females Spawned	Proportion of Females Spawned as Grilse
1993	794	748	1,542	n/p	n/p	622	2,164	0.29	n/p	n/p	n/p
1994	586	582	1,168	n/p	n/p	751	1,919	0.39	n/p	n/p	n/p
1995	1,118	1,260	2,378	n/p	n/p	945	3,323	0.28	n/p	n/p	n/p
1996	948	880	1,828	n/p	n/p	2,055	3,883	0.53	n/p	n/p	n/p
1997	3,232	3,073	6,305	n/p	n/p	189	6,494	0.03	n/p	n/p	n/p
1998	1,194	1,312	2,506	n/p	n/p	585	3,091	0.19	n/p	n/p	n/p
1999	792	818	1,610	n/p	n/p	1,540	3,150	0.49	n/p	n/p	n/p
2000	2,057	2,509	4,566	n/p	n/p	884	5,450	0.16	n/p	n/p	n/p
2001	2,021	2,361	4,382	n/p	n/p	1,427	5,809	0.25	n/p	n/p	n/p
2002	3,286	2,514	5,800	n/p	n/p	2,119	7,919	0.27	355	1,903	0.16
2003	2,280	2,828	5,108	n/p	n/p	3,009	8,117	0.37	32	2,173	0.01
2004	3,654	1,823	5,477	3,627	1,252	4,879	10,356	0.47	68	1,625	0.04
2005	2,486	4,777	7,263	807	149	956	8,219	0.12	26	1,980	0.01
2006	1,249	1,702	2,951	1,118	220	1,338	4,289	0.31	152	1,445	0.10
2007	336	675	1,011	29	11	40	1,051	0.04	7	624	0.01
2008	67	49	116	116	7	123	239	0.51	5	47	0.10
2009	337	393	730	762	61	823	1,553	0.53	39	375	0.09
2010	2,089	1,454	3,543	1,519	214	1,733	5,276	0.33	218	1,317	0.14
2011	830	1,579	2,409	12,050	1,463	13,513	15,922	0.85	218	1,256	0.15
2012	2,114	2,316	4,430	1,985	205	2,190	6,620	0.33	0	1,914	0.00
2013	2,052	1,646	3,698	1,391	92	1,483	5,181	0.29	12	1,381	0.01
2014	2,102	2,315	4,417	3,801	602	4,403	8,820	0.50	59	1,643	0.03
2015	2,555	2,615	5,170	2,511	617	3,128	8,298	0.38	4	1,736	0.00
2016	1,304	2,010	3,314	2,799	774	3,573	6,887	0.52	28	1,627	0.02
2017*	705	1,647	2,352	5,321	1,064	6,385	8,737	0.73	13	n/p	n/p

* Data provided through 11/16/2017

Table 2. Feed rate guide for juvenile fall Chinook salmon rearing at the Mokelumne River Fish Hatchery (modified from the Bio-Oregon Feed Size and Feed Rate Guidelines for salmon and trout). The feed rate is expressed as percent fish biomass per day.

Individual Fish Weight (g)	Fish/lb	Feed Size (mm)	Water Temperature (°C)							
			2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0
0.15-0.8	3000-570	0.3-0.6 (#0)	Feed to satiation							
0.8-1.3	570-350	0.6 (#1)	Feed to satiation							
1.3-2.3	350-200	0.9 (#2)	0.7	0.9	1.4	1.9	2.3	2.7	3.1	3.3
2.3-3.6	200-125	1.2	0.6	0.8	1.2	1.8	2.2	2.6	3.0	3.2
3.6-7.6	125-60	1.5	0.6	0.8	1.2	1.8	2.2	2.5	2.8	2.9
7.6-10.1	60-45	2.0	0.5	0.6	1.0	1.6	2.1	2.4	2.8	2.9

Table 3. Weekly feeding chart established for experimental groups 1-FT and 3-F at the Mokelumne River Fish Hatchery.

	Temp (C)	Temp (F)		Temp (C)	Temp (F)		Temp (C)	Temp (F)		Temp (C)	Temp (F)		Temp (C)	Temp (F)	
Week	10	50.0		11	51.8		12	53.6		13	55.4		14	57.2	
	BW (g)	DE (kJ)	% BW	BW (g)	DE (kJ)	% BW	BW (g)	DE (kJ)	% BW	BW (g)	DE (kJ)	% BW	BW (g)	DE (kJ)	% BW
0	0.3			0.3			0.3			0.3			0.3		
1	0.4	0.19	3.0%	0.4	0.22	3.3%	0.4	0.24	3.6%	0.4	0.26	3.8%	0.4	0.28	4.1%
2	0.5	0.24	2.8%	0.6	0.27	3.0%	0.6	0.30	3.2%	0.6	0.33	3.5%	0.6	0.37	3.7%
3	0.7	0.29	2.6%	0.7	0.33	2.8%	0.8	0.37	3.0%	0.8	0.42	3.2%	0.9	0.46	3.3%
4	0.8	0.34	2.4%	0.9	0.39	2.6%	1.0	0.45	2.8%	1.1	0.51	2.9%	1.2	0.58	3.1%
5	1.0	0.40	2.3%	1.1	0.46	2.4%	1.3	0.54	2.6%	1.4	0.62	2.7%	1.5	0.70	2.8%
6	1.3	0.46	2.1%	1.4	0.54	2.3%	1.6	0.63	2.4%	1.7	0.73	2.5%	1.9	0.84	2.6%
7	1.5	0.53	2.0%	1.7	0.63	2.2%	1.9	0.74	2.3%	2.2	0.86	2.4%	2.4	1.00	2.5%
8	1.8	0.60	1.9%	2.1	0.72	2.0%	2.3	0.85	2.1%	2.6	1.00	2.2%	3.0	1.16	2.2%
9	2.1	0.68	1.8%	2.5	0.82	1.9%	2.8	0.98	2.0%	3.2	1.15	2.0%	3.6	1.35	2.1%
10	2.5	0.76	1.7%	2.9	0.93	1.8%	3.3	1.11	1.9%	3.8	1.32	2.0%	4.3	1.54	2.1%
11	2.9	0.85	1.6%	3.4	1.04	1.7%	3.9	1.25	1.8%	4.5	1.49	1.9%	5.1	1.76	2.0%
12	3.3	0.95	1.6%	3.9	1.16	1.7%	4.6	1.40	1.8%	5.3	1.68	1.8%	6.0	1.98	1.9%
13	3.8	1.05	1.5%	4.5	1.29	1.6%	5.3	1.57	1.7%	6.1	1.88	1.8%	7.1	2.23	1.8%
14	4.3	1.15	1.5%	5.1	1.43	1.6%	6.0	1.74	1.6%	7.1	2.09	1.7%	8.2	2.48	1.7%
15	4.9	1.26	1.5%	5.8	1.57	1.5%	6.9	1.92	1.6%	8.1	2.32	1.6%	9.4	2.76	1.7%
16	5.5	1.38	1.4%	6.6	1.72	1.5%	7.8	2.11	1.5%	9.2	2.55	1.6%	10.7	3.05	1.6%

	BioVita Starter
	BioVita Fry
	BioVita Supreme

Table 3. Weekly feeding chart established for experimental groups 1-FT and 3-F at the Mokelumne River Fish Hatchery.