**State of California**
**The Resources Agency**
**DEPARTMENT OF FISH AND GAME**

# A COMPREHENSIVE MONITORING PLAN FOR STEELHEAD IN THE CALIFORNIA CENTRAL VALLEY


By
Christopher D. Eilers, Jennifer Bergman
Pacific States Marine Fisheries Commission
Ryan Nielson
Western EcoSystems Inc.



**Fisheries Branch**
**Administrative Report Number: 2010-2**
**October 2010**

## NOTE TO READERS

*A Comprehensive Monitoring Plan for Steelhead (Oncorhynchus mykiss) in the California Central Valley* is a science based collaborative approach to collect steelhead population data. A result of requests from fisheries resource managers and resource federal and state agencies leadership, the development of this plan was funded by the CALFED Ecosystem Restoration Program with additional funding support from the California Department of Water Resources and the United States Bureau of Reclamation. This document will also be useful to other monitoring programs in that the material has broad application and will assist in the monitoring of other fish populations.

This plan identifies the actions needed to fill knowledge gaps and collect baseline information on population abundance and distribution, which will help assess the recovery of California Central Valley steelhead populations using a statistically rigorous approach. In addition the document contains recommendations for continued juvenile steelhead monitoring and the development of new technologies/methods to improve the understanding of life history traits and population dynamics. The goal of this monitoring plan is to provide the data necessary to assess the restoration and recovery of steelhead populations by determining the distribution, abundance, and population trends of these fish. The objectives of the plan include: estimate steelhead population abundance with levels of precision; examine trends in steelhead abundance; and identify the current spatial distribution and assess changes. The plan includes recommendations for the development of a centralized database and a coordinated reporting system to be utilized by all Central Valley steelhead monitoring programs.

As with all of its products, Fisheries Branch is very interested in ascertaining the utility of this document, particularly regarding to its application to the monitoring and management decision process. Therefore, we encourage you to provide us with your comments. Please be assured that they will help us direct future efforts. Comments should be directed to Dr. Russell Bellmer, Fisheries Branch Monitoring Program Lead, 830 S Street, Sacramento, CA 95814, 916 327-5540, rbellmer@dfg.ca.gov.

Terry Foreman
Acting Chief
Fisheries Branch

## ACKNOWLEDGEMENTS

Outstanding contributions from Jim Griswold, Jim Hopelain, and Connie Shannon added greatly to the document. Cover photograph by Doug Killam. The authors would like to thank everyone who gave us their time and assistance for the development of this monitoring plan. Special thanks to all of the biologists that we met with throughout the Central Valley to discuss steelhead monitoring and to visit the watershed(s) they monitor. We would like to thank the Interagency Ecological Program Steelhead Project Work Team members for providing comments on earlier drafts of this plan and our presentations of the plan at meetings. Also, we thank those members and other participants at a workshop that provided comments for the final draft plan or as written comments. We would like to thank George Edwards (CDFG), Alice Low (CDFG), Russ Bellmer (CDFG), Jim Hopelain (PSMFC) and Stan Allen (PSMFC) for providing guidance and assistance throughout the development of this plan, and also reviewing the plan in development and final stages. Thank you to Jim Hopelain and Jim Griswold (WEST Inc.) for contributing to this plan. Thank you to Connie Shannon (PSMFC) for developing all the maps, reviewing the plan, and contributing to the data management chapter. We acknowledge and thank the following individuals: Doug Killam (CDFG), Colleen Harvey-Arrison (CDFG), Matt Brown (USFWS), Jess Newton (USFWS), Sarah Giovannetti (USFWS), Tracy McReynolds (CDFG), Clint Garman (CDFG), Joe Johnson (CDFG), Randy Benthin (CDFG), Jason Kindopp (CDWR), Ryon Kurth (CDWR), Kyle Hartwigsen (CDWR), Duane Massa (PSMFC), Mike Healey (CDFG), Robert Vincik (CDFG), John Hannon (USBR), Michelle Workman (USFWS), Casey Del Real (EBMUD), Robyn Bilski (EBMUD), Jose Setka (EBMUD), Steve Tsao (CDFG), Tim Heyne (CDFG),Ryan Cuthbert (FISH BIO), Christy Sonke (FISH BIO), J.D. Wikert (USFWS), Shirley Witalis (NMFS), David Swank (NMFS), Terry Jackson (CDFG), Jonathan Nelson (CDFG), Jesse Anderson (CFS), Clark Watry (CFS), Kathleen Perry (CDFG), Tom Schroyer (CDFG), Doug Threloff (USFWS), Ramon Martin (USFWS), Rob Titus (CDFG) and many others who helped us during the development of this plan.

Edited by Fisheries Branch Monitoring Program Lead Dr. Russell J. Bellmer at 830 S Street, Sacramento, CA 95814, 916 327-5540, rbellmer@dfg.ca.gov

This project was funded by the CALFED Ecosystem Restoration Program with additional funding support from the California Department of Water Resources and the United States Bureau of Reclamation.

# A COMPREHENSIVE MONITORING PLAN FOR STEELHEAD IN THE CALIFORNIA CENTRAL VALLEY

## EXECUTIVE SUMMARY

California Central Valley steelhead (*Oncorhynchus mykiss*) (anadromous rainbow trout) were listed as threatened under the Federal Endangered Species Act in 1998; threatened status was reaffirmed in 2006. Steelhead were historically distributed throughout the Central Valley and the number adults may have approached 1 to 2 million adults prior to the 1800s. Today, little information is available about the abundance of steelhead in the Central Valley. The restoration of California's anadromous fish populations are mandated by State and Federal laws. Currently there is virtually no coordinated, comprehensive, and consistent monitoring of steelhead in the Central Valley. In 2004, the Interagency Ecological Program Steelhead Project Work Team developed a proposal to develop a comprehensive monitoring plan for Central Valley steelhead. In 2007, development of this steelhead monitoring plan was funded by the CALFED Ecosystem Restoration Program through a Directed Action. Implementation of the recommended monitoring programs contained with this plan will provide data needed to help assess the restoration and recovery of steelhead in the Central Valley. Full initial implementation cost is estimated to be approximately $3,967,000 with subsequent annual costs of approximately $2,165,000. Implementation staff (Plan Coordinator, Database Architect, and Statistician) is recommended with an additional annual total cost of $258,899.

### INTRODUCTION

This plan has been developed to monitor steelhead (anadromous rainbow trout, *Oncorhynchus mykiss*) in the Central Valley of California. The plan identifies the actions needed to fill knowledge gaps, and collect baseline information on population abundance and distribution, which will help assess the recovery of the Central Valley steelhead population and the effects of habitat restoration actions using a statistically rigorous approach. These monitoring activities among several agencies are associated with steelhead investigations within the Sacramento and San Joaquin river systems. Also recommended is the continued work with juvenile steelhead and the development of new technologies to improve the understanding of steelhead life history and population dynamics.

The goal of this monitoring plan is to provide the data necessary to assess the restoration and recovery of Central Valley steelhead by determining the distribution, abundance, and population trends of these fish.

Objectives include:

- Estimate steelhead population abundance with estimated levels of precision in the Central Valley.
- Examine trends in steelhead abundance in the Central Valley.
- Identify the spatial distribution of steelhead in the Central Valley to assess their current range and observe changes in their range.

Recommended monitoring actions in the plan to obtain the information needed to address the goal and objectives include the following:

1. Estimate the abundance of adult steelhead in the mainstem Sacramento River using a mark-recapture study with large wire fyke traps,
2. Examine the spatial distribution of steelhead across the Central Valley using distribution surveys,
3. Monitor the status and abundance of steelhead in select rivers in the following Diversity Groups:
    - Northwestern California
    - Basalt and Porous Lava
    - Northern Sierra Nevada
    - Southern Sierra Nevada

The plan includes development of a centralized database to be utilized by all programs monitoring steelhead in the Central Valley and a coordinated reporting system for annual reports.

## BACKGROUND

California Central Valley anadromous rainbow trout (*Oncorhynchus mykiss*) (commonly known as steelhead) were listed as threatened under the Endangered Species Act (ESA) in 1998; threatened status was reaffirmed in 2006. Steelhead included in this listing consist of all naturally produced steelhead in the Sacramento and San Joaquin rivers and their tributaries, excluding steelhead originating from San Francisco and San Pablo Bays and their tributaries.

Steelhead were historically distributed throughout California's Central Valley, with populations ranging from the Pit River in the northern part of the state to the Kings River in the south. Population estimates prior to European settlement are not available, but may have approached 1 to 2 million adults annually. Counts of fish migrating upstream of Red Bluff Diversion Dam from 1967 – 1991 indicate a decline from nearly 20,000 adults in 1968 to less than 1000 fish in 1991. It is estimated that 80 percent of historical steelhead spawning and rearing habitat is now located above impassible dams. Remnant steelhead populations are presently distributed throughout the mainstem of the

Sacramento and San Joaquin Rivers, as well as many of the major tributaries of these rivers.

The forthcoming National Oceanic and Atmospheric Administration-National Marine Fisheries Service (NOAA-NMFS) Central Valley Steelhead Recovery Plan divides the Central Valley steelhead Evolutionarily Significant Unit into five ecoregions or diversity groups based on differences in climatological, hydrological, and geological conditions. These diversity groups include the:

- Northwestern California
- Basalt and Porous Lava
- Northern Sierra Nevada
- Southern Sierra Nevada
- Central Western California

The goals of the NOAA-NMFS recovery plan include demonstrating at least two viable steelhead populations in each diversity group using the concept of population viability which models the likelihood of a population going extinct based on several population metrics (abundance, production, spatial distribution, and diversity).

The ultimate goal of the Federal Endangered Species Act is to restore populations to the point at which they no longer need protection. In general, this means demonstrating population viability (the population is no longer at risk of extinction). To demonstrate an increase in steelhead population size, a standardized monitoring plan for steelhead in the Central Valley is necessary to meet this objective.

***Historic and Current Steelhead Monitoring in the Central Valley***

Sacramento River basin steelhead monitoring in the Central Valley began in 1953 with a six-year project designed to evaluate returns of hatchery steelhead to Central Valley rivers. The project successfully used large fyke traps to capture returning adult steelhead in the Sacramento River. The project generated useful population abundance, status, and life history data for wild and hatchery origin steelhead. Almost all of the baseline information regarding Central Valley steelhead stocks is derived from this program. The recommended monitoring described in Chapter 2 is a modified and updated version of this project.

From 1967-1993, steelhead run-size estimates were generated from fish counts in the fish ladder at Red Bluff Diversion Dam (RBDD). From these counts, estimates of the natural spawner escapement upstream of RBDD were generated. Because RBDD impacted winter-run Chinook salmon by delaying their upstream migration, dam operations were changed in 1993 so that dam gates were raised earlier in the season. This change in operation eliminated the need for fish to navigate fish ladders and likewise eliminated the ability to generate accurate run-size estimates for the Upper Sacramento River basin.

Various forms of counting stations have been implemented in Upper Sacramento tributaries for the purposes of counting immigrating adult steelhead since the 1940s. The earliest counts were generated using fish weirs to trap and count steelhead; and more recently electric fish counters, video cameras or hydroacoustic devices associated with fish ladders or weirs have been used to estimate steelhead passage. All of these methods become unreliable during periods of high stream flow and turbid water.

At present, steelhead monitoring programs in the Central Valley lack statistical power, are not standardized and in many cases lack dedicated funding. These monitoring efforts operate at a local scale and are insufficient for determining steelhead population viability throughout the Central Valley Steelhead ESU and therefore do not meet the needs of the ESA. Many existing monitoring programs in the Central Valley are focused on Chinook salmon (*O. tshawytscha*). These programs are inadequate for monitoring steelhead populations due to differences in steelhead and Chinook life history traits (immigration timing, spawning time, spawning requirements, rearing time, rearing requirements, emigration timing, reproductive strategy, etc).

***Identification of Priorities***

Meetings were held with California Department of Fish and Game (CDFG) Regions 1, 2, and 4, CDFG Fisheries Branch, as well as the United States Fish and Wildlife Service (USFWS; Red Bluff office) for the purpose of identifying stream priorities, potential sampling sites, recommended monitoring methods, and targeted life stages. In addition, the NMFS Public Draft Recovery Plan was reviewed to identify populations of steelhead that will likely need to be monitored for the Recovery Plan.

**Region 1/USFWS – Red Bluff**

CDFG Region 1 biologists identified Mill, Deer, Antelope, Bear and Cottonwood creeks as the streams that should be targeted by the monitoring plan. USFWS recommended that Clear Creek and Battle Creek continue to be monitored using current methods.

**Region 2**

CDFG Region 2 biologists identified Butte Creek, Feather River, Yuba River, American River, and Mokelumne River as target systems.

**Region 4**

Biologists in CDFG Region 4 suggested that steelhead monitoring be focused initially on the Stanislaus River due to the presence of a weir at river mile 31.5 near Riverbank, CA. Monitoring on the Tuolumne River, Merced River, and San Joaquin River mainstem were also recommended.

Monitoring of steelhead populations in Region 4 is especially challenging due to a paucity of fish. Steelhead populations in Region 4 are depressed limiting monitoring methods and statistical analyses. Increased electro-fishing juvenile surveys are need in the San Joaquin River Basin. As conditions improve more monitoring projects can be implemented.

**CDFG Fisheries Branch**

Biologists in the Fisheries Branch feel that specific research and monitoring to assist in steelhead management through sport fishing regulations is vital.

Fisheries Branch biologists also desire long term life cycle monitoring stations be implemented on several systems throughout the Central Valley. Due to the lack of hard structures in the Central Valley where these life cycle monitoring stations could be implemented, the plan does not focus on these stations as a viable option for monitoring steelhead in the near future.

**NMFS Recovery Plan**

The public draft Recovery Plan by the NMFS Southwest Region established three priority levels to help guide the recovery efforts for watersheds that are currently occupied by steelhead. The highest priority is Core 1 populations, which were identified based on multiple factors, including: (1) the known ability or significant immediate potential to support independent populations; (2) the role of the population in meeting a spatial or redundancy viability criteria; (3) the severity of the threats facing the populations;(4) the potential for ecological or genetic diversity the watersheds and populations could provide to the species; and (5) the capacity of the watershed and population to respond to critical recovery actions needed to abate those threats identified. This monitoring plan includes all of NMFS high priority Core 1 and some Core 2 streams.

***Identification of Steelhead***

Steelhead are defined as rainbow trout that migrate to the ocean as juveniles and return as adults to freshwater streams to spawn. Currently lacking is a biological field method to accurately distinguish anadromous adults from resident adults. For monitoring purposes in this plan, a "steelhead" is defined as any rainbow trout greater than 16 inches (40.6 cm) that is present in anadromous waters.

## MAINSTEM SACRAMENTO RIVER STEELHEAD MARK-RECAPTURE STUDY

Historically, wire fyke traps were used to estimate population abundance of steelhead immigrating into the Sacramento River Basin (Hallock et al. 1957), the results of which provide almost all of our baseline information on historical steelhead populations. This plan recommends that a pilot study be undertaken to evaluate the current effectiveness of wire fyke traps in the mainstem Sacramento River. Preferred trapping locations in the Sacramento River are located downstream of the American River confluence, but upstream of the Sacramento-San Joaquin River Delta (upstream of Elk Slough).

***Mark-Recapture Pilot Program***

A pilot mark-recapture program is recommended in the mainstem of the Sacramento River to evaluate trapping success and the degree to which fish will be injured during the trapping process. In addition, an estimate the abundance of wild and hatchery steelhead with estimated precision and bias will be developed.

### *Data Collection*

The mark-recapture technique to be used is a temporally stratified design where sampling at multiple river locations is used to estimate the abundance of the migrating adult steelhead population in discrete time segments corresponding to possible variations in passage rates during the migration period. The stratified approach is being used since steelhead may migrate in pulses of high, medium and low run abundance over the migration period (Hallock 1989). The method consists of counting adults captured at designated trapping sites and releasing tagged fish in the case of hatchery origin steelhead and caudal marked (genetic tissue sample) wild steelhead back into the population at sites downstream from recapture sites. The temporal segments of the hatchery run and the wild run are estimated separately then added to achieve a total population estimate for the hatchery population and for the wild population.

The method of capturing fish for both marking and recapture will employ four or more 12-foot diameter by 20-foot long wire fyke traps set along the river bank during August through October. The study design requires traps to be set in series from downstream to upstream, with enough distance between single traps so that tagged and untagged fish mix thoroughly.

All captured hatchery steelhead should be enumerated, measured (fork length), sexed (if possible), checked for injuries, checked for the presence of tags, tagged with an external t-bar anchor tag (Floy tag), and given a secondary mark to detect tag shedding. All wild steelhead should be enumerated, measured (fork length), checked for injuries, and sexed (if possible). Wild steelhead (intact adipose fin) will not be floy tagged unless permitted by NMFS, however, they will be given a minor caudal clip. Scale samples may be collected from all steelhead to estimate the age structure of the run. Minor caudal fin clips will serve as tissue samples for genetic analysis.

A computer simulation showed that there is moderate variability around estimates of wild and hatchery steelhead abundance given hypothetical levels of probability of capture and certain assumptions about the mark-recapture model. Bias in estimates is relatively low (< 9 %). For a 4 trap effort level variability would not exceed about 23 percent for the coefficient of variation for the estimate of total abundance of wild steelhead. If 7 traps are used this drops to 15 percent. Considering the pilot study nature of this first attempt to achieve a fairly precise estimate of the total Sacramento River steelhead migration, a 23 percent error using a 4-trap effort level may be an acceptable compromise considering the extra time, maintenance, uncertainty and resources involved in employing an additional 3 fyke traps (7 traps total). If however, using the 4-trap effort level during the first weeks of the peak migration, it appears that the probability of capture is estimated at levels below 0.02, additional traps should be employed.

### *Project Strengths and Weaknesses*

Strengths:

- Provides mainstem abundance estimates
- Fish are handled when fresh from the ocean

- Wild fish do not need to be tagged only clipped
- Wild and hatchery population estimates
- Effect of sample size on population estimate can be modeled

Weaknesses:

- Trap avoidance may bias efficiency and population estimate
- Multiple sources of variation (hatchery: wild ratios, efficiency) factor in population estimate
- Concerns that trapping may delay or otherwise impact migrating Chinook salmon
- Concerns that hatchery fish are not suitable surrogates for wild steelhead

## CENTRAL VALLEY WIDE STEELHEAD DISTRIBUTION SURVEYS

A systematic steelhead distribution survey is recommended with the objective of monitoring the large network of Central Valley streams to establish current distribution and detect changes over time, which are important indicators of species recovery.

The optimal approach to monitoring for changes in steelhead distribution and population expansion involves using spatially balanced sampling and a rotating panel design. Rotating panel designs select a probability sample of units from a population of stream reaches with likely steelhead habitats and assign units to “panels” or sets that are always all visited during the same sampling occasion. Revisits to sample units are scheduled by organizing visits to entire panels on a rotating basis. This scheduling assures that “good” overall spatial coverage is achieved, and that an adequate number of revisits occur

### *Identification of the Sampling Units and Sample Frame*

For monitoring changes in steelhead distribution in the Central Valley, sample units will be defined as approximately 3.2 km (2 mi) stream reaches. The sample frame will be a list of all possible sample units, except for those in the following areas: stream reaches above physical barriers preventing upstream migration, first order streams that are too steep for spawning, stream reaches known to be inaccessible, and streams already being monitored via Redd surveys or Vaki/DIDSON/video device counters. In general, the areas excluded from sampling will be defined as areas known to be inaccessible, unavailable to steelhead, or areas already experiencing intense steelhead monitoring.

Following creation of the sample frame, sampled units will be ordered for sampling using a 1-dimensional method that uses the unit’s location within its watershed and the watershed’s location within the Central Valley. All watersheds in the Central Valley will first be ordered from north to south. Sample units within each watershed will then be ordered starting at the stream mouth (where it enters the Sacramento River or San Joaquin River) and moving upstream. This ordering will ensure that sampled units will be spread out and will represent all areas of the Central Valley, in proportion to their geographic sizes.

### *Selecting Sampling Units for Monitoring*

A random subset of sample units in the sample frame will be selected for monitoring. Selecting the subset of sample units will be carried out using an equi-probable generalized random tessellation stratified (GRTS) sampling method (Stevens and Olsen 2004). The GRTS sampling method produces a randomized list of sample units that is spatially balanced and also allows easy addition and deletion of units while maintaining that balance.

***Visitation Schedules***

Sample units selected by the GRTS mechanism will be allocated to different panels, each following a different revisit schedule. The panels will all follow a revisit schedule based on multiples of 4. Fifty percent of the sampled units will be randomly assigned to Panel 1 and revisited every 4 years. Thirty percent of the sampled units will be randomly assigned to Panel 2 and revisited every 8 years. The remaining 20 percent of the sampled units will be assigned to Panel 3 and visited only once during a thirty year period.

***Survey Effort***

Snorkel surveys or other methods such as redd surveys may be used to monitor each sampled unit. Regardless, these surveys will be repeated at least two times within a season to ensure timing of the visits to each sampled unit has a minimal effect on whether the threshold for increased monitoring is met.

## RECOMMENDED PROTOCOLS FOR ESTIMATING STEELHEAD ABUNDANCE USING DEVICE COUNTERS AND REDD SURVEYS

### Fish Device Counters

Three fish device counter technologies currently being used or tested in the Central Valley to monitor escapement of steelhead and Chinook salmon are recommended for use in the steelhead monitoring plan.. The counter technologies include Vaki Riverwatcher, a Dual-frequency Identification Sonar (DIDSON), and traditional optical video cameras (video).

Vaki Riverwatcher systems require fish to be directed through a narrow opening to pass the series of sensors. Vaki Riverwatcher systems in the Central Valley are installed in Alaskan Style weirs or within a fish ladder. The benefit of an Alaskan style weir type is that it remains operational at a wide range of stream discharges, and fish can be directed into the Vaki Riverwatcher. The upper stream discharge limit is somewhat site specific and dependent on the overall size of the weir, channel characteristics, and debris loads/types. At stream discharges above this threshold, the weir collapses. When flows decrease, the weir self-rights, providing that debris does not prevent the weir from righting. The benefits of using existing fish ladders at diversion dams are that the structure is permanent, cost savings of not building a weir, and the dam could be fish tight during certain flow conditions.

DIDSON devices use high or low frequency sound waves to produce high resolution underwater images. Originally DIDSON was designed for use by the Navy to help identify mines and divers underwater, however this technology has expanded into fisheries science. DIDSON has been found to be useful for monitoring run size of salmonids in multiple rivers in Alaska,Washington, Idaho and California. DIDSON not only provides count data, but also fish size, shape, behavior of the fish, and swimming motion of the fish. Since the DIDSON uses sound waves to produce images of fish, DIDSON can be used in turbid water conditions. In addition, DIDSON does not require fish to pass through a narrow location to capture an image. However DIDSON does requires specific features of the stream to examine the entire cross section of a river.

Video cameras rely on good visibility conditions to produce a reliable image of a fish. Video cameras are currently used to monitor steelhead and Chinook salmon in Central Valley streams, such as Bear, Cow, Cottonwood, Mill, Antelope, and Battle creeks, and the Mokelumne River. Species identification is possible with video systems. In addition to count data, fish size can be approximated, presence of an adipose fin and fish behavior can be examined.

Fish need to be directed into a narrow opening for video monitoring. Partial horizontal bar weirs are used in Bear, Cow, Cottonwood, Mill, and Antelope creeks to direct fish through the center of the weir where the video cameras (2-4 underwater cameras and one overhead camera) are located. The opening size of the weir is much larger than the size needed for the Vaki Riverwatcher to produce reliable images of fish. Benefits of a horizontal bar weir include that they are reasonably fish tight, debris can easily pass them, they can withstand relatively high flow conditions, and they are relatively inexpensive to build and install.

Video cameras alone are a less powerful tool than using both a video camera and DIDSON. Fish cannot be observed in turbid water using a video camera. A DIDSON or a similar device is needed in conjunction with each video camera to enumerate fish when water is too turbid for the video camera alone. Video cameras are needed to identify fish to species, where species identification with a DIDSON can be possible if the fish species has identifying features. Without a DIDSON, the number of fish passing a video monitoring station during periods of turbid water will be unknown.

***Recommendations to Estimate Steelhead Abundance with Device Counters***

This plan recommends quantifying the uncertainty in Vaki Riverwatcher, DIDSON, and traditional video cameras (fish device counters) count data when used to obtain estimates of total abundance from the counts. Fish device counters should be calibrated to the manufactures guidelines and installed in the optimal location for monitoring all passing fish.

There are at least six types of counting errors that may affect estimates of the number of fish passing by a device counter:

1) **Missed counts**: A missed count occurs when a fish passes the device counter but is not recognized.
2) **False counts**: A false count occurs when another object is mistaken for a fish (e.g., waterfowl, muskrats, leaves, sticks, or bubbles).
3) **Mixed counts**: A mixed count can occur when a species other than the target species is recorded and is not correctly identified.
4) **By-passed counts:** By-passed counts are the result of the target fish swimming around the device counter and are never in the range within which the fish can be recorded.
5) **Double counts**: Double counts occur when fish which have been counted once drop back below the device counter, and then again enter the range of the device counter and are counted for a second time.
6) **Observer or technician errors**: Errors can be made by the individual(s) processing the images or device counter data.

Three principal methods are recommended to assess the accuracy and variability of the device counter data. The first method relies on comparing device counts to paired visual counts from a counting tower, using groups of fish allowed to pass through a weir. The second method relies on comparing device counts to paired visual counts from a counting tower using unconstrained steelhead. The third method for assessing device counter accuracy and variability involves the use of artificial targets or tethered fish that can be passed across the recording field at measured turbidity, depths and distances from the device in order to evaluate the error rate. Alternatively, a DIDSON unit could be paired with another device counter for a certain number of trials. Since the DIDSON is not limited by the range of turbidity expected for Central Valley streams the counts from the two devices can be compared, using the DIDSON count as truth.

**Redd Surveys**

Redd counts are commonly used for monitoring annual trends in the abundance of spawning salmonids. However, if Redd are not detected with 100 percent accuracy, counting errors may obscure important population trends. In addition, in order to estimate fish abundance using redd counts corrected for observer error one must also estimate the number of females per redd and the ratio of females to males in the population.

This plan recommends and describes field methods and data analysis methods to be used for obtaining a total steelhead redd count for a watershed and using this count to estimate total abundance with Redd survey data. In order to estimate total abundance with accuracy and precision, redd retention rates, observer error, missed surveys, the number of females per redd, and the ratio of females:males must be accounted for.

## RECOMMENDED MONITORING FOR THE NORTHWESTERN CALIFORNIA DIVERSITY GROUP: CLEAR CREEK AND COTTONWOOD CREEK

The Northwestern California Diversity Group includes tributaries to the Sacramento River that drain the eastern slopes of the Northern California Coastal Mountain Range (Sweany, Putah, Cache, Stoney, Elder, Thomes, Cottonwood, Beegum, and Clear creeks).

This monitoring plan recommends intense monitoring for steelhead populations in Clear Creek and Cottonwood Creek.

CLEAR CREEK

Clear Creek was identified by NMFS as having a high potential to support a viable independent population of steelhead. Steelhead redd surveys conducted since 2001 by the USFWS indicate a small but increasing population. Clear Creek has been the target of numerous habitat restoration activities over the past few years which have included increased base flows, spawning gravel injections, riparian restoration, bank stabilization, and dam removal.

This monitoring plan recommends that a weir and fish counter device be installed in Clear Creek to monitor steelhead population size. In addition, this plan recommends the USFWS continue to monitor the steelhead population in Clear Creek from river mile 1.7 to Whiskeytown Dam using their kayak-based and snorkel-based redd surveys. The spatial and temporal distribution of spawning can be examined with redd surveys. In addition, the abundance of steelhead estimated using redd surveys can be compared to the estimate from the device counter.

COTTONWOOD CREEK

The Cottonwood Creek Watershed, including three main tributaries, the South Fork, North Fork, and Beegum Creek, has a moderate potential to support a viable population of steelhead. Abundance estimates are not available, but *O. mykiss* are found throughout the watershed, and the watershed is designated as critical habitat for steelhead.

A video monitoring station with video cameras, a DIDSON, and horizontal bar weir is recommended for monitoring steelhead in Cottonwood Creek from at least September through June. A DIDSON unit is recommended in conjunction with video cameras due to high flow and turbid water conditions.

## RECOMMENDED MONITORING FOR THE BASALT AND POROUS LAVA DIVERSITY GROUP: COW CREEK, BEAR CREEK, AND BATTLE CREEK

The Basalt and Porous Lava Diversity Group includes tributaries to the Sacramento River that drain the southern and western slopes of the Cascade Range (Upper Sacramento, McCloud, and Pit rivers, and Little Cow, South Cow, Old Cow, Clover, Oak Run, Bear, and Battle creeks).

This plan recommends intense monitoring for steelhead in Cow, Bear, and Battle creeks. Recommended protocols for device counters should be incorporated into the monitoring programs to estimate adult abundance. Other rivers in the Basalt and Porous Lava Diversity Group are recommended to be monitored through distribution surveys.

COW CREEK

This plan recommends that steelhead monitoring should be conducted in Cow Creek from at least September through June using video cameras, a DIDSON, and a partial horizontal bar weir. Currently, CDFG uses a video monitoring station in Cow Creek to monitor Chinook salmon escapement.

BEAR CREEK

This plan recommends that steelhead monitoring should be conducted in Bear Creek using video cameras and a horizontal partial bar weir from at least September through June. In addition, a DIDSON is recommended to monitor steelhead during periods of turbid water.

BATTLE CREEK

Battle Creek has been identified as a high potential to support a viable independent population of steelhead. Battle Creek has had persistent spawning populations of steelhead in both the north and south forks. The creek exhibits suitable flows year round (average base flows of 500 cfs).

The Battle Creek watershed will be considered a conservation stronghold for steelhead once restored as described in the Salmon and Steelhead Restoration Project (NMFS 2009). Numerous Battle Creek habitat restoration activities are ongoing or planned for the near future including increased base flows, riparian restoration, bank stabilization, and dam removals. The USFWS has an ongoing monitoring program on Battle Creek to investigate the response of anadromous salmonids to these restoration activities (including redd surveys for adult salmonids and a rotary screw trapping operation for monitoring juvenile salmonid abundance). The presence of the USFWS weir and fish passage system at Coleman National Fish Hatchery on Battle Creek provides an exceptional opportunity to monitor immigrating steelhead.

This monitoring plan recommends that the population of steelhead in Battle Creek should continue to be monitored by USFWS at the Coleman National Fish Hatchery ladder using a fish trap and video cameras from at least September through June.

## RECOMMENDED MONITORING FOR THE NORTHERN SIERRA NEVADA DIVERSITY GROUP: ANTELOPE, MILL, DEER, AND BUTTE CREEKS, FEATHER, YUBA, AMERICAN, AND MOKELUMNE RIVERS

Monitoring steelhead in Paynes and Big Chico creeks, Bear River, Auburn Ravine/Coon and Dry creeks, and the Cosumnes River is recommended to occur through the distribution surveys.

Monitoring to estimate adult steelhead abundance is recommended in Antelope, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, and Mokelumne rivers.

ANTELOPE CREEK

Antelope Creek has a high potential to support a viable population of steelhead and is considered a high priority (Core 1) for recovery by NMFS. Monitoring steelhead is recommended using video cameras, a DIDSON, and a partial horizontal bar weir. A DIDSON in conjunction with video cameras will be needed to count fish during turbid water events.

MILL CREEK

Mill Creek has been identified as a conservation stronghold for the Central Valley steelhead Evolutionarily Significant Unit, and with key recovery actions has a high potential for sustaining a viable steelhead population. Monitoring is recommended using video cameras, a DIDSON and a partial horizontal bar weir from at least September through June.

DEER CREEK

Deer Creek has been identified as a conservation stronghold for the Central Valley steelhead Evolutionarily Significant Unit, and with key recovery actions has a potential for sustaining a viable steelhead population. CDFG Region 1 is aware of steelhead presence in Deer Creek and recommended monitoring.

Monitoring is recommended using video cameras, a DIDSON, and a partial horizontal bar weir from at least September through June. A DIDSON will be needed to count fish during turbid water events.

BUTTE CREEK

NMFS has characterized Butte Creek as having a moderate potential to support a viable steelhead population. Steelhead abundance estimates do not exist, however steelhead have been noted in reports by CDFG wardens from angler catches.
Monitoring is recommended using a Vaki Riverwatcher system in the upstream exit of the fish ladder at Durham Mutual Diversion Dam (pending landowner approval) from at least September through June. This site was determined to be the most suitable for a Vaki Riverwatcher by representatives of the Vaki Riverwatcher Company.

FEATHER RIVER

NMFS has characterized the Feather River below Oroville Dam, as having a moderate potential to support a viable steelhead population. The moderate potential is based on the presence of a hatchery-supported population that is known to naturally reproduce in the Low Flow Channel.

The California Department of Water Resources (CDWR) plans to install a resistance board weir with a fish device counter in the Feather River. The weir on the Feather River is currently in the planning stages and should be installed in 2010-2011. A fish device counter at the weir is recommended for monitoring steelhead from at least September through June.

<u>YUBA RIVER</u>

The lower Yuba River, below Englebright Dam, is identified as having a high potential to support a viable population of steelhead. Favorable conditions include: (1) a persistent population and relatively large naturally reproducing steelhead population; (2) flow and water temperature conditions generally support all life stage requirements; (3) the river is not hatchery supplemented; (4) spawning habitat availability does not appear to be limited; and (5) the river exhibits high habitat restoration potential.

Current monitoring of steelhead in the lower Yuba River is recommended to be continued using the Vaki Riverwatcher systems located in the north and south fish ladders at Daguerre Point Dam (DPD). Monitoring at DPD occurs continuously all year long.

<u>AMERICAN RIVER</u>

The American River watershed is characterized as having a moderate potential to support a viable steelhead population. Current monitoring by U. S. Bureau of Reclamation (USBR) is recommended to continue using steelhead redd surveys. Surveys should be conducted between December and April (or later depending on peak spawn timing). Crew members should fully survey both main and secondary river channels, as steelhead have been observed to select spawning locations in or near side channels.

<u>MOKELUMNE RIVER</u>

East Bay Municipal Utility District (EBMUD) conducts redd surveys to enumerate Chinook salmon and steelhead redds in the Mokelumne River. All known salmonid spawning habitat is surveyed from Camanche Dam to Elliot Road. Redd surveys are conducted weekly from the beginning of October through the end of March.

EBMUD monitors fish passage using video monitoring in the fish ladder at the Woodbridge Irrigation District (WID) Dam. The ability to video monitor depends on WID gate operations. Currently, video monitoring is possible half-way through the fall-run Chinook salmon immigration period. However, potentially by 2010-2011 EBMUD may be able to monitor through December. Video monitoring in the fish ladder will not be possible past December due to gate operations.

Current Redd survey monitoring by EBMUD is recommended to continue. In addition, EBMUD should continue to report steelhead passage observed at WID from video monitoring. In the future, this plan recommends examining the feasibility of installing a weir with a fish device counter above or below the WID dam to monitor steelhead.

## RECOMMENDED MONITORING FOR THE SOUTHERN SIERRA NEVADA DIVERSITY GROUP: CALAVERAS, STANISLAUS, TUOLUMNE, AND MERCED RIVERS

Steelhead monitoring is recommended in the Calaveras, Stanislaus, Tuolumne, and Merced rivers. Monitoring in the other rivers of the Southern Sierra Nevada Diversity Group will occur through the recommended distribution surveys.

### CALAVERAS RIVER

The Calaveras River has a high to moderate potential of supporting a viable steelhead population. Monitoring is recommended by using a resistance board weir and Vaki Riverwatcher system, or horizontal-bar weir with a video camera and DIDSON to monitor adult steelhead. Monitoring steelhead should be from September through June each year to ensure weir operation is conducted during the entirety of steelhead immigration and spawning period.

### STANISLAUS RIVER

Large *O. mykiss* have been observed at a fish counting weir in the Stanislaus River. It is recommended that the current monitoring program using a resistance board weir and Vaki Riverwatcher system continue and be extended through June to encompass the entire steelhead immigration and spawning period. Typically, the weir is operated from September through December annually (the main objective is to determine fall-run Chinook salmon escapement).

### TUOLUMNE RIVER

The Tuolumne River has a potential to support a viable population of steelhead. Steelhead monitoring is required for the Turlock Irrigation District's Don Pedro Project (FERC Project No.2299) in the lower Tuolumne River. Currently a resistance board weir with a Vaki Riverwatcher system used for monitoring Chinook.

This monitoring plan recommends using the existing weir and Vaki Riverwatcher system on the Tuolumne River to monitor adult steelhead from at least September through June to encompass the steelhead immigration and spawning period.

### MERCED RIVER

The lower Merced River has a potential to support a viable steelhead population. Juvenile *O. mykiss* have been observed in the lower Merced River but population abundance data is lacking.

This monitoring plan recommends installing a resistance board weir and Vaki Riverwatcher system on the Merced River to monitor adult steelhead. Monitoring steelhead should be from September through June each year to ensure weir operation is conducted during the entirety of steelhead immigration and spawning period.

## AN OPTIMAL APPROACH TO STEELHEAD MONITORING

Permanent life cycle stations where immigrating adults and emigrating juveniles are enumerated are considered outside the realm of realistic expectations for the near future. However, the concept of permanent monitoring stations is identified because fishery mangers should be alert for opportunities that could make the permanent-facility concept viable.

If fishery managers wish to implement the use of permanent or semi-permanent in-stream structures to monitor steelhead throughout a stream's flow regime, investigations should initially focus on the feasibility of modifying existing structures in key streams. Otherwise, some type of permanent structure would have to be constructed within the stream channel that does not significantly interfere with the flow of water. Either way, the challenges of design, permitting, funding, and stakeholder and public acceptance would be significant. In this regard, the fish ladder and monitoring facility at Coleman National Fish Hatchery on Battle Creek may represent the best opportunity to modify an existing structure for life cycle monitoring of steelhead.

## JUVENILE STEELHEAD MONITORING IN THE CENRAL VALLEY

Although this monitoring plan focuses on abundance estimates of adult steelhead, monitoring of juvenile steelhead can provide valuable information for examining population factors, and for designing and evaluating habitat restoration projects. Estimating the abundance of rearing juveniles and smolt outmigrants would also be useful for estimating production and survival.

California's Central Valley currently has at least 36 existing monitoring programs that monitor juvenile steelhead to some degree. These programs include rotary screw traps, downstream fyke nets, trawling, seining, electrofishing, and snorkeling. Each of these methods has its limitations and challenges, and none of these programs have yet proven successful at generating adequate data to estimate abundance or develop trend analysis for steelhead juveniles. However, it is recommended that all existing steelhead juvenile monitoring projects continue and attempt to develop more efficient trapping or observation techniques with the objective of providing better juvenile steelhead abundance or production estimates, rearing, and emigration data for the future.

## RESEARCH NEEDED FOR EFFECTIVE MANAGEMENT OF CENTRAL VALLEY STEELHEAD

Though outside the objectives of this monitoring plan, implementation of the following projects would greatly increase understanding of steelhead biology and likewise improve management and monitoring of steelhead populations in the Central Valley.

1. Increase the understanding of the relationship between anadromous and resident forms of *O. mykiss* in Central Valley streams.

2. Investigate the degree of introgression and straying of hatchery fish into wild populations.

## DATA MANAGEMENT

A comprehensive monitoring plan would not be complete without addressing the need for managing all of the data collected from the recommended steelhead monitoring programs. Data management consists of recording data, creating and implementing a database to store collected data, entering data into the database, checking data quality, and reporting results. Well-designed data management systems can be costly to develop, however sharing a system among agencies and programs may enable cost sharing. Some of the agencies may be able to supply programming staff to assist with this effort. Soon multiple agencies and biologists within agencies will be implementing steelhead monitoring programs recommended in this monitoring plan. These monitoring programs will produce volumes of data spanning multiple years. Monitoring programs require a great deal of effort and expense; the data generated by them should be valued and protected. If monitoring data is not compiled, checked for accuracy, analyzed, and reported, the monitoring effort is wasted.

This plan's objective is to provide information and recommendations that will form the foundation of a data management system for Central Valley steelhead monitoring programs. Information regarding data capture methods, database systems, and data reporting was obtained through literature and acquiring information from several existing programs that collect and manage fisheries data.

### Recommendations for Development of a Data Management System

#### *Data Management Plan*
Develop a detailed data management plan with input from all agencies and individuals associated with recommended monitoring. A data management plan will help ensure that a database architect and biologists address all components, and help ensure that decisions made for each component are well documented.

#### *Data Capture*
Examine the feasibility of using electronic devices to capture data in the field. Several CDFG projects have used electronic data logger technology with success. This

technology facilitates data entry with error checking and provides an efficient means of uploading data to a database.

***Centralized Database System***

Develop a centralized database system that all steelhead monitoring programs have access to and are encouraged (required?) to use.

Benefits of a centralized database system include: (1) ensure data conforms to standard classifications; (2) ensure the validity of the data; (3) ensure the data integrity and internal consistency; (4) secure and maintain primary data; (5) allow easy access to primary data; (6) process the data efficiently; and (7) allow different datasets to be integrated, thereby increasing their overall utility. A centralized database in the Central Valley for steelhead data may foster peer review and discussion leading to collaboration, new research, additional analysis, and improved management decisions.

### Data Reporting and Sharing

***Annual reporting***

Annual reports for each steelhead monitoring program, and an annual summary report format of Central Valley steelhead monitoring will need to be developed. Annual program reports and a similar summary report are essential for reporting the results of the Central Valley steelhead monitoring programs.

This plan recommends that sufficient resources be made available for completing the annual program and summary reports. This may require a dedicated position to compile and produce the annual summary report.

***Data Sharing***

The CalFish Abundance Database is recommended for developing, maintaining, and standardizing adult steelhead abundance estimates to be made available to the public.

### Database architect/manager

This plan recommends that one full-time position be created for a database architect. The potential volume of data generated from steelhead monitoring in the Central Valley as recommended in this plan justifies a dedicated database manager.

## IMPLEMENTATION AND ADAPTIVE MANAGEMENT STRATEGY

Elements of this plan can be implemented immediately for the identified existing programs. Others will require new funding sources to implement. This plan expects that administrators will actively seek funding to implement many of the recommended projects in the very near future. High priority projects include the mainstem Sacramento

River mark-and-recapture (fyke trapping) project, and the various fish device counter projects recommended throughout the Central Valley.

This monitoring plan should be considered dynamic; the plan and individual monitoring programs will have on-going evaluation and refinement. Adaptive management will need to be incorporated as part of implementing the steelhead monitoring plan and associated monitoring programs.

This plan recommends that the existing Interagency Ecological Program (IEP) Central Valley Salmonid Project Work Team (PWT) provide the forum for the implementation phase. The Salmonid PWT has established technical subteams, such as the Steelhead, Juvenile Monitoring, Salmonid Escapement, Genetics, and Upper Sacramento River Basin PWTs. The Steelhead PWT encourages, facilitates, and coordinates steelhead monitoring, research, and information dissemination, and provides a technical forum for Central Valley steelhead.

Dedicated staff will be needed for the implementation of this plan. It is recommended that two full-time positions be created for 1) a monitoring plan coordinator, and 2) a database architect to work with the multiple agencies and entities involved in steelhead monitoring.

Biologists will need technical assistance with implementation and data analysis of the recommended monitoring programs described in this plan. This plan recommends hiring or contracting a statistician to assist with training observers, execution of study design, data analysis, and report writing. In addition, the statistician can develop user-friendly computer programs for management and/or analysis of the monitoring data, and conduct annual workshops for the field biologists to demonstrate the use of those programs. The annual workshop(s) would be an interactive meeting for the statistician to assist and train biologists regarding data collection, management and analysis.

## COST ESTIMATES FOR RECOMMENDED MONITORING STRATEGIES

### New Monitoring Programs

Below are cost estimates for the recommended steelhead monitoring programs that will be new to the Central Valley. Cost estimates were identified for equipment, personnel, and operating costs. For some programs, cost estimates were determined from similar monitoring programs in place or through communication with lead biologists on the rivers. For the other programs, personnel costs were determined using rates for a biologist with benefits ($25/hr and 0.28 benefit rate), technician with benefits ($16/hr and 0.28 benefit rate), and a temporary technician with limited benefits ($16/hr and 0.14 benefit rate) based on rates by the Pacific States Marine Fisheries Commission (PSMFC). In addition, an overhead cost was charged to all projects at a rate of 0.1248 (PSMFC) applied to project costs. These overhead rates did not apply to large equipment items, such as vehicles, boats, trailers, DIDSON units, Vaki Riverwatcher systems, etc. Travel costs were estimated using the state per diem rate for gas ($0.59/mile), lodging ($70) and incidentals ($46/day). Contingency costs were added to each project at a rate of at least 0.10 of the estimated project costs.

All of the cost estimates are estimates based on 2010 values, therefore upon implementation costs will need to become finalized based on the implementation of each recommended program. Existing equipment may be available, therefore costs could be reduced. For recommended programs using device counters, weirs may not be needed if hard structures are available (e.g., fish ladders of dam). In addition, a power grid and existing structure to house equipment may be available, all reducing costs of the programs. However, project costs can increase too. For example, construction of weirs depends on the costs of the materials (e.g., steel). Exchange rates may change between the US dollar and Icelandic krona when purchasing Vaki Riverwatcher systems. In addition, cost estimates for the distribution surveys are rough, extensive GIS and ground work must be completed to determine the sample frame, sample units, length of sample units, and the number of sample units to survey annually.

| | Start-up Cost Year 1 | Annual Cost Year 2+ |
|---|---|---|
| *New Steelhead Monitoring Programs* | *Cost in USD* | *Cost in USD* |
| **Sacramento Mainstem mark-recapture** | | |
| Pilot Study (3 months) | 237,935 | 148,079 |
| Full Implementation (4 months) | 269,058 | 191,643 |
| **Central Valley steelhead Distribution Surveys** | 675,323 | 482,408 |
| **Cottonwood, Cow, Bear, Antelope, Deer, and Mill Creeks –** Video/DIDSON Monitoring | 1,383,986 | 605,726 |
| **Clear Creek** – Vaki Riverwatcher System | 357,752 | 191,504 |
| **Butte Creek –** Vaki Riverwatcher System | 219,340 | 121,300 |
| **Merced River** – Vaki Riverwatcher System and a Alaskan style weir | 412,000 | 212,000 |
| **Calaveras River** – Vaki Riverwatcher System and a Alaskan style weir | 412,000 | 212,000 |
| *Total cost estimates for new monitoring programs* | **3,967,394** | **2,164,660** |

A full-time database architect, plan coordinator, and statistician are recommended for implementation of the monitoring plan. Annual costs are described below.

| | |
|---|---|
| $70,689 | Database Architect |
| $86,030 | Biologist/Plan Coordinator |
| $102,180 | Statistician |
| **$258,899** | TOTAL |

## TABLE OF CONTENTS

# CHAPTER 1

## INTRODUCTION

California Central Valley (CV) anadromous rainbow trout (*Oncorhynchus mykiss*) (commonly known as steelhead) were listed as threatened under the Endangered Species Act (ESA) in 1998 (FR Vol. 63 No. 53 13347-13371 1998); threatened status was reaffirmed in 2006 (FR Vol. 71 No. 3 834-862 2006). Steelhead included in this listing consist of all naturally produced steelhead in the Sacramento and San Joaquin rivers and their tributaries, excluding steelhead originating from San Francisco and San Pablo Bays and their tributaries (FR Vol. 65 No. 32 7764-7787 2000, FR Vol. 70 No. 170 52488-52627 2005).

Steelhead were historically distributed throughout California's CV, with populations ranging from the Pit River in the northern part of the state to the Kings River in the south (Figure 1) (Lindley et al. 2006). Population estimates prior to European settlement are not available, but may have approached 1 to 2 million adults annually (McEwan 2001). Counts of fish migrating upstream of Red Bluff Diversion Dam from 1967 – 1991 indicate a decline from nearly 20,000 adults in 1968 to less than 1000 fish in 1991 (McEwan and Jackson 1996). Numerous anthropological impacts including the construction of impassible dams, water diversions, gravel mining, stream sedimentation, water pollution, introduction of non-indigenous species, and the conversion of riparian zones to agricultural and urban land-uses are likely causes of these population declines (Lindley et al. 2006). Remnant steelhead populations are presently distributed throughout the mainstem of the Sacramento and San Joaquin Rivers, as well as many of the major tributaries (Figure 2) of these rivers. Steelhead presence in highly variable "flashy" streams and creeks in the CV is dependent on water flow and cool temperatures, which can change drastically from year to year (McEwan and Jackson 1996). It is estimated that 80 percent of historical steelhead spawning and rearing habitat is now located above impassible dams (Lindley et al. 2006) (Figure 1).

The restoration of California's anadromous fish populations are mandated by State and Federal laws. The Salmon, Steelhead Trout, and Anadromous Fisheries Program Act of 1988, enacted by California Legislature, directed the Department of Fish and Game to develop a program to double naturally spawning fish populations by the year 2000 (Fish and Game Code Sections 6900-6924). The Central Valley Project Improvement Act (CVPIA) in 1992 (Public Law 102-575), enacted by U.S. Congress, requires the Department of Interior to develop and implement a program that ensures the long term sustainability and viability of anadromous fish in the CV, at population levels not less than twice the average levels from 1967 – 1991 (Section 3406(b)(1)).

Furthermore, the ultimate goal of the Federal Endangered Species Act is to restore populations to the point at which they no longer need protection. In general, this means demonstrating population viability (the population is no longer at risk of extinction) (McElhany et al. 2000). As these laws require demonstration of an increase in steelhead population size, a standardized monitoring plan for steelhead in the CV is necessary to meet these objectives.

Expanded monitoring of the CV steelhead population was identified as a need by the Interagency Ecological Program Steelhead Project Work Team (IEP Steelhead PWT 1998). This report identified the actions needed to fill knowledge gaps, collect baseline information on population abundance and distribution, and to assess the effects of habitat restoration actions. The IEP steelhead PWT reconvened in 2002 and determined that none of the monitoring actions proposed in the 1998 report had been initiated, resulting in the current status of virtually no coordinated, comprehensive, and consistent monitoring of steelhead in the CV.

The forthcoming NOAA-NMFS Central Valley Steelhead Recovery Plan divides the CV steelhead ESU into six ecoregions or diversity groups based on differences in climatological, hydrological, and geological conditions (Lindley et al. 2007). These diversity groups include the Northwestern California group, the Basalt and Porous Lava group, the Northern Sierra Nevada group, the Southern Sierra Nevada group, the Central Western California group, and the Suisun Bay Tributaries group (Lindley et al. 2007). The goals of the recovery plan include demonstrating at least two viable steelhead populations in each diversity group using the concept of population viability (McElhany et al. 2000), which models the likelihood of a population going extinct based on several population metrics (abundance, production, spatial distribution, and diversity). Monitoring of the Suisun Bay Tributaries group is not included in this plan because these tributaries are not included in the Central Valley steelhead ESU or critical habitat Federal Register listings (FR Vol. 70 No. 170 52488-52627 2005, FR Vol. 71 No. 3 834-862 2006). Intense steelhead monitoring is included in this plan for select tributaries of the Northwestern California, Basalt and Porous Lava, Northern Sierra Nevada, and Southern Sierra Nevada diversity groups which are illustrated in Figure 3. Tributaries not selected for intense monitoring in these diversity groups and tributaries in the Central Western California group will be monitored through distribution surveys described in Chapter 3.

### *Historic and Current Steelhead Monitoring in the Central Valley*

Large scale (basin wide) steelhead monitoring in the CV began in 1953 with a six-year project designed to evaluate returns of hatchery steelhead to CV rivers (Hallock et al. 1957). The project successfully used large fyke traps to capture returning adult steelhead in the Sacramento River. Though the project generated useful population abundance, status, and life history data for wild and hatchery origin steelhead, the program was canceled due to a lack of interest in steelhead by administrators (Hallock 1989). Almost all of the baseline information regarding CV steelhead stocks is derived from this program. The recommended monitoring described in Chapter 2 is a modified and updated version of this project.

From 1967-1993, steelhead run-size estimates were generated from fish counts in the fish ladder at Red Bluff Diversion Dam (RBDD). From these counts, estimates of the natural spawner escapement upstream of RBDD were generated. Because RBDD impacted winter-run Chinook salmon by delaying their upstream migration, dam operations were changed in 1993 so that dam gates were raised earlier in the season. This change in operation eliminated the need for fish to navigate fish ladders and likewise eliminated the ability to generate accurate run-size estimates for the Upper Sacramento River basin.

Counting stations have been implemented in Upper Sacramento tributaries for the purposes of counting immigrating adult steelhead in the past. The earliest counts were generated using fish weirs near Leininger Bridge on Deer Creek in the 1940s. A fish trap located at Clough Dam on Mill Creek was used to count fish from 1953-1964 and 1979-1980. More recently (1988-1994), electric fish counters located in the fish ladders of Clough Diversion Dam and Stanford-Vina Diversion Dam (Deer Creek) were used to estimate steelhead passage. The electronic counting stations were not operated continuously due to malfunctions and high winter flows on Mill and Deer creeks. Though there is still potential to operate the Stanford-Vina counting station, the Clough station is no longer usable as the dam was breached in 1997 and subsequently removed. Both sites offer the potential to be converted to video monitoring stations using partial horizontal bar weirs.

**Figure 1**. Estimated historical steelhead distribution in California's Central Valley. The current steelhead ESU is outlined in gold. Historical distribution was adapted from Lindley et al. (2006).

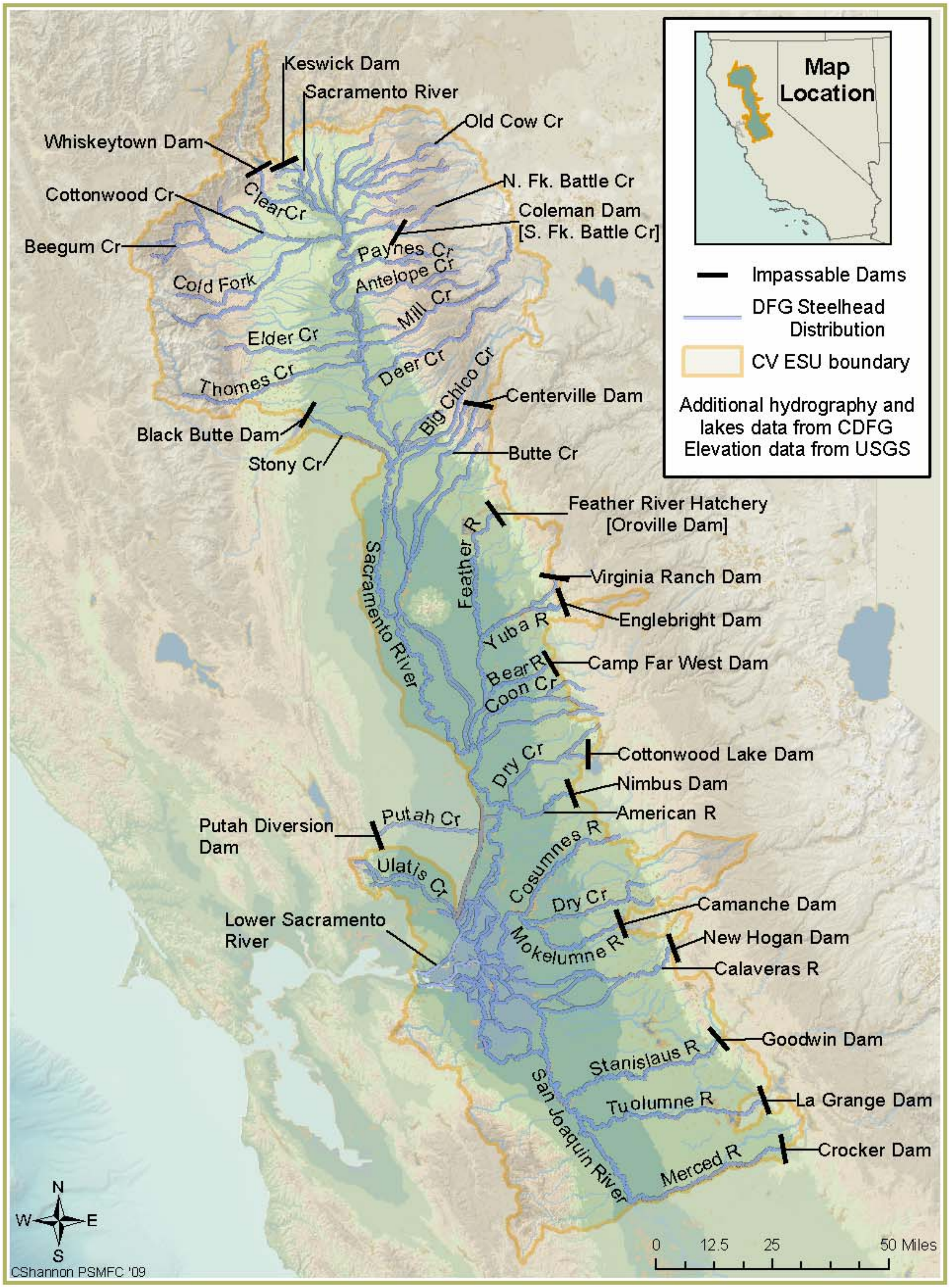


**Figure 2**. Current steelhead distribution in the Central Valley of California. Blue lines indicate known current steelhead distribution in the CV. Impassible dams block all fish access to areas upstream and are indicated by short black lines bisecting the rivers. The distribution is bordered by the NMFS Central Valley steelhead evolutionarily significant unit (ESU).

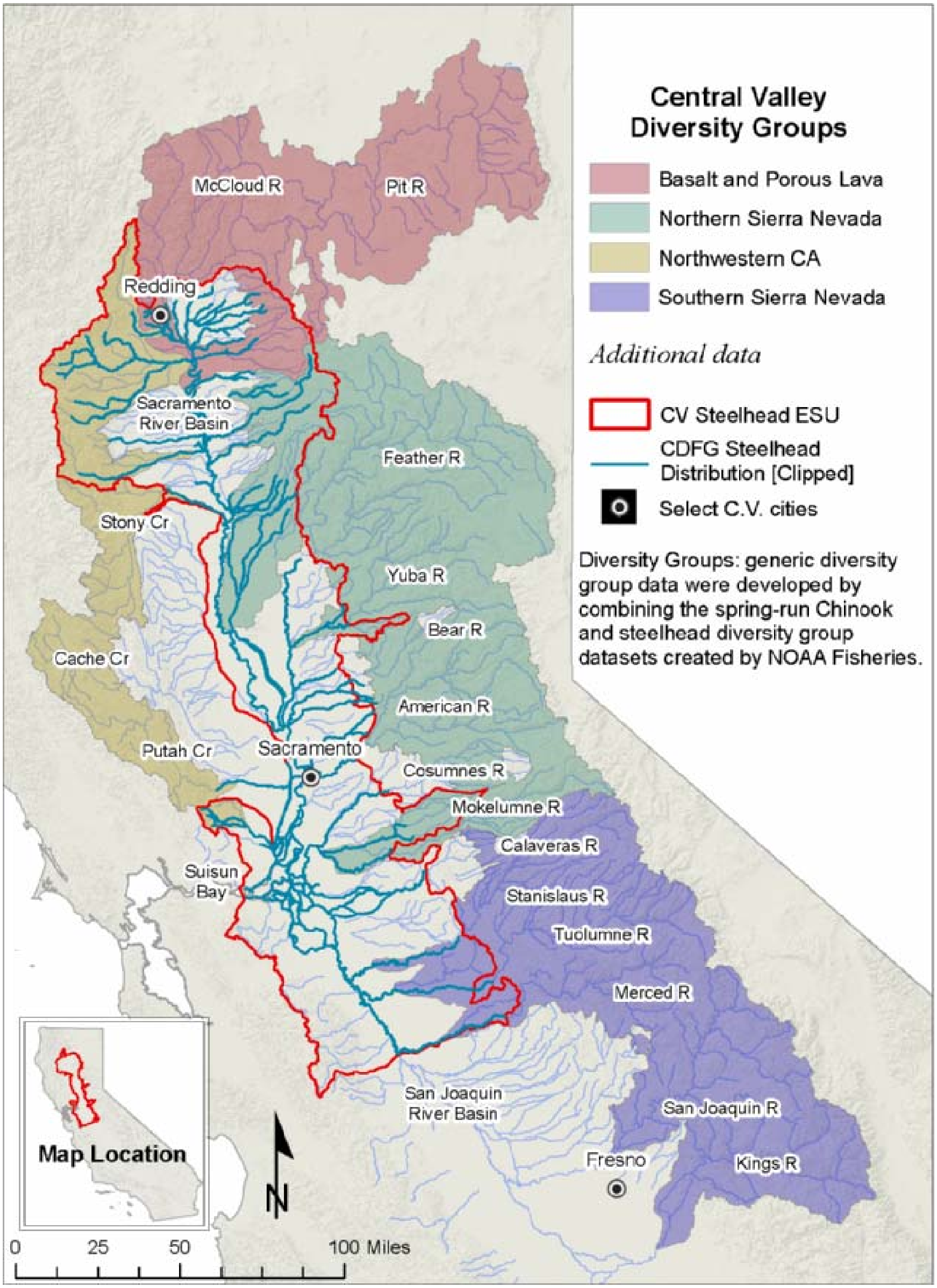


**Figure 3**. Generic Diversity Groups for spring-run Chinook salmon and steelhead identified by NOAA for the California Central Valley.

At present, steelhead monitoring programs in the CV are not based on sound statistical methodology, lack statistical power (the ability to detect trends), are not standardized, and in many cases lack dedicated funding. Many existing monitoring programs in the CV are focused on Chinook salmon (*O. tshawytscha*) primarily because of their commercial importance. These programs are inadequate for monitoring steelhead populations due to differences in steelhead and Chinook life history traits (immigration timing, spawning time, spawning requirements, rearing time, rearing requirements, emigration timing, reproductive strategy, etc). For a full review and critique of existing steelhead monitoring projects, please refer to Eilers (2008), Low (2007), and IEP Steelhead PWT (1999).

### *Goals and Objectives*

The goal of this monitoring plan for Central Valley steelhead is to provide recommendations for the development of steelhead monitoring programs that when implemented will provide the data necessary to help assess whether or not restoration and recovery goals are being achieved. Information obtained will be used to examine the distribution, abundance, and population trends of Central Valley steelhead.

Objectives include:

- Estimate steelhead population abundance with estimated levels of precision in the Central Valley,

- Examine trends in steelhead abundance in the Central Valley,

- Identify the spatial distribution of steelhead in the Central Valley to identify their current range and observe changes that may occur over time,

Recommended monitoring actions in the plan to obtain the information needed to address the goal and objectives include the following:

- Estimate the abundance of adult steelhead in the Sacramento River system using a mark-recapture study with large wire fyke traps placed in the mainstem Sacramento River,
- Examine the spatial distribution of steelhead across the CV using distribution surveys,
- Monitor the status and abundance of steelhead in select rivers in the Northwestern California Diversity Group, Basalt and Porous Lava Diversity Group, Northern Sierra Nevada Diversity Group, and Southern Sierra Nevada Diversity Group.

These monitoring actions are expected to result in Sacramento River basin-wide estimates of adult hatchery and wild steelhead population abundance, steelhead abundance estimates for select rivers, and the spatial distribution of steelhead in the CV.

### *Identification of Priorities*

Meetings were held with California Department of Fish and Game (CDFG) Regions 1, 2, and 4, CDFG Fisheries Branch, as well as the United States Fish and Wildlife Service (USFWS; Red Bluff office) for the purpose of identifying stream priorities, potential sampling sites, recommended monitoring methods, and targeted lifestages. In addition, the National Marine Fisheries Service's (NMFS) Public Draft Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon, Central Valley Spring-run Chinook Salmon, and the Distinct Population Segment of Central Valley Steelhead (Recovery Plan; NMFS 2009) was reviewed to identify populations of steelhead that will need to be monitored for the Recovery Plan.

**Region 1/USFWS – Red Bluff**
CDFG Region 1 biologists identified Mill, Deer, Antelope, and Bear Creeks as the streams that should be targeted by the monitoring plan. Cottonwood Creek was recommended for monitoring on the west side of the Sacramento River. Video monitoring has been successfully used on both Mill and Antelope creeks, although there is a challenge maintaining video weir integrity during high flows in wet years. Additionally, turbid water conditions can prevent the collection of meaningful data during these high flows. Dual-frequency Identification Sonar (DIDSON) units were recommended in addition to video monitoring stations. However, concerns were expressed with costs of the DIDSON units. Suggestions were made for deploying DIDSON units on 2-3 selected streams prior to turbid events. DIDSON data could then be used to compliment video monitoring for times when stream conditions prevent video monitoring. DIDSON units have been tested in Region 1 and were found to be powerful tools by being reliable (useable in flows as high as 16,000 cfs) and providing good information. In addition to the above Region 1 recommendations, USFWS recommended that Clear Creek and Battle Creek continue to be monitored using redd surveys (Clear Creek) and video monitoring and fish counts (Battle Creek).

**Region 2**
CDFG Region 2 biologists identified Butte Creek, Feather River, Yuba River, American River, and Mokelumne River as target systems. The American, Feather, and Mokelumne Rivers should be monitored due to the impacts that CDFG hatcheries have upon steelhead populations in these rivers. However, these hatchery supplemented rivers should not be considered surrogates for natural systems or "wild" steelhead streams. Region 2 recommended monitoring in Butte Creek and the Yuba River because: (1) ability to implement due to least flashy systems; and (2) no hatcheries to interfere with steelhead monitoring. The Cosumnes River was identified as having little water and few, if any, fish.

Yuba River video monitoring at Daguerre Point Dam should be continued and results considered as relative abundance estimates rather than absolute counts.

Due to the large sizes of many rivers in Region 2, deploying video monitoring weir structures on all target streams will likely not be possible. Thus, adult abundances may need to be generated using alternative techniques.

**Region 4**
Biologists in CDFG Region 4 suggested that steelhead monitoring be focused initially on the Stanislaus River due to the presence of a weir at river mile 31.5 near Riverbank, CA. Monitoring on the Tuolumne River, Merced River, and San Joaquin River mainstem were also recommended.

Monitoring of steelhead populations in Region 4 is especially challenging due to a paucity of fish. Steelhead populations in Region 4 are depressed to the point where monitoring and statistical methods are limited.

**CDFG Fisheries Branch**
Biologists in the Fisheries Branch feel that specific research and monitoring to assist in steelhead management through sport fishing regulations is vital. This plan recommends additional research projects to benefit future CV steelhead management (Chapter 11).

Fisheries Branch biologists also desire long term life cycle monitoring stations be implemented on several systems throughout the CV. Though these stations would allow better estimates of adult abundance and juvenile productivity, they require a stream be completely blocked so that a large percentage of passing fish may be counted and sampled. In the CV, the hard structure at the Coleman National Fish Hatchery on Battle Creek is likely the only hard structure that has the potential to monitor both adult and juvenile steelhead. This plan does not focus on these life-cycle monitoring stations as a viable option for monitoring steelhead throughout the CV in the near future, however Battle Creek should be considered as a potential opportunity (see Chapter 9).

**NMFS Recovery Plan**
The public draft Recovery Plan by the NMFS Southwest Region established three priority levels to help guide the recovery efforts for watersheds that are currently occupied by steelhead. The highest priority is Core 1 populations, which were identified based on multiple factors, including: (1) the known ability or significant immediate potential to support independent populations; (2) the role of the population in meeting a spatial or redundancy viability criteria; (3) the severity of the threats facing the populations;(4) the potential for ecological or genetic diversity the watersheds and populations could provide to the species; and (5) the capacity of the watershed and population to respond to critical recovery actions needed to abate those threats identified (NMFS 2009). Of secondary importance are Core 2 populations, which are areas that have the highest potential to support geographically diverse populations. Core 3 populations are present on an intermittent basis and are characterized as being dependent on other nearby populations for their existence, where their presence increases life history diversity to the Distinct Population Segment and is likely to buffer against catastrophic occurrences that may affect nearby populations.

Recovery priorities were established by NMFS (2009) for CV watersheds currently occupied by steelhead. These priorities were organized by Diversity Group and are described below.

| Diversity Group | Core 1 | Core 2 | Core 3 |
|---|---|---|---|
| **Northwestern CA** | Clear Creek | Cottonwood/Beegum | Thomes Creek |
| **Basalt and Porous Lava** | Battle Creek | Upper Sacramento River<br>Redding Area Tribs<br>Cow Creek | |
| **N. Sierra Nevada** | Antelope Creek<br>Mill Creek<br>Deer Creek<br>Lower Yuba River | Big Chico Creek<br>Butte Creek<br>Lower Feather River<br>Lower American River | Bear Creek Lower<br>Mokelumne River<br>Cosumnes River |
| **S. Sierra Nevada** | Calaveras River | Lower Stanislaus River<br>Lower Tuolumne River<br>Lower Merced River | |

***Development of the Monitoring Plan***

The development of this monitoring plan was a collaborative process with the IEP Steelhead Project Work Team (PWT) Members, which includes biologists throughout the CV from various agencies including the CDFG, NMFS, USFWS, California Department of Water Resources (CDWR), East Bay Municipal Utility District (EBMUD), United States Bureau of Reclamation (USBR) and others. The PWT developed the project proposal in 2004 and were involved throughout the development of the plan. Some members provided comments on earlier drafts of the plan and during project updates at PWT meetings. The final draft of the plan was reviewed by some PWT members and other participants at a workshop or written comments were provided. All of the comments we received were incorporated into the plan as best as we could.

***Additional California Central Valley Steelhead Data***

The monitoring actions in this plan are supported by other programs that have value for steelhead management. Additional steelhead data is collected from the CDFG Steelhead Report Card, counts of hatchery returns (potentially counts for both adipose fin clipped and non-adipose fin clipped fish) from the Coleman National Fish Hatchery, Nimbus, Feather River, and the Mokelumne River State Fish Hatcheries, CDFG's CV Angler Survey program, and independent monitoring efforts (such as in restoration areas or to answer specific research questions) conducted by fisheries consultants, academic organizations, and various agencies.

***Identification of Steelhead***

Steelhead are defined as *O. mykiss* that migrate to the ocean as juveniles and return as adults to freshwater streams to spawn. Steelhead fresh from the ocean are typically silvery in appearance with green backs and pink or red opercula and lateral coloration. However, as these fish remain in freshwater, the silvery coloration darkens and anadromous fish begin to more closely resemble freshwater resident *O. mykiss* in appearance. For monitoring purposes, a “steelhead” is defined as any *O.mykiss* greater than 16 inches (40.6 cm) that is present in anadromous waters (CDFG Freshwater Fishing Regulations 2008-2009 Title 14, Section 1.74). However, biologically some *O.mykiss* greater than 16 inches could be resident fish. Future research may help better differentiate steelhead from resident rainbow trout for monitoring purposes (identified as a need in Chapter 11).

# CHAPTER 2

## MAINSTEM SACRAMENTO RIVER STEELHEAD MARK-RECAPTURE PROGRAM

Historically, wire fyke traps were used to estimate population abundance of steelhead immigrating into the Sacramento River Basin (Hallock et al. 1957; Figure 4), the results of which provide almost all of our baseline information on historical steelhead populations. This plan recommends that a pilot study be undertaken to evaluate the current effectiveness of wire fyke traps in the mainstem Sacramento River.

Preferred trapping locations in the Sacramento River are located downstream of the confluence of the American River, but upstream of the Sacramento-San Joaquin River Delta (upstream of Elk Slough). Placing the traps in a location downstream of the American River ensures that all hatchery steelhead returning to the American and Feather Rivers would be susceptible to the fyke traps. Population estimates generated from this study would be useful for determining Sacramento River basin-wide population estimates and comparing these estimates to tributary monitoring efforts described in Chapters 5, 6, and 7.

Additional traps located near Knights Landing, CA may prove useful in attempting to duplicate the Hallock et al. (1957) study. Duplication of the historical study may allow comparisons of existing abundance to historic (1953-1957) abundance. Unfortunately, as the historic sampling location was located upstream of both the Feather and American River confluences (both of which are heavily supplemented by hatchery stocks), traps at the historic locations would encounter likely fewer fish than traps placed below the confluence of the American and Feather River (fish reared at the Nimbus and Feather River Hatcheries should return to their natal hatcheries before encountering traps).

Prior to full implementation of this program, a pilot program needs to be undertaken to evaluate trapping success and the degree to which fish will be injured during the trapping process. Hallock et al. (1957) reported that trapped steelhead were found to be in very good condition, with few visible cuts or bruises that may indicate an attempt of trapped fish to escape by swimming against the wire mesh. Fish that were left in the trap for up to three days remained in excellent condition. The interior wire mesh of the traps may need to be coated with or replaced by a soft rubber or plastic mesh if fish injury or mortality occurs.

***Mark-Recapture Pilot Program***

This plan recommends conducting a pilot mark-recapture program for multiple years in the mainstem of the Sacramento River to evaluate trapping success and the degree to which fish will be injured during the trapping process. In addition, wild and hatchery steelhead abundance estimates with known precision and bias will be generated. A computer simulation was developed to estimate the potential variability in mark-recapture population estimates. Details of the computer simulation are described in Appendix A.

***Data Collection***

The mark-recapture technique to be used is a temporally stratified design where sampling at multiple river locations is used to estimate the abundance of the migrating adult steelhead population in discrete time segments. The stratified approach is being used since steelhead may migrate in pulses of high, medium and low run abundance over the migration period (Hallock 1989). The method consists of counting all hatchery and wild adult steelhead captured at designated trapping sites and releasing tagged fish back into the population at sites downstream from recapture sites. The temporal segments of the hatchery run and the wild run are estimated separately then summed to achieve total abundance estimates.

The method of capturing fish for both marking and recapture will employ multiple wire fyke traps set with the catch openings facing downstream (Hallock et al. 1961, Hallock 1989). Four or more traps are to be used from August through October. The majority (approximately 92%) of steelhead catch in the Sacramento River occurred between August and September for four consecutive years (Hallock et al. 1961). The trap set furthest downstream will be reserved for marking fish only while the upstream-most trap will only involve recapture efforts. Both marking and recapture will occur at traps located between the extreme lower and upper traps. Traps will be set far enough apart to allow complete mixing of marked and unmarked fish so that the probability of capture is most likely to be similar for marked and unmarked fish. Marked fish will need to be ferried by boat or trucked upstream far enough that fallback is minimized and complete mixing between the released marked fish and unmarked fish will have occurred. In addition, all wild and hatchery fish captured will be marked in some fashion so that the total number of unique fish captured can be identified. Monitoring trapping and handling mortality of fish will need to occur and corrective actions employed if significant mortality is observed. Mortality is more likely if large numbers of fish are captured and fish need to be ferried for long periods of time. However, due to the low numbers of steelhead in the CV we do not expect to catch large numbers of steelhead in each trap. In addition, fish will not be ferried for long time periods. The boat will need to have a large holding tank with a continuous feed of new water to keep the fish in good condition.

Exact placement of the traps in the mainstem of the Sacramento River is unknown at this time and may require extensive preliminary investigations. The study design requires traps to be set in series from downstream to upstream, with enough distance between single traps so that tagged and untagged fish mix thoroughly. The size of the traps (Figure 3, approximately 20 feet long x 12 foot diameter) requires they be rolled into the river from the top of a levee, limiting locations at which the traps can be deployed. Because the traps need to be rolled into and out of the water, the levee banks cannot be too steep, undercut, or contain brushy vegetation. Furthermore, water depths at the base of the levee need to be deep enough to sufficiently cover the height of the trap (water depth of 10.5-12 feet), but not so deep that the trap is too deep to efficiently capture steelhead. Hallock et al. (1957) stated that the best trapping locations were located:

"…*on the deep side of the river, where the bank was almost vertical*…" and "…*particularly good fishing sites were those where the river first straightened out after making a sharp curve*…" and "…*excellent trap locations were also available along fairly straight stretches of river, but always on the swifter, deeper side*…".

All captured steelhead (hatchery and wild) will be enumerated, measured (fork length), sexed (if possible), sampled for scales (estimate age structure of the run), sampled for genetics tissue, checked for injuries, and checked for the presence of tags. All hatchery steelhead will be tagged with an external t-bar anchor tag each with a unique ID number (floy tag) for the mark-recapture study. If permitting allows, tagging wild fish with a floy tag is recommended to examine the assumption that capture probabilities of wild and hatchery fish are equal for different strata, and if these fish are recovered in the future they could provide some interesting information such as which river they immigrated into. However, recaptures of wild fish will not be used in the mark-recapture model. Tag shedding can be examined as hatchery fish will have an adipose fin clip (from the hatchery) and a caudal fin mark (genetic tissue sample), and wild fish will have a caudal fin mark (genetic tissue sample) with an adipose fin present. The estimated total number of hatchery fish in each stratum, along with an estimate of the ratio of wild to hatchery fish in the migration will be used to estimate the total number of wild fish. This method requires that stratum specific capture probabilities are the same for wild and hatchery fish, that fallback of fish captured at a downstream site and released upstream occurs at the same rates for wild and hatchery fish within each stratum, and that mortality is the same for all fish.

**Figure 4**. A large wire fyke trap constructed by CDFG Region 3 for striped bass population assessments. Traps are composed of chain link fencing, steel hoops, wooden stringers, and plastic mesh (in fish pot only).

The computer simulation showed that there is moderate variability around estimates of wild and hatchery steelhead abundance given hypothetical levels of probability of capture and certain assumptions about the mark-recapture model (Appendix A). Bias in estimates is relatively low (generally < 7 %) unless probability of capture and total abundance is extremely low. Larger errors were associated with lower trapping effort (4 traps versus 7 traps) and reduced the probability of capture. Considering the pilot study is a first attempt to achieve a fairly precise estimate of the total Sacramento River immigrating adult steelhead abundance, the small to moderate differences in bias and precision using only four fyke traps may be an acceptable compromise considering the extra time, maintenance, uncertainty and resources involved in employing additional traps.

***Data Analysis***

Detailed data analysis methods are described in Appendix A for estimating the total abundance of immigrating adult steelhead in the Sacramento River basin with estimated levels of precision and bias.

***Project Strengths and Weaknesses***

Strengths:

- Provides mainstem abundance estimates
- Fish are handled when fresh from the ocean
- Wild fish do not need to be tagged, only clipped
- Provides wild and hatchery population estimates
- Effect of sample size on population estimate can be modeled

Weaknesses:

- Trap avoidance for recaptures may bias efficiency and population estimate
- Multiple sources of variation (hatchery: wild ratios, efficiency) factor in population estimate
- Concerns that trapping may delay or otherwise impact migrating Chinook salmon
- Concerns that hatchery fish are not suitable surrogates for wild steelhead

***Considerations***

Oversized load permits are needed to transport the traps from storage to sites on the river (M. Gingras, CDFG, pers. comm., 2008). CalTrans permits are needed when transporting the traps on state highways and freeways, and county permits are needed when the traps are being transported via county roads. If traps are to be stored at and moved from the Region 3 headquarters in Stockton, county permits will be needed from San Joaquin, Sacramento, and Yolo Counties. Transportation of traps and setup for fishing takes approximately 4-5 hours per trap.

Estimating steelhead abundance at Red Bluff Diversion Dam may be possible by subtracting the tributary estimates (recommended programs in Chapters 5, 6, and 7) from the estimate for the mainstem of the Sacramento River. However assumptions will need to be made for the above RBDD estimate to be true. Assumptions include at least: (1) fish are not lost before being counted in the tributaries; and (2) all fish in the mainstem of the Sacramento River migrate only into the tributaries with monitoring and can be counted.

This RBDD estimate would be the best estimate at RBDD since the pre-1991 gate operations. Though not directly comparable to historical steelhead counts at RBDD, this estimate could provide basin-wide estimates of steelhead abundance that may be useful to biologists working on the CAMP (Comprehensive Assessment and Monitoring Program) for purposes of assessing progress towards the Central Valley Project Improvement Act doubling goals.

CV anglers, hatcheries, and monitoring programs should be notified of the mark-recapture study and to examine all captured steelhead for floy tags. However, anglers should not be used as a recapture technique for the mark-recapture study; the recapture technique is the large fyke traps. Removing fish in the study area could negatively impact the mark-recapture study for estimating abundance of steelhead. Collected floy tags should be sent to one common location. If the fish is going to be released from a hatchery or through monitoring programs, the following data should be collected: floy tag number, location of recovery, date, time, and any additional information believed to be needed. This will provide additional information about the fish, but will not be used for estimating abundance. Potentially in the future, a model could be developed to incorporate this recapture data.

Steelhead captured in the mark-recapture studies could be acoustic tagged or tagged with passive integrated transponder (PIT) tags for future studies. However, the effect that tagging has on the ability to recapture these fish is unknown. .Fish could be PIT tagged in the future to examine the movement of these fish; however an array of acoustic receivers needs to be in place in the CV before fish are pit tagged. Hatcheries could use handheld wands to scan all steelhead to detect PIT tags (for the mark-recapture study and other potential CV studies). However, the fish in the mark-recapture study will be floy tagged and can be visually identified for recapture information at the hatcheries. PIT tagging studies are discussed as a need for examining the life history of *O.mykiss* and straying of hatchery steelhead in Chapter 11.

# CHAPTER 3

## CENTRAL VALLEY WIDE STEELHEAD DISTRIBUTION SURVEYS

Steelhead monitoring in the Central Valley has not been a priority in recent years, so little is known about the current distribution of the species in the region. An objective for future steelhead monitoring in the Central Valley will be to monitor the large network of streams for changes in steelhead distribution and population expansion into low use areas, which is an important indication of species recovery.

The optimal approach to monitoring for changes in steelhead distribution and population expansion involves using spatially balanced sampling and a rotating panel design. Rotating panel designs select a probability sample of units from a population and assign units to "panels" (Stevens 2002, McDonald 2003), or sets, that are always all visited during the same sampling occasion. Revisits to sample units are scheduled by organizing visits to entire panels on a rotating basis. This scheduling assures that "good" overall spatial coverage is achieved, and that an adequate number of revisits occur. Below is a discussion of sample units and the sample frame, sample draw, panel construction, and rotation of effort among panels. In addition a discussion of survey effort and the potentially dynamic nature of the steelhead distribution in the Central Valley.

In the future, a threshold (e.g. steelhead per mile) could be added to the distribution surveys, where if the threshold is met intense monitoring of the steelhead population in a specific river would be initiated.

### *Identification of the Sampling Units and Sample Frame*

For monitoring changes in steelhead distribution in the Central Valley, sample units will be defined as sections of stream reaches all having approximately the same length. The sample frame will be a list of all possible sample units, except for those in the following areas: stream reaches above physical barriers preventing upstream migration, first order streams that are too steep for spawning, stream reaches known to be inaccessible, and streams already being monitored via redd surveys or Vaki/DIDSON/video device counters. In general, the areas excluded from sampling will be defined as areas known to be inaccessible, unavailable to steelhead, or areas already experiencing intense steelhead monitoring.

Following creation of the sample frame, sampled units will be ordered for sampling using a 1-dimensional method that uses the unit's location within its watershed and the watershed's location within the Central Valley. All watersheds in the Central Valley will first be ordered from north to south. Sample units within each watershed will then be ordered starting at the stream mouth (where it enters the Sacramento River or San Joaquin River) and moving upstream. Tributaries will be ordered based on the stream mile of their confluence with the mainstem. That is, units in lower (farthest down-stream) tributaries will appear before units in upper tributaries. In this way, ordering of the frame will continue recursively from main stem to tributaries until all units are placed in the frame. This ordering will ensure that sampled units will be spread out and will represent all areas of the Central Valley, in proportion to their geographic sizes.

A list of streams in the CV that potentially have steelhead will be presented in the 2009-2010 Steelhead Restoration and Management Plan for California (Bellmer and Nelson, CDFG, pers. comm., 2009). This list of streams will be used to help identify the sample frame and establish a list of all possible sample units. The current number of streams identified as potentially steelhead bearing in the CV is 229. This list of streams will be edited and modified by regional CDFG biologists before published in the revised 2009-2010 Steelhead Restoration and Management Plan.

***Selecting Sampling Units for Monitoring***
A random subset of sample units in the sample frame will be selected for monitoring. This sample will be randomly allocated to panels that receive different visitation schedules (see below). Selecting the subset of sample units will be carried out using an equi-probable generalized random tessellation stratified (GRTS) sampling method (Stevens and Olsen 2004). The GRTS sampling method produces a randomized list of sample units that is spatially balanced and also allows easy addition and deletion of units while maintaining that balance. Technical details of the GRTS sampling mechanism are not presented here (see Stevens and Olsen 2004 and McDonald 2003 for details).

The initial GRTS sample draw will take a 50 percent sample of units in the sample frame. This sized sample will be adequate to provide a collection of primary and secondary units. Primary units will comprise 40 percent of the 50 percent sample, or 20 percent (= $0.5 \times 0.4$) of units in the sample frame. Secondary, or "over-sample," units will replace primary units that could not be sampled for one reason or another. For example, sampled units with restricted access or units experiencing an extreme dry water year may be replaced (temporarily) with a secondary sample unit. Replacement of primary sample units with secondary units will ensure that the 20 percent sample size objective is maintained.

***Visitation Schedules***
Sample units selected by the GRTS mechanism will be allocated to different panels, each following a different revisit schedule. Typically, steelhead mature at approximately four years of age. For this reason the panels will all follow a revisitation schedule based on multiples of four. Fifty percent of the sampled units will be randomly assigned to Panel 1 and revisited every four years. Thirty percent of the sampled units will be randomly assigned to Panel 2 and revisited every eight years. The remaining 20 percent of the sampled units will be assigned to Panel 3 and visited only once during a twenty-four year period.

***Survey Effort***
Snorkel surveys or other methods such as redd surveys may be used to monitor each sampled unit. Regardless, survey protocol will be created and observer training will ensure that all surveys are conducted according to the protocol. Because the timing of the

distribution surveys may influence whether a sampled section of stream is occupied, watersheds will be visited in a random order each season, and sampled sections will be visited twice if no steelhead are identified during the first survey.

A large proportion of the land surrounding CV creeks is privately owned; therefore gaining access to sample units may be one of the greatest challenges to the implementation of this portion of the monitoring plan. The implementation of these surveys in the Sacramento and San Joaquin Basins may require drafting memoranda of understanding with landowners and gaining easements for personnel.

# CHAPTER 4

# RECOMMENDED PROTOCOLS FOR ESTIMATING STEELHEAD ABUNDANCE USING FISH DEVICE COUNTERS AND REDD SURVEYS

## Fish Device Counters

Three fish device counters are used in the California Central Valley (CV) to monitor escapement of steelhead and Chinook salmon within a watershed or river. The device counters include Vaki Riverwatcher, a Dual-frequency Identification Sonar (DIDSON), and traditional optical video cameras (video cameras). These devices provide enumeration data which are subject to a number of sources of error.

The Vaki Riverwatcher, DIDSON and video fish counters have advantages and disadvantages over traditional methods of collecting data to be used for estimating total abundance. The devices are expensive to buy and install, are vulnerable to vandalism and theft and must be installed at an appropriate in-river structure (Mackey 2005). They require regular monitoring, maintenance and servicing to maintain reliable operation and to insure that the data are of high quality. Damage by flooding of the in-river structure is always a possibility. Nevertheless, these devices have a number of strengths: they provide a fairly accurate and consistent count, they can function all year round, and they can operate with minimal impact on individual fish which is an important consideration when the status of the population is threatened or endangered. Moreover, a permanent record is obtained for fish passage which can be reviewed and corrected for error and used for training personnel to process the images.

Device counters are an optimal technique to estimate total steelhead abundance. Immigrating adult steelhead are difficult to monitor using other techniques such as carcass mark-recapture surveys, snorkel surveys, and redd surveys due to their life-history traits. Steelhead are iteroparous, and may not die after spawning; therefore, carcasses are not available for a mark-recapture survey. In addition, steelhead immigrate and spawn during the late-fall, winter and spring months when rivers have periods of flashy flows, high flows, and turbid water conditions reducing visibility. These poor water conditions have negative impacts on all of the techniques, but device counters can be used to count fish during poorer conditions than the other techniques. Below is a description of each fish device counter, and recommendations to quantify and account for counting errors in the data to estimate total abundance.

### *Vaki Riverwatcher Systems*

The Vaki Riverwatcher uses a linear sensory array to measure the height (ventral-dorsal) of a fish breaking infrared light beams emitted from a series of diodes positioned opposite a series of sensors. As a fish swims in a linear fashion (e.g. upstream or downstream) it breaks a second array of infra-red light beams. From the height of the fish and the rate it moves between the two arrays the counter is able to reconstruct an outline of the fish. This outline is then stored to be validated by the operator (Mackey 2005, Figure 5). A digital video camera system add-on is available for the Vaki Riverwatcher (Figure 5) to limit the rate of false counts. The Vaki Riverwatcher system with a digital camera system add-on was found to greatly improve the ability to identify O.mykiss and the presence of an adipose fin compared to a Vaki Riverwatcher with only digital photos and silhouette in the lower Yuba River, CA (R. Greathouse, PSMFC, pers. comm., 2010). Silhouettes alone currently cannot be used to identify steelhead. The Vaki Riverwatcher measures the body depth of the fish. A predefined body depth to length ratio for a species can be applied to the body depth to approximate the length of a fish, which is needed for identifying steelhead (greater than 16 inches) for monitoring purposes.

Vaki Riverwatcher systems require fish to be directed through a narrow opening to pass the series of sensors. Vaki Riverwatcher systems in the CV are installed in Alaskan Style weirs (Figure 6) or within a fish ladder. The benefit of an Alaskan style weir type is that it remains operational at a wide range of stream discharges, and fish can be directed into the Vaki Riverwatcher. The upper stream discharge limit is somewhat site specific and dependent on the overall size of the weir, channel characteristics, and debris loads/types. At stream discharges above this threshold, the weir collapses. When flows decrease, the weir self-rights, providing that debris does not prevent the weir from righting. The benefits of using existing fish ladders at diversion dams are that the structure is permanent, cost savings of not building a weir, and the dam could be fish tight during certain flow conditions. There is anecdotal evidence from similar weirs in California that fish may be able to jump over the resistance panels and avoid the counting chamber (Tim Heyne, CDFG, pers. comm., 2008), therefore examining if fish are capable of jumping over the resistance board weir should be examined (this may be as simple as setting cameras to record the weir crest).

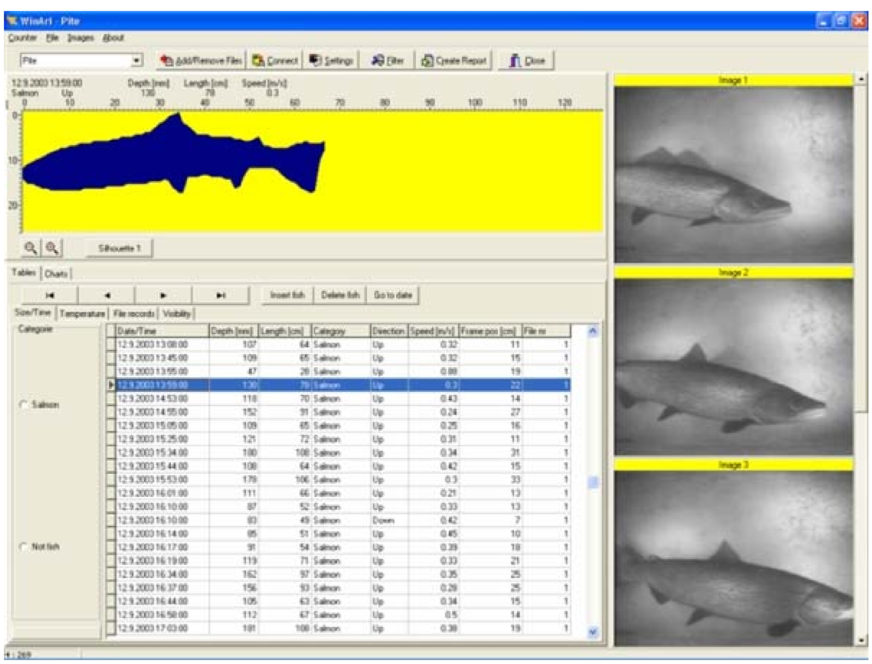


**Figure 5**. The Vaki Riverwatcher can be supplied with a digital camera system to record video or still images of fish passing through the scanner. The scanner triggers the camera to capture between 1 and 5 digital photos or a short video clip of each fish. The computer

then automatically links the digital images to the other information contained in the database for that individual fish such as size, passing hour, speed, silhouette image, temperature etc. Image taken from Vaki, Inc. website: http://www.vaki.is/Products/RiverwatcherFishCounter/CameraRW/.

**Figure 6**. Resistance board (Alaskan style) weir with a Vaki Riverwatcher System on the Stanislaus River, CA. Photo credit: David Hu, USFWS.

***Dual-frequency Identification Sonar***

DIDSON uses high (1.8MHz) or low (1.1 MHz) frequency sound waves to produce high resolution underwater images. Originally DIDSON was designed for use by the Navy to help identify mines and divers underwater, however this technology has expanded into fisheries science. DIDSON has been found to be useful for monitoring run size of salmonids in multiple rivers in Alaska (Maxwell and Gove 2004; Burwen et al. 2007), the Methow River, Washington (Galbreath and Barber 2005), the Secesh River, Idaho (Kucera 2009) and the San Lorenzo River, Big Creek, Scott Creek, and Mill Creek in California (Pipal et al. 2010; Johnson et al. 2006). DIDSON not only provides count data, but also fish size, shape, behavior of the fish, and swimming motion of the fish. Since the DIDSON uses sound waves to produce images of fish, DIDSON can be used in turbid water conditions. In addition, DIDSON does not require fish to pass through a narrow location to capture an image. However DIDSON does require specific features of the stream to examine the entire cross section of a river.

Pipal et al. (2010) developed guidelines for using DIDSON to monitor steelhead in coastal streams in central California. Their guidelines and recommendations for using DIDSON are based on evaluating DIDSON units on three rivers during monitoring activities for steelhead (San Lorenzo River, Santa Cruz County; Big Creek, Monterey County; and Scott Creek, Santa Cruz County). They provide guidelines for equipment and logistics, site selection, data collection and analysis methods, costs and species and life-history form (anadromous versus resident) identification.

Identifying steelhead from other species is an area of improvement identified by Pipal et al. 2010). Pipal et al. (2010) found that identifying between steelhead and Coho salmon (*O. kisutch*) and possibly Sacramento suckers (*Castostomous occidentalis*) was difficult in three California Rivers. Differences in fish size and migration timing allow for differentiating fish species with similar shape and size. Research is trying to improve species identification using patterns of echograms related to tail-beat patterns of fish. Muller et al. (2010) examined the echograms of DIDSON and found that the tail-beat frequency has the potential to differentiate Chinook salmon (*O. tshawytscha*) and sockeye salmon (*O. nerka*) in the Kenai River, Alaska.

***Optical Video Cameras***

Video cameras rely on good conditions (low to moderate flows with relatively clear water conditions) to produce a reliable image of a fish. Video cameras are used to monitor steelhead and Chinook salmon in CV Rivers, such as Bear Creek, Cow Creek, Cottonwood Creek, Mill Creek, Antelope Creek, Battle Creek, and the Mokelumne River. Fish can be identified to species when good images are available. In addition to count data, fish length can be approximated (needed for identifying steelhead), presence of an adipose fin and fish behavior can be examined.

Fish need to be directed into a narrow opening for video monitoring. Partial horizontal bar weirs are used in Bear, Cow, Cottonwood, Mill, and Antelope Creeks to direct fish through the center of the weir where the video cameras (2-4 underwater cameras and one overhead camera) are located (Figure 7 and 8). The opening size of the weir is much larger than the size needed for the Vaki Riverwatcher to produce reliable images of fish. Benefits of a horizontal bar weir include that they are fish tight, debris can easily pass them, they can withstand relatively high flow conditions, and they are relatively inexpensive to build and install. Video equipment is also located in a vault of a fish ladder for the Mokelumne River and for Battle Creek. The vault is a weather proof room with a viewing widow into the fish ladder. In some cases the fish ladder at the viewing window may need to be modified to channel fish closer to the window for video monitoring.

Video cameras alone are a less powerful tool than using both a video camera and DIDSON. Fish cannot be observed in turbid water using a video camera. A DIDSON or a similar device is needed in conjunction with each video camera to enumerate fish when water is too turbid for the video camera alone. Video cameras are needed to identify fish to species, where species identification with a DIDSON can be possible if the fish species has identifying features (described above). Without a DIDSON, the number of fish passing a video monitoring station during periods of turbid water will be unknown. Steelhead migration occurs during rainy months of the year in the CV. In addition, rivers in the upper Sacramento River basin can be naturally turbid during dry years and low flow conditions (D. Killam, CDFG, pers. comm., 2009).

**Figure 7**. An example of a partial horizontal bar weir currently in use in the upper Sacramento River basin (Cottonwood Creek) operated to monitor fall-run Chinook salmon. The weir directs fish through the central opening where they may be filmed by overhead and underwater cameras. Photo credit: Doug Killam, CDFG.

**Figure 8**. An example of favorable conditions for optical video cameras. The image shows a fall-run adult Chinook salmon (approximately 91 cm in length) passing the Battle Creek weir. Photo credit: Doug Killam, CDFG.

***Recommendations to Estimate Steelhead Abundance with Device Counters***

This plan recommends quantifying the uncertainty in Vaki Riverwatcher, DIDSON, and traditional video cameras (fish device counters) count data when used to obtain estimates of total abundance from the counts. Fish device counters should be calibrated to the manufactures guidelines and installed in the optimal location for monitoring all passing fish.

Each type of fish device counter has sources of counting errors that may affect estimates of the number of fish passing the device counter.

There are at least six types of counting errors that may affect estimates of the number of fish passing by a device counter:

- **Missed counts**: A missed count occurs when a fish passes the device counter but is not recognized. The fish may pass the device too quickly for an image to be recorded or turbidity may cause the sensors to fail. A missed count may also occur when two fish cross the device counter but only one fish is recorded. Periods when the device counter is malfunctioning or inoperative will result in missed counts.

- **False counts**: A false count occurs when another object is mistaken for a fish (e.g. waterfowl, muskrats, leaves, sticks, or bubbles).

- **Mixed counts**: A mixed count can occur when a species other than the target species is recorded and is not correctly identified.

- **By-passed counts:** By-passed counts are the result of the target fish swimming around the device counter and are never in the range within which the fish can be recorded. This type of error can occur during high water events or when the device counter has not been installed in a constricted enough area and the range of the counter is not adequate to detect all fish which migrate past the device. The range of accurate counts will depend on correct installation and aiming the device counter at the correct tilt angle for a given bottom topography, depth and stream width.

- **Double counts**: Double counts occur when fish which have been counted once drop back below the device counter, and then again enter the range of the device counter and are counted for a second time.

- **Observer or technician errors**: Errors can be made by the individual(s) processing the images or device counter data. For example, a file may become corrupted or lost, or the observer may under- or over-count fish. Both within and between observer errors are possible.

This plan recommends using at least three methods to assess the accuracy and variability of the device counter data. Details of the recommended field and data analysis methods are described in Appendix B. The first methods relies on comparing device counts to paired visual counts from a counting tower, using groups of fish allowed to pass through a weir (Holmes et al. 2006). The second method relies on comparing device counts to paired visual counts from a counting tower using unconstrained steelhead (Holmes et al.

2006). The third method for assessing device counter accuracy and variability involves the use of artificial targets or tethered fish that can be passed across the recording field at measured turbidity, depths and distances from the device in order to evaluate the error rate. Alternatively, a DIDSON unit could be paired with another device counter for a certain number of trials. Since the DIDSON is not limited by the range of turbidity expected for Central Valley streams, the counts from the two devices can be compared, using the DIDSON count as truth. Staging trials in which target-species and non-target species, either free or tethered, are released through the range of a video camera will be used to assess video performance in recognizing the target species and presence/absence of an adipose fin.

**Redd Surveys**

Redd counts are commonly used for monitoring annual trends in the abundance of spawning salmonids. However, if redds are not detected with 100 percent accuracy, counting errors may obscure important population trends (Maxell 1999). In addition, in order to estimate fish abundance using redd counts corrected for observer error one must also estimate the number of females per redd and the ratio of females to males in the population.

This plan recommends the field methods and data analysis methods described in Appendix C to be used for obtaining a total steelhead redd count for a watershed and using this count to estimate total abundance with redd survey data. In order to estimate total abundance with accuracy and precision, redd retention rates, observer error, missed surveys, the number of females per redd, and the ratio of females:males must be accounted for.

# CHAPTER 5

## RECOMMENDED MONITORING FOR THE NORTHWESTERN CALIFORNIA DIVERSITY GROUP: CLEAR CREEK AND COTTONWOOD CREEK

The Northwestern California Diversity Group includes tributaries to the Sacramento River that drain the eastern slopes of the Northern California Coastal Mountain Range (Sweany Creek, Putah Creek, Cache Creek, Stony Creek, Elder Creek, Thomes Creek, Cottonwood Creek, Beegum Creek, and Clear Creek).

Historically, the upper reaches (highest elevation reaches) of all tributaries in the Northwestern California diversity group are thought to have contained suitable habitat for steelhead spawning and juvenile rearing (Lindley et al. 2006). The lower reaches that run through the foothills and valley floor did not contain spawning habitat and typically became too warm in the summer to support juvenile rearing.

Steelhead have access to the mouths and lower reaches of all CV rivers (fish access to higher elevation reaches is blocked by dams) in the Northwestern California Diversity Group. Extant populations of steelhead are believed to occur in Clear Creek and Cottonwood/Beegum Creeks (NMFS 2009). These extant populations are characterized as having a moderate to high potential to support steelhead recovery (NMFS 2009). NMFS (2009) identified Clear Creek, Cottonwood/Beegum Creek, and Thomes Creek as priority watersheds for the recovery of steelhead. The lower elevation reaches of the other rivers in the diversity group are intermittent (due to water withdrawals), lack suitable spawning gravels, and are typically too warm in the summer months to support juvenile rearing.

This monitoring plan recommends intense monitoring for steelhead populations in Clear Creek and Cottonwood Creek. Recommended protocols for estimating adult abundance using device counters or redd surveys (Chapter 4) should be incorporated into the recommended monitoring programs described below. This plan recommends monitoring for steelhead for the other rivers in the Northwestern California Diversity Group through the recommended distribution surveys described in Chapter 3.

### CLEAR CREEK

Clear Creek was identified as having a high potential to support a viable independent population of steelhead (NMFS 2009). Steelhead redd surveys conducted since 2001 in Clear Creek indicate a small but increasing population (USFWS 2007). Clear Creek has been the target of numerous habitat restoration activities over the past few years which have included increased base flows, spawning gravel injections, riparian restoration, bank stabilization, and dam removal (Saeltzer Dam) (Newton and Brown 2004). The USFWS has an ongoing monitoring program on Clear Creek to investigate the response of anadromous salmonids to these restoration activities (including redd surveys for adult

Chinook salmon and steelhead and a rotary screw trapping operation for monitoring juvenile salmonid abundance). Steelhead spawning distribution has increased from the upper 4 miles to throughout the 18 miles of Clear Creek, with concentration in areas with newly injected gravel (USFWS 2008a). Hatchery steelhead (i.e., adipose fin-clipped) were not observed during the 2003-2007 redd surveys, suggesting straying rates of hatchery steelhead are likely low (USFWS 2008a).

This monitoring plan recommends the installation of a weir and fish device counter (i.e., Vaki Riverwatcher or video cameras with a DIDSON) to estimate steelhead abundance in Clear Creek. Currently, the USFWS monitors steelhead in Clear Creek using a kayak and snorkel-based redd surveys. The fish device counter will allow the USFWS to compare their redd survey estimates to the device counter estimates. The USFWS should continue their redd surveys from river mile 1.7 to Whiskeytown Dam to examine spawning distribution and for evaluation of their habitat restoration and enhancement efforts. Clear Creek, unlike other tributaries in the Northwestern California diversity group experiences stable flows year round and suitable water temperatures for summer rearing of juvenile steelhead (Newton and Brown 2004). Whiskeytown Dam, located at river mile 18.1, fully controls flow into the mainstem of the creek, limiting flashy flood flows. The summer water temperature in Clear Creek is maintained at a lower average temperature than most other Northwestern California diversity group tributaries via cold water from the Trinity River that is diverted into Whiskeytown Reservoir. Flow-temperature models for Clear Creek have indicated that suitable summer rearing temperatures can be achieved at flows as low as 150 cfs (Newton and Brown 2004).

COTTONWOOD CREEK

The Cottonwood Creek Watershed, including three main tributaries, the South Fork, North Fork, and Beegum Creek, has a moderate potential to support a viable population of steelhead (NMFS 2009). Cottonwood Creek is a major tributary to the Sacramento River system that supports steelhead spawning (CH2MHILL 2007). Abundance estimates are not available, but *O. mykiss* are found throughout the watershed, and the watershed is designated as critical habitat for steelhead (Lindley et al. 2007). CDFG Region 1 recommended Cottonwood Creek for steelhead monitoring due to feasibility reasons and previous observations of steelhead in Cottonwood Creek.

A video monitoring station with video cameras, a DIDSON, and horizontal bar weir is recommended for monitoring steelhead in Cottonwood Creek from at least September through June. CDFG has monitored Chinook salmon and *O. mykiss* in Cottonwood Creek using a video cameras with a partial horizontal bar weir (Doug Killam; CDFG; Pers. Comm.; 2009). The video monitoring was stopped in December for the 2009 survey period due to lack of funding. To effectively monitor steelhead in Cottonwood Creek, the video station will need to be moved upstream in the watershed to avoid flashy floods in the winter that may damage the video weir (Doug Killam, CDFG, Pers. Comm., 2009). The video monitoring should be operated through June to ensure all upstream migrants are counted. A DIDSON is needed in conjunction with video cameras due to high flow and turbid water conditions. This river can be too turbid for use of video cameras even during dry years.

# CHAPTER 6

## RECOMMENDED MONITORING FOR THE BASALT AND POROUS LAVA DIVERSITY GROUP: COW CREEK, BEAR CREEK, AND BATTLE CREEK

The Basalt and Porous Lava Diversity Group includes tributaries to the Sacramento River that drain the southern and western slopes of the Cascade Range (Upper Sacramento River, McCloud River, Pit River, Little Cow Creek, South Cow Creek, Old Cow Creek, Clover Creek, Oak Run Creek, Bear Creek, and Battle Creek).

Historically, most of the tributaries in the Basalt and Porous Lava diversity group are thought to have contained suitable habitat for steelhead spawning and juvenile rearing (Lindley et al. 2006). At present, access to habitat in the main tributaries (Upper Sacramento River, Pit River, and McCloud River) is blocked by Keswick and Shasta Dams. Steelhead can still access the mouths and lower reaches of the rivers that join the Sacramento River below Keswick Dam (Little Cow, South Cow, Old Cow, Clover, Oak Run, Bear, and Battle Creeks).

This plan recommends intense monitoring for steelhead in Cow, Bear, and Battle Creeks. Recommended protocols for device counters (Chapter 4) should be incorporated into the recommend monitoring programs described below to estimate adult abundance. Other rivers in the Basalt and Porous Lava Diversity Group are recommended to be monitored through the distribution surveys described in Chapter 3.

### COW CREEK

The Cow Creek Watershed is considered to have a moderate potential to support a viable steelhead population (NMFS 2009). Empirical steelhead spawning estimates have not been calculated for Cow Creek; however CDFG estimated that historic spawning runs of up to 500 steelhead may have occurred (SHN 2001 as cited in NMFS 2009).

This monitoring plan recommends monitoring steelhead in Cow Creek from at least September through June using video cameras, a DIDSON, and a partial horizontal bar weir. Currently, CDFG uses a video monitoring station in Cow Creek to monitor Chinook salmon escapement (D. Killam, CDFG, Pers. Comm., 2009). Video monitoring was stopped for 2009 in December due to lack of funding. The video station would likely need to be moved up in the drainage to avoid massive flood wipeouts during winter months, and monitoring extended through June. In addition, a DIDSON will be needed to observe fish passage during turbid water events. Even during dry years, water may become too turbid to observe fish passage using video cameras alone (D. Killam, CDFG, Pers. Comm., 2009).

BEAR CREEK

Bear Creek is a tributary to the Sacramento River (possibly a Redding Area Tributary as identified by NMFS 2009) where a spawning steelhead population has been observed (D. Killam, CDFG, Pers. Comm., 2009). Steelhead spawning populations in Bear Creek were monitored by CDFG through the fall of 2008 and spring of 2009, and will be monitored from the fall of 2009 through the summer of 2010 ((D. Killam, CDFG, Pers. Comm., 2009). Though the final report is still forthcoming, preliminary results indicate that Bear Creek received a larger than expected steelhead spawning population (D. Killam, CDFG, Pers. Comm., 2009). The unexpectedly high spawning population observed in what was previously thought to be a sub-optimal stream highlights the need to expand our knowledge of steelhead spawning populations using distribution surveys (Chapter 3).

This monitoring plan recommends that steelhead in Bear Creek should continue to be monitored using video cameras and a horizontal partial bar weir from at least September through June. In addition, a DIDSON will be needed to monitor steelhead during periods of turbid water. Even during dry years, water may become too turbid to observe fish using video cameras alone (D. Killam, CDFG, Pers. Comm., 2009). Currently, a DIDSON is not being used on Bear Creek resulting in a lack of data during turbid water periods.

BATTLE CREEK

Battle Creek has been identified as a high potential to support a viable independent population of steelhead (NMFS 2009). Battle Creek has had persistent spawning populations of steelhead in both the north and south forks of Battle Creek. The creek exhibits suitable flows year round (average base flows of 500 cfs); the highest base flows of any tributary to the Sacramento River between Keswick Dam and the Feather River (Whitton et al. 2008). Flows in the creek are influenced primarily by precipitation and snowmelt, though both north and south forks receive considerable water inputs from springs flowing through basalt formations (Whitton et al. 2008). These same spring-fed tributaries help to maintain suitable water temperatures for juvenile rearing in the summer.

The Battle Creek watershed will be considered a conservation stronghold for steelhead once restored as described in the Salmon and Steelhead Restoration Project (NMFS 2009). Numerous Battle Creek habitat restoration activities are ongoing or planned for the near future including increased base flows, riparian restoration, bank stabilization, and dam removals. The USFWS has an ongoing monitoring program on Battle Creek to investigate the response of anadromous salmonids to these restoration activities (including redd surveys for adult salmonids and a rotary screw trapping operation for monitoring juvenile salmonid abundance). The presence of the USFWS weir and fish passage system at Coleman National Fish Hatchery on Battle Creek provides an exceptional opportunity to monitor immigrating steelhead.

This monitoring plan recommends that the population of steelhead in Battle Creek should continue to be monitored by USFWS at the Coleman National Fish Hatchery ladder using a fish trap and video cameras from at least September through June. As the recently reconstructed hatchery weir and fish trap is presumed to be "fish-tight", highly accurate counts are possible.

## CHAPTER 7

## RECOMMENDED MONITORING FOR THE NORTHERN SIERRA NEVADA DIVERSITY GROUP: ANTELOPE, MILL, DEER, AND BUTTE CREEKS, FEATHER, YUBA, AMERICAN AND MOKELUMNE RIVERS

The Northern Sierra Nevada diversity group includes tributaries to the Sacramento River that drain the western slopes of the Sierra Nevada Mountains (Paynes Creek, Antelope Creek, Mill Creek, Deer Creek, Big Chico Creek, Butte Creek, Feather River, Yuba River, Bear River, Auburn Ravine/Coon Creek, Dry Creek, American River, Cosumnes River, and Mokelumne River). The Northern Sierra Nevada and Southern Sierra Nevada diversity groups are split at the Mokelumne River. This division reflects the greater importance of snowmelt runoff to the southern group and distinguishes the diversity groups by Sacramento River or San Joaquin River basins (Lindley et al. 2007).

Monitoring steelhead in Paynes Creek, Big Chico Creek, Bear River, Auburn Ravine/Coon Creek, Dry Creek, and the Cosumnes River is recommended to occur through the distribution surveys described in Chapter 3. A few juvenile *O. mykiss* have been captured in a rotary screw trap on Big Chico Creek during 1999-2003, and very few *O. mykiss* have been observed during snorkel surveys for spring-run Chinook salmon (C. Garman; CDFG; Pers. Comm., 2010). The Pacific Gas and Electric (PG&E) and CDWR's (2009) draft Habitat Expansion Plan are recommending to improve steelhead and spring-run Chinook salmon passage in Big Chico Creek by repairing the Iron Canyon Fish Ladder. If this recommended action is implemented, more intense monitoring of the steelhead population in Big Chico Creek could be implemented at the fish ladder.

This monitoring plan recommends monitoring steelhead in Antelope Creek, Mill Creek, Deer Creek, Butte Creek, Feather River, Yuba River, and the American River. Recommended protocols for estimating adult abundance using device counters or redd surveys (Chapter 4) should be incorporated into the recommended monitoring programs described below.

### ANTELOPE CREEK

Antelope Creek has a high potential to support a viable population of steelhead and is considered a Core 1 recovery focus (NMFS 2009). Comprehensive abundance data is not available, but Antelope Creek is believed to support a population of steelhead (NMFS 2009). CDFG Region 1 biologists identified Antelope Creek as a steelhead bearing stream and recommended steelhead monitoring in Antelope Creek. The Pacific Gas and Electric (PG&E) and CDWR's (2009) draft Habitat Expansion Plan are recommending to improve steelhead and spring-run Chinook salmon passage in Antelope Creek by removing the instream low-water crossing structure at Paynes Crossing with a bridge.

This monitoring plan recommends monitoring steelhead in Antelope Creek using video cameras, a DIDSON, and a partial horizontal bar weir. A DIDSON in conjunction with video cameras will be needed to count fish during turbid water events. Even during dry years, the creek may become too turbid to observe fish passage using video cameras alone (D. Killam, CDFG, Pers. Comm., 2009).

MILL CREEK

Mill Creek has been identified as a conservation stronghold for the CV steelhead Distinct Population Segment, and with key recovery actions has a high potential for sustaining a viable steelhead population (NMFS 2009). In 2007-2008, immigrating adult steelhead were observed in Mill Creek using video monitoring (Killam and Johnson 2008). CDFG Region 1 biologists recommended steelhead monitoring in Mill Creek.

This monitoring plan recommends monitoring steelhead in Mill Creek using video cameras, a DIDSON and a partial horizontal bar weir from at least September through June. Steelhead monitoring for the fall of 2009 through the summer of 2010 is being conducted by CDFG using video cameras at the top of a fish ladder of a diversion dam (D. Killam; CDFG; Pers. Comm.; 2009). A DIDSON or a similar device will be needed to observe fish passage during turbid water events. Even during dry years, the creek may become too turbid to observe fish passage using video cameras alone (D. Killam; CDFG; Pers. Comm.; 2009). DIDSON was found to reliably estimate Chinook salmon escapement in Mill Creek during a pilot study examining the efficacy of DIDSON and a Biosonics split-beam system (Johnson et al. 2006).

DEER CREEK

Deer Creek has been identified as a conservation stronghold for the CV steelhead Distinct Population Segment, and with key recovery actions has a potential for sustaining a viable steelhead population (NMFS 2009). Steelhead monitoring data is lacking, however some juvenile outmigration data exists (NMFS 2009). Deer Creek was identified as a priority stream in the AFRP Final Restoration Plan, where five actions were recommended to increase the production of anadromous fish (USFWS 2001). CDFG Region 1 is aware of steelhead presence in Deer Creek and recommended monitoring.

This monitoring plan recommends monitoring steelhead in Deer Creek using video cameras, a DIDSON, and a partial horizontal bar weir from at least September through June. A DIDSON will be needed to count fish during turbid water events. Even during dry years, the stream may become too turbid to observe fish passage using video cameras alone (D. Killam, CDFG, Pers. Comm., 2009).

BUTTE CREEK

NMFS (2009) has characterized Butte Creek as having a moderate potential to support a viable steelhead population. Steelhead abundance estimates do not exist, however steelhead have been reported by CDFG personnel in angler catches (BCWC 1999). CDFG Region 2 recommended steelhead monitoring in Butte Creek.

This plan recommends monitoring steelhead in Butte Creek using a Vaki Riverwatcher system in the upstream exit of the fish ladder at Durham Mutual Diversion Dam (pending landowner approval) from at least September through June. This site was determined to be the most suitable for a Vaki Riverwatcher by representatives of the Vaki Riverwatcher Company (C. Garman, CDFG, Pers. Comm., 2010). Vaki Riverwatcher systems have been used successfully to enumerate fish passage in the fish ladders at Daguerre Point Dam on the lower Yuba River. A portion of the ladder exit may need to be blocked to narrow the exit and direct fish through the Vaki Riverwatcher system. The Durham Mutual Water Company has the ladders gated and an existing building with power. Pending landowner approval, a security lock box and solar panels would not be needed, reducing the cost of this program.

FEATHER RIVER

NMFS (2009) has characterized the Feather River below Oroville Dam, as having a moderate potential to support a viable steelhead population. The moderate potential is based on the presence of a hatchery-supported population that is known to naturally reproduce in the Low Flow Channel (between River Miles 59 and 67; NMFS 2009).

The California Department of Water Resources (CDWR) plans to install a resistance board weir with a fish device counter in the Feather River (J. Kindopp, CDWR, Pers. Comm. 2010). The weir on the Feather River is currently in the planning stages and should be installed in 2010-2011. A fish device counter at the weir is recommended for monitoring steelhead from at least September through June.

YUBA RIVER

The lower Yuba River, below Englebright Dam, is identified as having a high potential to support a viable population of steelhead (NMFS 2009). Potential of having a viable steelhead population in the lower Yuba River is high because (1) the river supports a persistent population and historically the largest naturally reproducing steelhead population in the CV (McEwan and Jackson 1996); (2) flow and water temperature conditions generally support all life stage requirements; (3) the river is not hatchery supplemented; (4) spawning habitat availability does not appear to be limited; and (5) the river exhibits high habitat restoration potential (NMFS 2009).

This monitoring plan recommends that the current monitoring of steelhead in the lower Yuba River be continued using the Vaki Riverwatcher systems located in the north and south fish ladders at Daguerre Point Dam (DPD). Monitoring at DPD occurs continuously all year long. The Vaki Riverwatcher systems captures still photos, silhouettes, and has the potential to be configured to capture short video clips or digital photos for each fish passage event. During turbid water conditions, the system may be unable to capture still photos, yet silhouette images are still captured. Further work needs to be done to investigate steelhead morphometrics so that silhouette images may be identified to fish species with a known range of statistical confidence.

The Vaki Riverwatcher systems on the lower Yuba River are powered by a series of solar panels and emergency back-up batteries. Prior to 2009, the system would shut down due to lack of power produced by the old solar panels. In 2009, the Anadromous Fish Restoration Program (AFRP) within the USFWS provided the funds to purchase new solar panels to effectively power the systems during extended rainy periods in the winter (peak steelhead immigration time).

In 2009 and the beginning of 2010, the lower Yuba River Accord's River Management Fund (RMF) was used to purchase a new Vaki Riverwatcher system for the north fish ladder at DPD, and new housing structures for the computers. The old system in the north ladder was moved to the south ladder due to better operation. The new system in the north ladder produces high quality images of steelhead and the presence of an adipose fin can be examined. Identifying steelhead and the presence of an adipose fin was difficult with the old system. The computer systems that control the Vaki Riverwatcher systems were attached to the fish ladders in locations vulnerable to environmental conditions (flooding from flash flood events and direct sunlight). RMFs were used to construct cement building on each side of the river to better protect the computer systems. All of these upgrades will enhance monitoring fish passage year-round.

## AMERICAN RIVER

The American River watershed is characterized as having a moderate potential to support a viable steelhead population (NMFS 2009). NMFS (2009) has given the American River a Core 2 recovery focus for steelhead. CDFG Region 2 recommended monitoring steelhead in the American River.

Video monitoring of fish in the American River is not possible due to both the large size of the river and high recreational use of the river by residents of the Sacramento metropolitan area. This plan recommends USBR to continue to conduct their steelhead redd survey described by Hannon and Deason (2005). Surveys should be conducted between December and April (or later depending on peak spawn timing). Crew members should fully survey both main and secondary river channels, as steelhead have been observed to select spawning locations in or near side channels (Hannon and Deason 2005).

## MOKELUMNE RIVER

East Bay Municipal Utility District (EBMUD) conducts redd surveys to enumerate Chinook salmon and steelhead redds in the Mokelumne River (Rible 2009). All known salmonid spawning habitat is surveyed from Camanche Dam to Elliot Road. Redd surveys are conducted weekly from the beginning of October through the end of March.

EBMUD monitors fish passage using video monitoring in the fish ladder at the Woodbridge Irrigation District (WID) Dam. The ability to video monitor depends on WID gate operations. When gates are down, fish do not need to use the fish ladder with video monitoring equipment, therefore total fish passage cannot be monitored. Currently, based on gate operations, video monitoring is possible half-way through the fall-run Chinook salmon immigration period. However, potentially by 2010-2011 EBMUD will be able to monitor through December (S. Del Real, EBMUD, Pers. Comm., 2010). Video monitoring in the fish ladder is not possible past December due to gate operations. Therefore, total steelhead passage cannot be estimated using the video monitoring.

This monitoring plan recommends that EBMUD continue to monitor steelhead using their redd surveys. In addition, EBMUD should continue to report steelhead passage observed at WID from video monitoring. In the future, this plan recommends examining the feasibility of installing a weir with a fish device counter above or below the WID dam to monitor steelhead.

# CHAPTER 8

## RECOMMENDED MONITORING FOR THE SOUTHERN SIERRA NEVADA DIVERSITY GROUP: CALAVERAS, STANISLAUS, TUOLUMNE, AND MERCED RIVERS

The Southern Sierra Nevada diversity group includes tributaries to the Sacramento River that drain the western slopes of the Sierra Nevada Mountains (Calaveras River, Stanislaus River, Tuolumne, Merced, Chowchilla River, Fresno River, Upper San Joaquin River, Kings River, Kaweah River, Kern River, and Caliente Creek). Though immigrating steelhead can still access the lower elevation valley and foothill reaches of the Calaveras, Stanislaus, Tuolumne, and Merced Rivers, they are prevented from reaching critical spawning reaches by impassible dams. NMFS has indicated that steelhead are currently extirpated from all waters in the diversity group that are upstream of the Merced-San Joaquin confluence (Chowchilla River, Fresno River, Upper San Joaquin River, Kings River, Kaweah River, Kern River, and Caliente Creek).

This monitoring plan recommends monitoring steelhead in the Calaveras, Stanislaus, Tuolumne, and Merced Rivers. Recommended protocols for estimating abundance using device counters or Redd surveys (Chapter 4) should be incorporated into the recommended programs described below. Monitoring in the other rivers of the Southern Sierra Nevada Diversity Group will occur through the recommended distribution surveys (Chapter 3).

### CALAVERAS RIVER

The Calaveras River was identified by NMFS (2009) as a Core 1 population with a moderate potential to support a viable steelhead population. In 2002, fisheries monitoring was initiated to provide information about *O. mykiss* in the Calaveras River. Emigration monitoring is being conducted using rotary screw traps, and a pilot study was conducted to examine the feasibility of using pit tags to evaluate *O. mykiss* life-history characteristics (http://sanjoaquinbasin.com). A snorkel survey conducted bi-weekly from mid-march to late-October, 2002 found densities of 100-200mm and 200-300mm O. mykiss to be low (< 1 fish/100m2) at the beginning of the survey and higher (9-13 fish/100m2) at the end of the season (Stillwater Sciences 2004). For the 2009-2010 survey year, 2,723 *O. mykiss* were captured in the rotary screw traps as of June 6, 2010 (FishBIO 2010). Zimmerman et al. (2009) confirmed that of the five out of the 957 fish examined for life history status using otolith Sr:Ca ratios along the transects of otoliths were steelhead. Of the five confirmed steelhead, two of the steelhead were from the Calaveras River. The CDFG, CDWR, Defenders of Wildlife, The Fishery Foundation of California, and the University of the Pacific are active in the restoration of the Calaveras River in cooperation with the USFWS Anadromous Fish Restoration Program (AFRP).

This monitoring plan recommends monitoring steelhead in the Calaveras River using a fish device counter and weir. Adult steelhead monitoring would provide additional information to the current monitoring efforts. Potentially an existing or future fish ladder at a barrier could be retrofitted with a fish device counter.

STANISLAUS RIVER

Large *O. mykiss* have been observed at a fish counting weir in the Stanislaus River (NMFS 2009). The resistance board weir on the Stanislaus River is owned by the Anadromous Fish Restoration Program (AFRP) within the USFWS; daily weir operation is contracted to FishBIO, a fisheries and ecological consulting group. Typically, the weir is operated from September through December annually (the main objective is to determine fall-run Chinook salmon escapement). However, if funds are available the weir is operated through June (C. Sonke, FishBio, Pers. Comm., 2010). The weir is equipped with a Vaki Riverwatcher system and is capable of capturing still images or short video clips of passing fish in addition to fish silhouettes created by the Vaki Riverwatcher.

This monitoring plan recommends monitoring steelhead in the Stanislaus River using the existing resistance board weir and Vaki Riverwatcher system. The survey period should extend through June to encompass the steelhead immigration and spawning period. There is anecdotal evidence from similar weirs in California that fish may be able to jump over the resistance panels and avoid the counting chamber (Tim Heyne, CDFG, Pers. Comm., 2008). Because of this, this plan recommends evaluating if fish are capable of jumping over the resistance board weir (this may be as simple as setting cameras to record the weir crest).

TUOLUMNE RIVER

The Tuolumne River has a potential to support a viable population of steelhead (NMFS 2009). Steelhead monitoring was required for the Don Pedro Project (FERC Project No.2299) in the lower Tuolumne River. "Bound counts" population estimate surveys using snorkeling were conducted in July 2008, March 2009, and July 2009 to estimate the abundance of juvenile (<150 mm) and adult (≥150 mm) *O. mykiss* (Ford and Kirihara 2009). The abundance of juvenile and adult *O. mykiss* populations with a 95% confidence interval was estimated to be 1,905 – 3,047 and 325 – 914 respectively.

A resistance board weir with a Vaki Riverwatcher system on the Tuolumne River is owned by the Turlock Irrigation District (TID) and operation is contracted to FishBIO. The weir and system was installed in 2009 to monitor fall-run Chinook salmon escapement. However, depending on funding, fish passage monitoring may continue through June (C. Sonke, FishBio, Pers. Comm., 2010).

This monitoring plan recommends using the existing weir and Vaki Riverwatcher system on the Tuolumne River to monitor adult steelhead from at least September through June to encompass the steelhead immigration and spawning period.

MERCED RIVER

The lower Merced River has a potential to support a viable steelhead population (NMFS 2009). Juvenile *O. mykiss* have been observed in the lower Merced River (Good et al. 2005), but population abundance data is lacking.

This monitoring plan recommends installing a resistance board weir and Vaki Riverwatcher system on the Merced River to monitor adult steelhead. Monitoring steelhead should be from September through June each year to ensure weir operation is conducted during the entirety of steelhead immigration and spawning period.

# CHAPTER 9

## AN OPTIMAL APPROACH TO STEELHEAD MONITORING

The following briefly discusses an optimal approach to steelhead monitoring but is considered outside the realm of realistic expectations for the near future. However, the concept of permanent monitoring stations is identified because fishery mangers should be alert for opportunities that could make the permanent-facility concept viable.

The monitoring strategies for adult steelhead outlined in Chapters 2-8 consist primarily of methods that have been proven successful in the CV, are realistic for immediate implementation, and have the likelihood of generating some measure of population status. Even if these methods only provide a measure of relative abundance, the strategy is useful for validating the current threatened status of the CV steelhead ESU. However, most of these monitoring techniques may not be suitable for monitoring steelhead during relatively high stream flows that are typical most years during adult steelhead spawner immigration.

A more aggressive monitoring strategy could involve the placement of fixed permanent structures in selected streams to allow adult and juvenile steelhead monitoring during all but the extreme highest stream flow levels. Such a structure would allow free flow of water but direct movement of fish through a counting chamber or live trap where direct observations and individual sampling could be conducted. An example of an adult salmonid monitoring structure not associated with a reservoir-impoundment dam is the fish ladder and monitoring facility at Coleman National Fish Hatchery on Battle Creek. The RBDD is an example of a structure constructed for the principal purpose of diverting water that incorporates a fish counting chamber as a secondary feature. Another example of a permanent monitoring structure but designed solely for the purpose of monitoring adult salmonids (not associated with a hatchery or dam) is the facility on the lower Shasta River within the Klamath River drainage. None of these structures are suitable for juvenile monitoring in their current form. However, consideration should be given to modifying the fish ladder at Battle Creek with a trap to monitor juveniles.

If fishery managers wish to implement the use of permanent or semi-permanent in-stream structures to monitor steelhead throughout a stream's flow regime, investigations should initially focus on the feasibility of modifying existing water diversion structures in key streams. Otherwise, some type of permanent structure would have to be constructed within the stream channel that does not significantly interfere with the flow of water. Either way, the challenges of design, permitting, funding, and stakeholder and public acceptance would be significant.

Permanent monitoring structures offer the opportunity to strengthen the ability to monitor steelhead using other methodologies. For example, a monitoring structure paired with a redd survey generates a stronger estimate of the relationship between the number of spawners and the number of redds, resulting in better population estimates from the redd survey. Life cycle stations located upstream of video monitoring stations allow better calibration of the video stations. The knowledge gained from these paired studies can then be applied to steelhead monitoring in other streams. Monitoring stations with built-in fish traps offer the opportunity to collect biological samples and recover tag data which can be used in the projects described in Chapter 11 (scales for life history analyses, genetic samples, PIT tag studies, or presence of CWT).

The implementation of permanent monitoring stations is the optimal solution for monitoring steelhead populations but requires significant agency and stakeholder initiative and funding. Other significant challenges to construction of permanent facilities include pre-project environmental impact reports, environmental permitting, landowner approval or land acquisition, engineering requirements, and safety issues, to name a few. Estimating costs for permanent monitoring stations is beyond the scope of this plan, but due to these concerns it is safe to assume each structure would cost several million dollars.

# CHAPTER 10

## JUVENILE STEELHEAD MONITORING IN THE CENTRAL VALLEY

Juvenile steelhead (steelhead rearing in fresh water or leaving the system) monitoring can provide valuable information for examining population status and evaluating habitat restoration projects. While juvenile data can be used to assess status, translating that data to adult abundance is not straightforward and requires substantial knowledge of local conditions—including typical survival rates and limiting factors McElhaney et al. (2000). Estimating the abundance of juvenile migrants is needed for estimating production and survival (NMFS 2009). Smolt production provides a measure of both a population's potential to increase in abundance and a population's ability to weather future periods of poor ocean conditions (McElhaney et al. 2000). Stage-specific abundance estimates for freshwater (eggs-to-smolts) and marine (smolts-to-adults) life-stages enable the examination of mortality between the life-stages, therefore partitioning survival among the life-stages (Volkhardt et al. 2007). Hypotheses can then be generated for examining restoration efforts on the population (Moussalli and Hilborn 1986). For example, McHugh et al. (2004) developed a simulation model to evaluate the improvement of egg-to-smolt survival rates for Chinook salmon with various habitat improvement actions in the Snake River. Juvenile monitoring can also provide information about the diversity of the population. Diversity traits that can be monitored at the juvenile life-stage include outmigration timing, size at outmigration, juvenile behavior, and genetic diversity (McElhaney et al. 2000).

California's Central Valley (CV) currently has at least 36 existing monitoring programs that monitor juvenile steelhead to some degree (Eilers 2008; Table 1). Juvenile monitoring programs exist in 17 watersheds, the mainstem of the Sacramento River, lower Sacramento River, San Joaquin River, North Delta, Central Delta, Lower Delta, San Francisco/San Pablo Bays, and Suisun Bay (Table 1). Various active and passive survey methods are used to monitor juvenile steelhead in these water bodies. Active methods include electrofishing, seining, trawling, snorkeling, and angling. Passive methods include: rotary screw traps (RSTs), fyke nets, and tagging (acoustic and pit tagging studies). Variables measured for each program varies, but some of the variables measured are: abundance, emergence timing, outmigrant timing, presence/absence, mortality, growth, recovery of marked fish, species richness, and diversity (Table 1).

The RST is the most common method used in the CV (17 programs; Table 1) for estimating abundance or production of juvenile Chinook salmon and steelhead, but has limitations. Eilers (2008) identified weaknesses for each existing monitoring program. Weaknesses vary somewhat for programs that use RSTs, but are similar overall. In most cases, capture rates for juvenile steelhead are too low to conduct capture efficiency tests, limiting the ability to estimate abundance or production with any meaningful confidence. Capture rates are low due to low numbers of juvenile steelhead present in the river; juveniles are large at emigration and can avoid the traps, or both. Some programs use trap capture efficiency estimates of Chinook salmon for steelhead, however tests have not been conducted to determine if using estimates from Chinook salmon is valid. On lower Clear Creek, steelhead fry numbers were high enough in 2008-2009 to conduct three capture efficiency tests (M. Brown, USFWS, Pers. Comm., 2010; Earley et al. 2009). Capture efficiency estimates for steelhead were lower than the estimates for Chinook salmon. Many programs do not generate abundance or production estimates and can only report steelhead presence, observed numbers, and relative abundance. The amount of time juveniles spend in fresh water varies from one to three years, while some juveniles never leave fresh water and mature as rainbow trout (IEPSPWT 1998). When juveniles emigrate at larger sizes, these fish are able to avoid the RSTs. CDWR (2002) found that most steelhead captured in RSTs on the Feather River were newly emerged (about 25 mm), and through dive surveys found that steelhead of 60 mm could avoid the RSTs in certain locations and water velocities. Most juveniles in the Feather River did not emigrate immediately after emergence and are believed to occupy a “home range”; therefore emigration did not occur when they were most susceptible to trapping (CDWR 2002). Another limitation of RSTs is that data gaps often exist because RSTs must be pulled from the river during periods of high flow to prevent fish mortalities, therefore examining changes in abundance or production over time could be difficult impossible. To further complicate juvenile monitoring, increased stream flow seems to be related to juvenile emigration and increased flows may “trigger” downstream migrations. In this situation, most juvenile fish are emigrating at a time when RSTs need to be out of the water to prevent the trap from being damaged (C. Harvey-Arrison, CDFG, Pers. Comm., 2008)

Monitoring programs were developed in the San Joaquin, Sacramento-San Joaquin Delta (near Chipps Island and at Sacramento) with the explicit purpose to monitor juvenile Chinook salmon using Kodiak or mid-water trawls (Eilers 2008). Larger fish (i.e., steelhead smolts) could be less susceptible to trawling techniques; therefore tow catches of steelhead may not accurately represent steelhead abundance or production. Currently, these existing programs capture and report a small number of steelhead smolts annually.

Electrofishing was used in Mill Creek, Deer Creek, Feather River, American River, Mokelumne River, Stanislaus River, and the Merced River to monitor juvenile steelhead in the past (Eilers 2008). Abundance cannot be estimated in Mill and Deer Creeks, as the surveys were conducted opportunistically and were not standardized. In addition, the main objective of the surveys was to examine emergence, rearing timing, and growth. Tagging studies conducted using electrofishing in conjunction with snorkel surveys was used in the Feather River to examine fish habitat use and growth. However, electrofishing was limited to side channels of the Feather River, due to the large size of the mainstem of the river. These surveys cannot estimate abundance. In the Mokelumne River, electrofishing and seines were used to monitor salmonid abundance, growth, feeding habits, and emigration timing. Electrofishing was conducted four times annually (January, May, July, and October), and seining is conducted monthly from January through June. Catch-per-effort is used to estimate relative abundance of juvenile steelhead in the Mokelumne. One potential drawback for using electrofishing in more rivers is difficulties in permitting due to the possibility of injuring threatened or endangered fish in anadromous salmonid waters. Electro-fishing juvenile monitoring surveys will conducted in June and August on the Tuolumne and Merced Rivers.

Snorkel Surveys are used to monitor juvenile steelhead in the Feather River (described above), Tuolumne River, and Stanislaus River (Eilers 2008). The Turlock and Modesto irrigation districts (Districts) have conducted snorkel surveys in the Tuolumne River for juvenile Chinook salmon and steelhead (rainbow trout) since 1982; however the survey methods have varied through the years (Ford and Kirihara 2009). During July 11-16, 2008, March 16-25, 2009, and July 9-14, 2009 the Districts conducted "bound counts" population estimate surveys for *O. mykiss* using snorkeling in a two-phase survey design (Ford and Kirihara 2010). A bounded count population estimator was used to estimate juvenile *O. mykiss* population estimates with 95% confidence intervals. Prior to 2008, density of *O. mykiss* in index areas of the Tuolumne River was calculated as the number of trout per 100 $m^2$ (Ford and Kirihara 2010). Snorkel surveys are conducted in the lower Stanislaus River to determine the distribution, abundance, and habitat use patterns of steelhead (rainbow trout; Kennedy and Cannon 2002). The Stanislaus River is surveyed bi-weekly year round from one mile below Goodwin Dam downstream to the vicinity of Oakdale, where the area is divided into eight reaches and two to four sites are surveyed per reach. Therefore, a total of 22 sites cover the range of habitat types within each reach. Relative abundance is calculated as the number of age-0 and age-1 trout per 100 $m^2$.

Seines are used to monitor juvenile salmonids in the Deer Creek, Stony Creek, American River, Mokelumne River, Merced River, Tuolumne River, and Sacramento-San Joaquin Delta and Tributaries. Seines in Stony Creek are used to capture fish daily from March-June annually at multiple sampling reaches between river mile 14 and river mile 19.5 (Eilers 2008). Fish counts are enumerated. Seines in conjunction with other survey methods were used in a study on the American River from 2006-2009 to determine environmental factors that contribute to *O. mykiss* life-history, abundance and density were calculated. Seines in conjunction with electrofishing are used to examine emergence timing, rearing conditions, and relative growth of juveniles in Deer Creek, where RSTs are used for enumerating fish. Seines in conjunction with electrofishing are used to index juvenile abundance in the Mokelumne River (described above). In the Merced River, seines in conjunction with electrofishing and minnow traps were used to measure relative abundance of juveniles using catch-per-effort from 200-2010. In the Tuolumne River, surveys are conducted at two week intervals typically from January through May at eight sites (Ford and Kirihara 2010). Low catches of young of the year and juvenile *O. mykiss* are observed, which is typical in the seine monitoring. Since 1976, seines have been used in the Sacramento-San Joaquin Delta and Tributaries to monitor long-term abundance and distribution for juvenile Chinook salmon and other special status fish entering the Delta (Eilers 2008). Larger fish (steelhead smolts) are less susceptible to seining techniques.

Fyke nets were used at the mouth of Stony Creek from 2001-2003 to estimate catch-per-effort based on the number of fish caught within the fyke nets and volume of water fished (Eilers 2008).

Monitoring juvenile steelhead to provide an index of population productivity and a basis for estimating juvenile abundance is difficult given the life-history characteristics of the species and the environmental conditions during the timing of emergence, rearing and emigration. After emergence, steelhead can leave a watershed as fry or stay for one to three years, potentially never leaving the system before spawning (IEPSPWT 1998). As steelhead become larger, they can avoid RSTs, trawls, and seines with unknown avoidance for fyke traps. RSTs with capture efficiency tests would provide data necessary to index population productivity and provide a basis for estimating juvenile abundance for a particular size or life-stage (i.e, yolk-sac-fry, fry, parr, silvery parr, smolt, adult), due to the efficiency of the traps. However, varying flows and turbidity levels could affect the ability of fish to avoid a trap. In addition to trap avoidance, juvenile steelhead numbers are low in many rivers; therefore capture efficiency tests cannot be conducted.

Snorkeling and electrofishing are methods that are used for indexing population productivity and estimating abundance for juvenile steelhead in the Mokelumne River, Stanislaus River and Tuolumne River. Use of electrofishing throughout the CV is unlikely due to the large size or rugged terrain of some rivers. In addition, permitting for electrofishing in anadromous salmonid waters may be difficult. Snorkel surveys may be a promising method for providing an index of population productivity and abundance for juvenile steelhead in other CV rivers. Some rivers may not have suitable conditions for snorkel surveys, such as rivers with naturally turbid water (e.g. Mill Creek).

This monitoring plan recommends that the current existing juvenile monitoring programs (Table 1) continue with their monitoring. Programs that were developed to primarily target Chinook salmon or identify the presence/absence of steelhead should continue to report numbers of steelhead observed. For those programs that use RSTs, capture efficiency tests should be conducted when numbers of steelhead are high enough to meet minimum requirements for mark-recapture efficiency tests. The USFWS Comprehensive Assessment and Monitoring Program (CAMP) has developed a draft RST protocol for Chinook salmon. When the CAMP RST protocol is finalized, this plan recommends using the protocol for steelhead monitoring with RSTs or a very similar protocol to the CAMP RST protocol. The CAMP protocol is being written with the intent to standardize data collection and analysis of RST data. Sampling periods identified in the protocol are for Chinook salmon. However, the protocols recommend RSTs in the upper Sacramento River basin to be operated year round. Over time, biologists will be able to discern which life-stages of juvenile steelhead can be captured and when trapping is most effective in the rivers they monitor. The USFWS (2008b) current draft RST protocol provides information for operating and maintaining the traps, conducting trap efficiency tests, and managing, analyzing, and reporting data. If capture efficiency tests cannot be conducted, the numbers of captured steelhead should continue to be reported.

This monitoring plan recommends examining the feasibility of conducting snorkel surveys in CV watersheds that are recommended for intense adult monitoring (Chapters 5, 6, 7, and 8) to provide an index of population productivity and juvenile steelhead abundance estimates, if other methods cannot be used. The Ford and Kirihara (2010) survey design could be used as an example. Snorkel surveys have limitations as well for monitoring juvenile steelhead. For conducting snorkel surveys, waters must have adequate visibility (Dolloff et al. 1996). Observing species and size of species could be difficult; therefore fish can be incorrectly identified or fail to be detected. Fish can be counted for more than once. Fish behavior during the night and day time could influence what is observed. Observers may vary on a crew and experience can change overtime, making observer bias difficult to account for when examining changes in abundance. A snorkel survey must be well designed to account for potential sources of bias and error with snorkel surveys.

Differentiating juvenile steelhead and resident rainbow trout is currently impossible and may never be possible, but distinction may be important because of the way the two forms are managed. This plan recommends conducting research studies to examine the life-history characteristics of *O. mykiss* (Chapter 11).

Table 1. Existing juvenile steelhead monitoring programs in California's Central Valley (Updated from Eilers 2008).

| Stream | Target Species | Monitoring Method | Variables Measured | Agency | Contact |
|---|---|---|---|---|---|
| Mainstem Sacramento River | All Chinook runs, steelhead | Rotary screw trap | Abundance, outmigrant timing | USFWS | Bill Poytress (530) 527-3043 |
| Mainstem Sacramento River | All Chinook runs, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Diane Coulon (530) 865-9331 |
| Clear Creek | All Chinook runs, steelhead | Rotary screw trap | Abundance, outmigrant timing | USFWS | Matt Brown (530) 527-3043 |
| Battle Creek | All Chinook runs, steelhead | Rotary screw trap | Abundance, outmigrant timing | USFWS | Matt Brown (530) 527-3043 |
| Mill Creek | Spring-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Colleen Harvey Arrison (530) 527-9490 |
| Mill Creek | Spring and fall-run Chinook, steelhead | Seining | Abundance, emergence timing | CDFG | Colleen Harvey Arrison (530) 527-9491 |
| Deer Creek | Spring-run Chinook, steelhead | Rotary screw trap | Relative abundance, outmigrant timing | CDFG | Colleen Harvey Arrison (530) 527-9490 |
| Deer Creek | Spring and fall-run Chinook, steelhead | Seining | Abundance, emergence timing | CDFG | Colleen Harvey Arrison (530) 527-9491 |
| Stony Creek | All Chinook runs, steelhead | Beach seine, fyke net | Presence/absence | USBR | Richard Corwin (530) 528-0512 |
| Butte Creek | Spring-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Tracy McReynolds (530) 895-5111 Clint Garman (530) 895-5110 |
| Lower Sacramento River | All Chinook runs, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Robert Vincik (916) 227-6842 |
| Lower Sacramento River | All Chinook runs, steelhead | Kodiak/mid-water trawl | Spatial / temporal distribution, outmigration timing | USFWS | Paul Cadrett (209) 946-6400 |
| Sacramento River and Feather River | Winter-run and spring-run Chinook, steelhead | Fyke nets and filtration boxes on diversions | Mortality associated with water diversions | NRS | Dave Vogel (530) 527-9587 |
| Feather River | Fall and Spring-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | DWR | Jason Kindopp (530) 534-2381 |
| Feather River | Steelhead | Snorkel, enclosures | Distribution, abundance, habitat use, growth | DWR | Jason Kindopp (530) 534-2381 |

Table 1. Continued.

| Stream | Target Species | Monitoring Method | Variables Measured | Agency | Contact |
|---|---|---|---|---|---|
| Yuba River | Fall-run, spring-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Tracy McReynolds (530) 895-5111 |
| American River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | CDFG | Mike Healey (916) 358-4334 |
| American and Mokelumne Rivers | Steelhead | Angling, seining, PIT tagging, acoustic tagging, | Environmental variables related to fish emigration | CDFG, UCSC, NMFS | Rob Titus (916) 227-6390 |
| Putah Creek | All species present | Electrofishing | Fish assemblages, environmental variables | UCD | Peter Moyle (530) 752-6355 |
| Lower Sacramento River, Lower San Joaquin River, North Delta, Central Delta, South Delta, San Francisco/San Pablo Bays | All Chinook runs | Beach seine | Abundance, outmigrant timing, recovery of marked smolts | USFWS | Paul Cadrett (209) 946-6400 |
| Suisun Bay | All Chinook runs | Mid-water trawl | Abundance, outmigrant timing, recovery of marked smolts | USFWS | Paul Cadrett (209) 946-6400 |
| Mokelumne River | Fall-run Chinook, steelhead | Seining and electrofishing | Distribution, abundance | EBMUD | Jose Setka (209) 365-1467 |
| Mokelumne River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | EBMUD | Jose Setka (209) 365-1467 |
| Mokelumne River | Steelhead | Acoustic tagging | Migration timing and paths, residency rates | EBMUD | Jim Smith (209) 365-1467 |
| San Joaquin River | Fall-run Chinook, steelhead | Kodiak trawl at Mossdale | Abundance, outmigrant timing | CDFG | Tim Heyne (209) 853-2533 |
| Calaveras River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | FISHBIO | Michele Palmer (530) 343-2101 |
| Stanislaus River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | FISHBIO | Michele Palmer (530) 343-2101 |
| Stanislaus River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing | USFWS CFS | Clark Watry (209) 847-7786 |
| Stanislaus River | Fall-run Chinook, steelhead | Snorkel survey | Spatial/temporal distribution, density | USBR | John Hannon (916) 978-5524 |

Table 1. Continued.

| Stream | Target Species | Monitoring Method | Variables Measured | Agency | Contact |
|---|---|---|---|---|---|
| Stanislaus River | Chinook and steelhead | Snorkel (primary) seining, | Abundance, environmental variables | USBR | Mark Bowen (303) 445-2222 |
| Tuolumne River | Fall-run Chinook, steelhead | Rotary screw trap | Abundance, outmigrant timing, recovery of marked smolts | TID | Tim Ford (209) 883-8275 |
| Tuolumne River | Fall-run Chinook, steelhead | Beach Seining, snorkel surveys | Abundance, outmigrant timing, recovery of marked smolts | TID | Tim Ford (209) 883-8275 |
| Merced River | Fall-run Chinook, *O. mykiss* | Rotary screw trap | Abundance, outmigrant timing, presence and absence | NRS, MID | Dave Vogel (530) 527-9587 |
| Merced River | Fall-run Chinook, *O. mykiss* | Rotary screw trap | Abundance, outmigrant timing, presence/absence | USFWS CFS | John Montgomery (209) 847-7787 |
| Merced River | Fall-run Chinook, *O. mykiss* | Rotary screw trap | Abundance, outmigrant timing | CDFG | Dennis Blakeman (209) 853-2533 |
| Merced River | Fall-run Chinook, *O. mykiss*, all other species present | Beach seine, minnow traps | Species richness, species diversity, habitat use | UCSB | Steve Zeug (805) 893-4989 |

# CHAPTER 11

# RESEARCH NEEDED FOR EFFECTIVE MANAGEMENT OF CV STEELHEAD

Though outside the objectives of this monitoring plan (abundance and distribution of steelhead in the CV), implementation of the following projects would greatly increase understanding of steelhead biology and likewise improve management of steelhead populations in the CV.

## *O. mykiss Life History*

Adequate data on the distribution and abundance of steelhead in the CV is not sufficient for assessing population and ESU viability because the effect of resident *O. mykiss* populations on the viability of steelhead populations is unknown (Lindley et al. 2007).

Little work exists to describe the relationship of anadromous and resident *O. mykiss* in CV rivers. Otoliths were collected from *O. mykiss* in the anadromous reaches of six CV watersheds, and otolith microchemistry was used to examine the occurrence of anadromous steelhead in those watersheds (Zimmerman et al. 2008 and 2009). Anadromous *O. mykiss* were found to be present in all six watersheds with the highest proportions in the upper Sacramento River and Deer Creek and the lowest in the San Joaquin tributaries. Zimmerman et al. (2009) recognized that they were unable to collect sufficient numbers of samples to determine the actual contribution of anadromous and resident *O. mykiss* in these rivers at any one time due to difficulty in obtaining otoliths (lethal sampling). Mitchell (2010) used scale analysis to examine age, growth, and life history of *O. mykiss* in the lower Yuba River. Scales were collected from juveniles and adults by trapping fish at the Daguerre Point Dam fish ladder, hook-and-line sampling, angler surveys, and rotary screw traps. Samples collected from trapping at the fish ladder indicate that 14 percent of the fish were steelhead, while only one percent of the fish caught by anglers were found to be steelhead. Mitchell (2010) attributed the differences in proportions of steelhead were likely due to the differences in the size composition of anadromous and resident forms and the size selectivity and efficiency of the sampling gears.

This plan recommends investigating the use of scale analysis to determine relationships between anadromous and resident *O. mykiss* populations. Scales can be quickly removed from the fish with little risk of injury to the fish. In addition, the scales can be analyzed relatively quickly without the added cost as needed for otolith preparation. However, Mitchell (2010) reported that scale analysis does have uncertainties and potential sources of error. Mitchell (2010) stressed the importance of good study design to minimize potential biases with size selectivity and efficiency of sampling techniques. A reference collection of known scale patterns and features of key life-history stages is required to verify scale readings. These features may differ from stream to stream, especially for juveniles. Tests could be developed to quantify the error of using scales to identify life-history status.

Scales will be collected from fish captured in the recommended mainstem mark-recapture study (Chapter 2), and scales could be collected if trapping fish was added to the video monitoring stations recommended in Chapters 5, 6, 7, and 8. In addition, scales could be collected from fish that are captured during juvenile monitoring (Chapter 10), at hatcheries, and fish observed during CDFG angler surveys.

A large number of otoliths would likely be needed to produce statistically meaningful results to examine the relationship between steelhead and rainbow trout in a given year. Due to the lethal means of otolith collection, a long term project designed to investigate anadromous and resident proportions of the population using otoliths should be initiated that encompasses long time periods (e.g. 10 to 20 years). Otolith collection would therefore be spread over several calendar years and multiple year classes of fish. Regardless of the duration of otolith collection, efforts should be made to minimize the take of live fish. Otoliths may be collected from carcasses found during other monitoring/research activities (such as dead fish washed onto weir panels), or collected from anglers during creel surveys.

The life history status of *O. mykiss* in CV Rivers could also be examined through tagging studies. Migration of juveniles could be examined by tagging them with passive integrated transponder (PIT) tags or acoustic tags and having an array of receivers in a river. An extensive array of acoustic receivers is already in place throughout the CV. For example, *O. mykiss* in the Merced River could be captured and tagged, and their behavior could be examined.

***Introgression of Hatchery Fish into Wild Populations/Hatchery Straying***

There is considerable concern among fisheries biologists and managers that "domesticated" hatchery steelhead may stray from the hatcheries where they were raised and spawn with wild populations, thereby influencing wild populations through hatchery selected traits.

Currently, identifying steelhead released from a hatchery is possible, as all CV hatcheries implement 100% marking of steelhead using an adipose clip. However, hatchery steelhead may spawn in-river with hatchery or wild fish. The progeny of these in-river spawning hatchery fish likely exhibit the effects of hatchery domestication selection, but lack a physical mark for identification. Genetic markers may be used to identify and measure the degree of hatchery genetic introgression into wild populations. Because genetic samples can be collected without killing the fish, every captured steelhead can be sampled, resulting in large sample sizes. These samples can then be compared to genetic profiles from known hatchery stocks. Garza and Pearse (2008) and Nielsen et al. (2005) provide baseline genetic databases of steelhead for future studies. Parentage-based tagging (PBT) is a recently developed intergenerational genetic tagging method that potentially could be used to investigate the impacts of hatchery fish on wild fish. With PBT, the broodstock at a hatchery or the in-river spawning adults (e.g. at a weir) are sampled and genotyped, and these genotypes provide genetic tags for all of their offspring. Garza and Anderson (NOAA, Pers. Comm., 2010) developed panels of 96 single nucleotide polymorphisms (SNPs) that are sufficiently powerful to implement PBT in California salmonid hatcheries for both Chinook salmon and steelhead. They envision a future data collection system for salmonid fishery management that integrates PBT with standard genetic stock identification (GSI), as an integrated PBT/GSI program which provides stock of origin for every fish, and exact parent pair (and therefore age) of all fish for which the parents were sampled.

Genetic tissue samples will be collected from fish captured in the mainstem Sacramento River mark-recapture program (Chapter 2); and could be collected if trapping was added to fish device counter stations recommended in Chapters 4, 5, 6, and 7. In addition, tissue samples could be collected from fish that are captured at the hatcheries as well as from fish sampled during the CDFG angler surveys. In addition, downstream migrant trapping of juveniles could be used to collect samples and determine the extent to which hatchery steelhead are spawning in natural areas.

Estimating the degree of hatchery straying may be possible by implanting coded-wire tags (CWT) into hatchery steelhead during production prior to release. Once the tag is recovered, the fish's hatchery of origin and brood year could be ascertained. Depending on available funding, all hatchery steelhead could be coded-wire tagged (current production goals are 1,730,000 steelhead annually for the four (4) hatcheries in the CV: Coleman, Feather River, Nimbus, and Mokelumne River Hatcheries). The actual cost of tagging fish with CWTs is relatively low (tags cost ~$0.10 per tag) and hatcheries in the CV have access to tagging trailers for automated CWT tagging (reducing labor costs to tag fish). However, the recovery of tags would be very difficult. The CWT must be removed from the fish's snout for reading; therefore the fish must be sacrificed. Typically hatcheries release steelhead after spawning as they may survive to spawn again. The few steelhead carcasses observed during mark-recapture carcass surveys for Chinook salmon could be collected, but the small sample size would not provide meaningful information. CWTs would have to be collected from harvested fish observed during the angler survey. Angler cooperation would be necessary for the project to work, and anglers may be hesitant to allow CDFG technicians to collect heads from their fish.

An alternative to CWT tagging would be to tag hatchery steelhead with passive integrated transponder (PIT) tags. These tags consist of a microchip embedded in a glass sheath and are considerably more expensive than CWTs (PIT tags cost ~$1 - $5 each depending on quantity ordered, labor is expensive as fish need to be tagged by hand. In addition, detecting PIT tags using handheld wands and stationary arrays are also expensive. PIT tags have advantages over CWTs, primarily that PIT tags can be read without sacrificing or cutting open a fish, and they are individual-specific. Furthermore, automated systems incorporated into weir structures, diversion dams, or other choke points in a river could provide automated readings of all tags that pass the structure.

Automated detection of hatchery PIT-tagged fish released into the Columbia River (tags are detected at each hydropower dam on the river) by Washington and Oregon hatcheries has provided invaluable information on survival, emigration rates, ocean survival, immigration rates, age at return, straying rates, and iteroparity. A project using PIT tags to estimate hatchery straying would be best served by deploying multiple automated PIT tag detectors throughout the CV, so that similar results could be obtained. PIT tagging of hatchery of fish is not worth the labor and PIT tag costs unless investments are made in these automated detectors. An array of receivers would also benefit tagging studies for other fish species in the CV.

# CHAPTER 12

# DATA MANAGEMENT

Fisheries management often uses data in a summarized or analyzed form. Storing and maintaining data in raw form allows data to be readily retrieved in the future for data users to verify analyses, perform data analyses on long-term datasets, synthesize data on a regional scale, and account for variance in the data for analyses and modeling.

Significant resources (i.e., time, money, and personnel) are used to collect Chinook salmon and some steelhead data in California's Central Valley (CV), therefore the data is valuable both monetarily and for fisheries management. Low (2007) reported that the CV adult Chinook salmon escapement monitoring programs cost annually approximately 3.7 million dollars and juvenile programs cost 5.7 million dollars. Annual personnel needs for the escapement monitoring programs are 22.8 and 45 person-years of biologist and technician time, respectively. The juvenile programs require annually 35.4 and 47.9 person-years of biologist and technician time, respectively. Significant additional resources will be required for implementation of the steelhead monitoring programs recommended in this plan (Chapter 14).

Obtaining raw field data for CV steelhead and Chinook salmon has been reported to be difficult (Williams et al. 2007; Kimmerer et al. 2001). The lack of a centralized data system and accompanying descriptions of methodologies has hindered fisheries evaluations, including assessing the recovery of listed species (Pipal 2005) and assessing the effectiveness of restoration actions designed to increase the natural production of Chinook salmon and steelhead (D. Threloff, USFWS, Pers. Comm., 2010).

Data management for the existing steelhead and Chinook salmon monitoring programs varies between agencies and for individual programs within agencies. Data are maintained in a variety of ways. Some programs retain paper data sheets and only summaries of the data are recorded digitally, some enter all or most field data to spreadsheets (e.g. Microsoft Excel) or database applications (e.g. Microsoft Access). Data quality assurance and control procedures are often not reported, completely lacking, or vary in inconsistency, which makes it difficult determine the quality of the data. Annual reports may be difficult to obtain, where programs make reports available upon request, post to individual websites, email to specific individuals, or submit to CalFish. CalFish is a cooperative program involving a growing number of agency and organization partners. CalFish's mission statement is to create, maintain, and enhance high quality, consistent data that are directly applicable to policy, planning, management, research, and the recovery of anadromous fish and related aquatic resources in California; and provide data and information services in a timely manner in formats to meet the needs of the end users.

The method chosen to maintain data by individual CV monitoring programs is likely due to available resources (i.e., time, money, and personnel). In addition, sometimes managers and biologists tend to minimize the concept that data maintenance and management require a carefully conceived planning and implementation process. Summarizing data on paper data sheets and archiving those data sheets requires much fewer resources than entering raw or summarized data into a spreadsheet or a database application. Creating a database application requires the largest amount of resources because biologists are less likely to be familiar with developing databases.

A comprehensive monitoring plan would not be complete without addressing the need for managing all of the data collected from the recommended steelhead monitoring programs. Soon multiple agencies and biologists within agencies will be implementing monitoring programs recommended in the CV steelhead monitoring plan. These monitoring programs will produce volumes of data spanning multiple years. Monitoring programs require a great deal of effort and expense; the data generated by them should be valued and protected.

The mark of good science is that the data from a scientific study (e.g. monitoring programs) can be used by other scientists to repeat the evaluation, and that the same results should be produced (Crawford and Rumsey 2009). In order for this to occur, data must be verifiably accurate, complete, consistent, and well documented. A well-designed data management system with standard data management protocols will help ensure that monitoring data are of the highest quality practicable and may be used with confidence to examine population trend and status.

This plan’s objective was to provide information and recommendations that will help form the foundation of a data management system for CV steelhead monitoring programs. Information was obtained through literature and acquiring information from several existing programs that collect and manage fisheries data.

### Recommendations for Development of a Data Management System

The goal of a data management system is to maintain, in perpetuity, data that results from monitoring programs (NPS 2008) to ensure high quality data standards. Standards include accuracy, security, longevity, and usability. Data management is complex and requires a carefully conceived data management system. An example of a comprehensive data management system is by the National Park Service (NPS 2008) for their Inventory and Monitoring Program. The NPS data management guidance document (NPS 2008) describes in detail their objectives, laws and policies, and details for multiple topics that should be addressed. These topics include: infrastructure (computers, servers, and hardware), architecture (applications, database systems, etc.), project management and the data life cycle (e.g., data collection, data entry, data archival, data reporting, etc), data management roles and responsibilities (e.g., biologists, agencies, and database architect), databases, quality assurance and quality control, data documentation, data ownership and sharing, data dissemination, records management, archiving, and implementation.

This plan recommends developing a detailed data management plan for the CV steelhead monitoring programs. A database architect will need to be hired during the implementation phase of this plan (Chapter 13) and work with the biologists and agencies that are monitoring steelhead to develop the data management plan. The Interagency Ecological Program (IEP) Central Valley Salmonid Project Work Team (PWT) is being recommended to provide the forum for the implementation phase of this plan (Chapter 13). The NPS (2008) guidelines for data management document provide an example of a plan. In addition SteamNet (2009) developed an outline for the components needed in a data management plan (outline provided in Appendix D). StreamNet is a cooperative information management and data dissemination project focused on fisheries and aquatic related data and data related services in the Columbia River basin and the Pacific Northwest. Their data management plan outline captures many of the components that a database architect and biologists will need to address. Components include: data capture, database systems, data quality control, reporting, data sharing, data security, etc. A discussion of some of these components is described below. A data management plan will help ensure that all components are addressed and decisions made for each component are well documented.

The cost to develop a data management system is beyond the scope of this plan. Costs will include the database architect (~$70,689 annually). Additional costs will include the development a centralized database management system. Costs will vary based on the type of system chosen (e.g., highly centralized or distributed type system described below) or if an existing database structure can be used. Cost estimates are provided from some existing database systems described in Appendix D (e.g., WDNR database costs about $250,000 annually to maintain and improve). The data management plan is expected to develop cost estimates and identify potential funding sources for the data management system.

***Data Capture***

Paper data sheets are traditionally used to capture fisheries data in the field; however capturing data on electronic devices is becoming more popular and have many benefits compared to paper data sheets. Electronic devices, such as a rugged tablet Personal Computer (PC) and a Personal Digital Assistant (PDA) improve the efficiency and quality of data recording, data quality control checking, and data entry (Appendix D). Applications can be developed for the electronic devices to efficiently record data, such as drop down menus and check boxes. In addition, quality control of the data can occur while recording data, where the application has established validation rules (e.g. length and weight limits for different fish species and flagging missing data in fields). With a paper data sheet, these errors may not be noticed until data entry in the office.

Data from electronic devices are easily imported into a database. Whereas, entering data on paper data sheets into a database is very time consuming. Proofing the data that was entered into the database is also time consuming and standard protocols for proofing methods may not exist. Proofing is essential for improving the quality of the data. Basic quality checks still need to be completed for data that was uploaded from an electronic device into a database; however these checks are completed using automated routines designed in a database application. Overall, electronic devices are more cost effective than paper data sheets (Appendix D). While there are upfront costs to purchase the devices and setup costs, there are cost savings for data entry and proofing. In addition, the devices allow data to be available immediately for analysis and report writing.

This plan recommends examining the feasibility of using electronic devices to capture data in the field for the recommended CV steelhead monitoring programs.

***Centralized Database Management Systems***

Archiving field data sheets is important for all programs, however an archived field data sheet is not recommended to be a primary data storage method. Quality control of data summaries is difficult. Data stored on datasheets does not allow analyses to be easily replicated and verified or additional analyses to be completed. Sharing data or responding to data requests is not efficient and may not be possible for large datasets. Individual paper datasheets within a large collection may become difficult to locate.

While Microsoft Excel spreadsheets are used to complete data analyses, spreadsheets used for storing and archiving raw field data has underlying problems and are not appropriate. Use of spreadsheets does not guarantee that data is managed consistently overtime. A new spreadsheet may be developed for each new field season. Over time, the design of the spreadsheet may change slightly or dramatically, so the spreadsheet from the first monitoring season may bear little resemblance to the most recent season. Spreadsheets often do not contain documentation or metadata needed to understand them. Data are likely not easy to pool across years nor are they easy to pool with similar data from other projects, therefore data becomes difficult and very time consuming to use. Data quality control is time consuming and data can become unknowingly erroneous if sorting functions of the software are used incorrectly.

Databases in Microsoft Access must be designed appropriately to have the desired benefits of managing raw field data in a relational database. A relational database is a collection of data items organized as a set of formally-described tables from which data can be accessed or reassembled in many different ways without having to reorganize the database tables, therefore providing efficiency and protection of the data. Relational databases are easy to extend, where a new data category can be added to a table without modifying all existing applications. Another advantage of developing a database in Access or another similar program is the ability to easily query data to look for data outside of expected ranges (e.g. length or weight limits for a species) and set value limits for fields (e.g. length or weight) that would flag the data entry person that the value is not acceptable. Access does not only allow an individual to query data into a format to export to Excel or other software program for analysis, but has capabilities to perform analyses. However, a database must be designed correctly to get the desired benefits of a relational database. Microsoft Access may also be used to develop a table for data storage, essentially a spreadsheet.

A centralized database system accommodates data from many separate locations pooling the data into a relational database at a single location. There are a variety of ways to create a centralized database system. In a highly centralized database, raw field data may be entered directly to the central server database. In this case, data do not reside on personal computers. Another type of centralized database system includes a central database, but in addition, stand alone applications (e.g. Access databases) distributed for use on personal computers. These distributed databases communicate with the central server database periodically to share data. Uploads to the central server may or may not be automated. If uploads are not automated then upload deadlines need to be established in a data management plan.

For both of the centralized database systems, front end applications are developed for working with specific types of monitoring data. These front end applications streamline data entry, basic analysis, reporting, download, and export processes. Data quality control features can be built into ether configuration and both systems require some manual checking of data. Thus quality control procedures would be similar. There are advantages and disadvantages to each configuration and some of these are presented in Appendix D; however, recommending one type centralized configuration over the other is beyond the scope of this document.

Costs go up and efficiency suffers when there is a lack of standardization or when distributed databases are modified. Both of the centralized database systems require identifying the data fields in advance. Individualized applications for a distributed type database requires require additional time and expense to develop, document, and maintain. Problems synchronizing or uploading data to the central database may result when unauthorized modifications are made to the distributed databases. Additional time to make adjustments and fix problems related to these modifications may quickly overtax staffing and result in cost overruns.

Data entered directly to a central database may seem to be less accessible to staff, however, summary and analysis functionality applications can be developed to facilitate working with the data within the database. Additionally, the application can be designed to offer data that is easily queried and exported to a personal computer for additional analysis. There may be a significant cost savings if data are entered to and stored directly to one server, rather than periodically with the distributed type system.

Benefits of a centralized database system include (FAO 2000): (1) ensure data conforms to standard classifications; (2) ensure the validity of the data; (3) ensure the data integrity and internal consistency; (4) secure and maintain primary data; (5) allow easy access to primary data; (6) process the data efficiently; and (7) allow different datasets to be integrated, thereby increasing their overall utility. A centralized database in the CV for steelhead data may foster peer review and discussion leading to collaboration, new research, additional analysis, and improved management decisions. Data collected incidentally for non-target species will also be readily available. These data are often not reported formally. These data include steelhead and steelhead redds observed during

Chinook surveys. They also include lamprey, sturgeon, and many other species observations.

This plan recommends that a centralized database system be created for and used by the steelhead monitoring programs throughout the CV. In addition, this plan recommends that those who implement creating the centralized database consider the recommendations received from database developers/managers of existing centralized databases (Appendix D). Similar recommendations are being drafted for a CV Adult Chinook Salmon Escapement Monitoring Plan's data management section. Field data collected for both species should be included into a single database if these recommendations are adopted by both the steelhead and Chinook monitoring programs. This is appropriate since similar methods are used to monitor both species. In addition, monitoring programs may be collecting data for both species. The front end applications will enable the user to identify information for each species and combining the two will save database development and maintenance costs.

This plan has not attempted to estimate development, implementation, and maintenance costs for either centralized database system. Cost information for a few of the example databases are provided in Appendix D. Likely, costs are higher for the distributed system. The additional costs may be minimal or at least minimized if the distributed databases are identical or nearly identical (i.e., few if any modifications) to the central database.

The database architect hired to create a centralized database system will need to work with biologists from multiple agencies and entities. They will need to determine which database type works best to meet the needs of the biologists and management. The database application should be designed specifically to capture the raw field data collected from the CV steelhead monitoring programs. Data fields will need to be identified for each survey method (potential fields are described in Appendix D). The application should be built to ease data entry and data management tasks. Additional functionality can be added to address summary, analysis, and reporting needs (potential data analysis and reporting needs are described in Appendix D). The database does not need to be made available to the general public although developing access is feasible. Data access and security will be identified in the data management plan described above. Other options for sharing data with the public are provided in the section below, "Sharing data with the public."

Juvenile steelhead and Chinook salmon are sampled with rotary screw traps (RST) operated in the mainstem Sacramento River and many tributaries of the Sacramento and San Joaquin rivers. The Comprehensive and Assessment Monitoring Program (CAMP) is currently working on a way to standardize and document the existing RST data so that consistent production estimates for Chinook salmon can be generated for existing juvenile RST monitoring programs. Data gathered for the CAMP program must be complete, accurate, and well documented. Changes implemented as a result of this effort will produce improvements to steelhead data as well. This plan recommends that all agencies operating RSTs collaborate with and support the CAMP's efforts to improve

RST data collection and reporting. This plan recommends that the database architect hired by the CAMP collaborate with the database architect hired for developing a centralized database for steelhead from the recommended monitoring programs.

## Data Reporting and Sharing

### *Annual reporting*

Annual reports for each CV steelhead monitoring program, and an annual summary report format of CV steelhead monitoring will need to be developed. Annual reports are produced for each CV Chinook salmon escapement monitoring program. In addition, the CDFG produces a summary of CV Chinook salmon monitoring activities (i.e., Annual Report Chinook Salmon Spawner Stocks in the California's Central Valley, 2004). This report has been produced annually since 1961. The report is a summary of the annual reports produced by the individual CV programs. Annual program reports and a similar summary report are essential for reporting the results of the CV steelhead monitoring programs.

This plan recommends that sufficient resources are available for completing the annual program and summary reports. This may require a dedicated position to compile and produce the annual summary report. There has been difficulty getting annual summarized reports for Chinook salmon escapement monitoring programs published within a year or two of the field season. For example, the most recent CV summary report is for the 2004-2005 season. Because this report compiles the annual reports from multiple programs, finishing reports is often delayed because one or more of the individual reports have not been finalized (J. Azat, CDFG, Pers. Comm., 2010). With funding shortfalls this will most likely continue to be a problem. Report writing often remains unfinished because report writing is secondary to collection of field data. (J. Azat, CDFG, Pers. Comm., 2010).

This plan recommends that all of the CV annual steelhead monitoring reports be posted to a common location for easy access by the stakeholders, including the public. A website, such as CalFish, would provide the means to centralize and organize these data. Currently, annual reports for Chinook salmon escapement monitoring in the upper Sacramento River Basin are published on CalFish. Additionally, CalFish is working to develop a new digital library component that will organize and offer a wide range of fisheries information (R. Carlson, PSMFC, Pers. Comm., 2010). CalFish is a cooperative program and some funding may be required to ensure that the CalFish program will continue. Funding would need to be acquired and maintained in order for this reporting approach to be successful.

### *Data Sharing*

The CalFish Abundance Database is recommended for developing, maintaining, and standardizing adult steelhead abundance estimates and hatchery return data to be made available to the public. The CalFish Abundance Database format is nearly identical to the StreamNet database format, used by Idaho, Oregon, and Washington. This database has already been used to store historic CV adult Chinook salmon escapement estimates with monitoring information from a variety of collection and estimation methods. The database provides sufficient detail to convey the relative accuracy of each population trend index record. In addition, spatial datasets are created and published to map viewers hosted by CDFG and CalFish. These spatial datasets summarize each trend or index and provide way to view the survey location and then access the detailed tabular data mentioned above. These spatial data are specifically designed for use in California and enable spatial queries of the data via the CalFish map viewer.

The Regional Mark Information System (RMIS) database formats are recommended for use to develop, maintain, and standardize hatchery release, recovery, and catch/sample data. Although hatchery steelhead are not currently coded wire tagged (CWT) in the CV, they are marked with an adipose fin clip which allows differentiation of wild and hatchery fish in the field. There is future potential for hatchery steelhead to be marked with a CWT or some other device such as a passive integrated transponder (PIT) tag. In either case, the RMIS formats are already available or may be modified to accommodate this information. While use of the RMIS formats will ensure that CV data are retained in standardized formats and will enable public access to these data via the RMIS website, the RMIS query system is outdated and difficult to master. Developing a new database query system to interface with RMIS standard data formats and present data that is in a user friendly format would benefit users. Technical assistance and a programmer would be needed to develop this new web application.

# CHAPTER 13

## IMPLEMENTATION AND ADAPTIVE MANAGEMENT STRATEGY

This monitoring plan provides a framework to examine the status and trends in abundance, as well as the distribution of steelhead in the Central Valley (CV), and was not intended to provide an implementation plan or work plan. Implementation of this long-term monitoring plan will be an additional phase needed for monitoring steelhead. Successful implementation of this monitoring plan will not be possible without the collaborative and dedicated efforts of multiple agencies and entities throughout the CV. Many factors will need to be addressed during the implementation phase, such as (1) governance (e.g. responsibilities, oversight, and coordination); (2) resource support (e.g. existing or new funding sources, technical support, dissemination of information, periodic external expert review); (3) priorities (e.g. decisions about the order of implementation of the plan's elements); (4) timelines (e.g. implementing recommended monitoring actions and data management, reporting results, evaluations); (5) and on-going evaluation and refinement of monitoring plan (e.g. evaluation if goal and objectives are being met, need for new objectives, need for changing monitoring actions or adding monitoring actions).

There are many constraints to monitoring steelhead, such as natural factors (e.g. environmental conditions) and institutional factors (e.g. limited funding, permitting). While this plan has identified likely the best monitoring programs to overcome these constraints, uncertainties will still exist regarding the ability to achieve the plan's objectives. Recommended monitoring programs with the same survey technique will likely have the same uncertainties. For example, video monitoring stations with a horizontal bar weir require particular stream features for installation. Sites have not been established for the recommended video monitoring stations, therefore installing all of the recommended stations is uncertain. Uncertainties for the recommended monitoring programs are listed in Table 2. Permitting will be required for all of the recommended monitoring programs (new permits or renewal of permits). This plan recommends that a plan coordinator (described below) help programs acquire permits needed to implement the monitoring programs.

This monitoring plan should be considered dynamic; the plan and individual monitoring programs will have on-going evaluation and refinement. Adaptive management will need to be incorporated as part of implementing the steelhead monitoring plan and associated monitoring programs. Adaptive management is an approach allowing decision makers to adjust, refine, or modify the plan and monitoring activities based on obtained information and needs for steelhead management. As information is obtained through monitoring and research, this plan may need to be modified to better achieve the goal and objectives. In addition, research and management may identify additional objectives and information needs for steelhead monitoring. After each monitoring program is implemented, results and information obtained will be evaluated to determine if the objectives and goal of the monitoring plan are being achieved. If they are being achieved, the monitoring program will continue. If a monitoring program is not providing the needed information, decisions will need to be made for future monitoring. Options for the monitoring program may include (depending of the information obtained): (1) modify the monitoring program (e.g. survey period, survey frequency, and study location); (2) continue with status quo; (3) implement a new monitoring program; or (4) terminate the monitoring program. Research and management could provide information to evaluate the monitoring programs, implement the options described above (e.g. new monitoring technique), modify the plan if additional data needs and additional objectives are identified or other new information is obtained (e.g. steelhead and resident rainbow trout are more defined). A conceptual model for an adaptive management strategy is displayed in Figure 8.

This plan recommends that the existing Interagency Ecological Program (IEP) Central Valley Salmonid Project Work Team (PWT) provide the forum for the implementation phase. The Salmonid PWT has established technical subteams, such as the Steelhead, Juvenile Monitoring, Salmonid Escapement, Genetics, and Upper Sacramento River Basin PWTs. The Steelhead PWT encourages, facilitates, and coordinates steelhead monitoring, research, and information dissemination, and provides a technical forum for CV steelhead. The Steelhead PWT meets semi-annually and team members include project leaders from various agencies and entities that are responsible for all of the existing steelhead monitoring programs in the CV, and researchers studying steelhead in the CV. Other PWTs provide similar functions and roles as the Steelhead PWT, focused on different topics. Team members of the other PWTs may need to be involved in the implementation phase.

Dedicated staff will be needed for the implementation of this plan. This plan recommends hiring a plan coordinator and database architect to work with the multiple agencies and entities involved in steelhead monitoring through the PWT meeting(s) and on an individual basis. Duties of the coordinators will include: (1) develop an implementation plan or work plan in collaboration with all of the agencies and entities involved in steelhead monitoring (factors listed above will need to be discussed and decisions documented within the implementation plan); (2) develop a data management plan or incorporate into the implementation plan a data management section with identified resources (i.e., money, time, and personnel) needed for implementation; (3) oversee that all annual reports are posted to an established central location; (4) write an annual summary report for all CV steelhead monitoring; (5) assist with acquiring funds for monitoring programs and the data management system; and (6) assist with adaptive management of the programs.

Biologists will need technical assistance for completing the recommended monitoring programs and data analyses described in this plan. This plan recommends hiring or contracting a statistician to be involved with the implementation of the plan from the beginning. The statistician will provide technical assistance at an annual workshop and throughout the year with individual biologists to carry out recommended monitoring procedures and analyze data. The annual workshop would be an interactive meeting for the statistician to assist and train biologists regarding data analysis, address questions regarding data analysis and data collection/study design for future years. In the end, everyone would be on the same page with all technical questions addressed.

Table 2. Uncertainties in the recommended monitoring programs in providing accurate and precise abundance estimates, trends in abundance, or spatial distribution in the Central Valley.

| Monitoring | River | Life-Stage | Uncertainties |
|---|---|---|---|
| Mark-Recapture Study | Mainstem Sacramento and San Joaquin | Adult | (1) Ability to capture steelhead; (2) Ability to recapture steelhead; (3) Installing and operating traps; (4) Sample size and recapture rates; (5) Size selectivity of the gear; (6) Funding |
| Distribution Surveys | Central Valley Rivers | Adult | (1) Environmental conditions; (2) Accessability to selected rivers (e.g., remote location, dangerous terrain, landowner access permisison);(3) Funding |
| Redd Survey | Clear Creek | Adult | (1) Environmental conditions; (2) Data gaps; (3) Probability to detect redds; (4) Low numbers of steelhead; (5) Funding |
| Redd Survey | American River | Adult | |
| Redd Survey | Mokelumne River | Adult | |
| Video Monitoring | Cottonwood Creek | Adult | (1) Environmental conditions; (2) Installing a weir (if applicable); (3) Shut-downs of video equipment; (4) Ability to identify fish species; (5) Precision and accuracy of software used to count fish (e.g., Winari, Digital Video Recorders); (6) Conducting validation tests (7) Funding |
| Video Monitoring | Cow Creek | Adult | |
| Video Monitoring | Bear Creek | Adult | |
| Video Monitoring | Antelope Creek | Adult | |
| Video Monitoring | Mill Creek | Adult | |
| Video Monitoring | Deer Creek | Adult | |
| Video Monitoring | Battle Creek | Adult | |
| Video Monitoring | Butte Creek | Adult | |
| Video Monitoring | Feather River | Adult | |
| Video Monitoring | Yuba River | Adult | |
| Video Monitoring | Merced River | Adult | |
| Video Monitoring | Stanislaus River | Adult | |
| Video Monitoring | Tuolumne River | Adult | |
| Rotary Screw Traps | Central Valley Rivers | Juvenile | (1) Environmental Conditions; (2) Low numbers of steelhead; (3) Ability to conduct efficiency tests; (4) Size selectivity of the gear; (5) Data gaps (due to high flows); (6) Funding |
| Electrofishing | Central Valley Rivers | Juvenile | (1) Environmental Conditions; (2) Size of rivers; (3) Ability to conduct efficiency tests; (4) Size selectivity of the gear; (5)Permitting; (6) Funding |
| Snorkeling | Central Valley Rivers | Juvenile | (1) Environmental Conditions; (2) Size of rivers; (3) Ability to conduct efficiency tests; (4) Size selectivity of the gear; (5) Data gaps (due to high flows); (6) Funding |
| Beach Seines | Central Valley Rivers | Juvenile | (1) Environmental Conditions; (2) Low numbers of steelhead; (3) Ability to conduct efficiency tests; (4) Size selectivity of the gear; (5) Data gaps (due to high flows); (6) Funding |
| Trawling | Central Valley Rivers | Juvenile | (1) Environmental Conditions; (2) Low numbers of steelhead; (3) Ability to conduct efficiency tests; (4) Size selectivity of the gear; (5) Data gaps (due to high flows); (6) Funding |

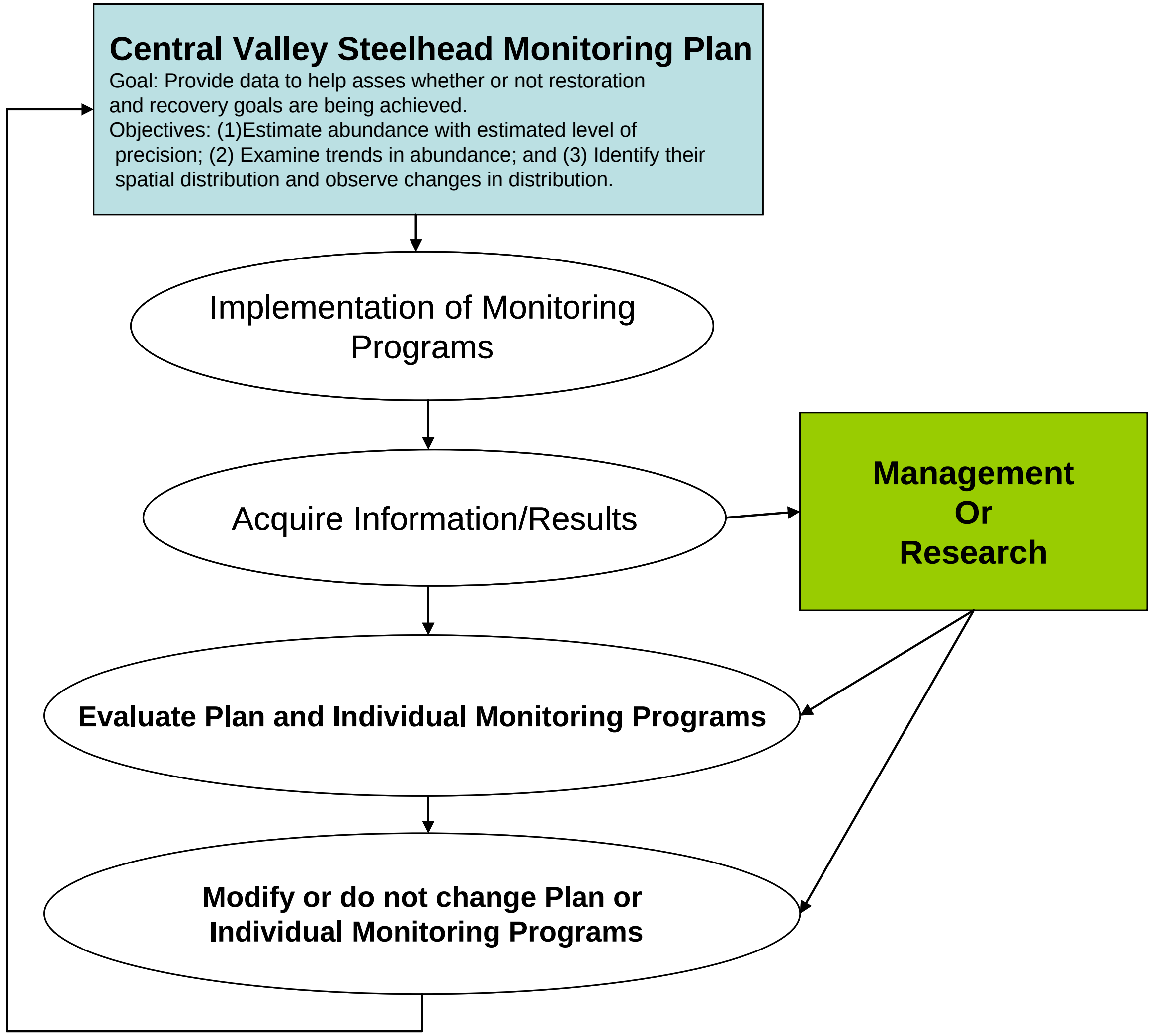


Figure 8. Conceptual model of the adaptive management strategy for the Central Valley steelhead monitoring plan and associated monitoring programs.

## CHAPTER 14

## COST ESTIMATES FOR RECOMMENDED MONITORING STRATEGIES

### New Monitoring Programs

Below are cost estimates for the recommended steelhead monitoring programs that will be new to the Central Valley. Cost estimates were identified for equipment, personnel, and operating costs. For some programs, cost estimates were determined from similar monitoring programs in place or through communication with lead biologists. For the other programs, personnel costs were determined using rates for a biologist with benefits ($25/hr and 0.28 benefit rate), technician with benefits ($16/hr and 0.28 benefit rate), and a temporary technician with limited benefits ($16/hr and 0.14 benefit rate) based on rates by the Pacific States Marine Fisheries Commission (PSMFC). In addition, an overhead cost was charged to all projects at a rate of 0.1248 (PSMFC) applied to project costs. These overhead rates did not apply to large equipment items, such as vehicles, boats, trailers, DIDSON units, Vaki Riverwatcher systems, etc. Travel costs were estimated using the state per diem rate for gas ($0.59/mile), lodging ($70) and incidentals ($46/day). Contingency costs were added to each project at a rate of at least 0.10 of the estimated project costs.

All of the cost estimates are estimates based on 2010 values, therefore upon implementation costs will need to become finalized based on the implementation of each recommended program. Existing equipment may be available, therefore costs could be reduced. For recommended programs using device counters, weirs may not be needed if hard structures are available (e.g. fish ladders of dam). In addition, a power grid and existing structure to house equipment may be available, all reducing costs of the programs. However, project costs can increase too. For example, construction of weirs depends on the costs of the materials (e.g. steel). Exchange rates may change between the US dollar and Icelandic króna when purchasing Vaki Riverwatcher systems. In addition, cost estimates for the distribution surveys are rough, extensive GIS and ground work must be completed to better determine the sample frame, sample units, length of sample units, and the number of sample units to survey annually.

### Mainstem Sacramento Mark-Recapture Study

#### *Pilot Study*

A three-month (August through October) pilot mark-recapture study should be conducted to assess uncertainties associated with the use of fyke traps for larger scale steelhead monitoring (e.g. injury rates, capture rates, capture potential, etc). Although the traps originally designed by Hallock et al. (1957) are no longer available, similar traps have been constructed by CDFG Region 3 to sample striped bass populations in the Sacramento River. Twelve traps are owned by CDFG Region 3; the proposed pilot study may be able to borrow these traps for the pilot study. Based on existing striped bass surveys conducted annually in the Sacramento River in April and May (during peak catches of striped bass), up to nine traps can be tended in an 8-hour day with an experienced crew of 3-4 people (M. Gingras and M. Harris, CDFG, Pers. Comm., 2009).

| *Labor –Pilot Study* | *Personnel Needs* |
|---|---|
| Trap construction (4 traps) | 2 weeks, 4 Technicians |
| Trap installation (4 traps) | 4 days, 4 Technicians |
| Tending traps (4 traps) | 3 months, 4 Technicians |
| Trap removal (4 traps) | 4 days, 4 Technicians |
| End of year trap repair | 1 month, 2 Technicians |
| Data QA/QC | 1 month, 1 Technician |
| Project Lead and Reporting | 8 months, 1 Biologist |

Based on above labor estimates, one technician will be needed for four months and three technicians for five months. A biologist will be needed for 8 months to complete reconnaissance work for trap placement, project oversight, and reporting. The total labor cost estimates for the pilot mark-recapture study on mainstem Sacramento River are estimated to be $110,826.

Costs for supplies, equipment, and operating expenses are estimated to be $97,415 (details described below).

Overhead charges are applied to personnel costs, operating costs, and most equipment costs (excluded are vehicles, boat, and trailer). Overhead was estimated to be $17,253.

| *Supplies, Equipment, and Operating costs – Pilot Study* | *Cost in USD* |
|---|---|
| Raw materials for constructing (4) traps | 4,000 |
| Measuring board (2) | 200 |
| Tagging gun (4) | 400 |
| Floy anchor tags (500) | 450 |
| Dip Nets (3) | 60 |
| Tagging gun needles (12) | 240 |
| Repair Materials (2x4 boards, hardware, etc) | 250 |
| Waders (5) | 450 |
| Wading Boots (5) | 350 |
| Life Vests (5) | 250 |
| Rain Gear (5) | 500 |
| Gloves (5) | 100 |
| Rite in the Rain Paper | 90 |
| Clip Boards (3) | 75 |
| Vehicle (4WD Crew cab pickup) | 30,000 |
| Boat and Trailer | 40,000 |
| Operating expenses (gas, maintenance, misc. equipment, computer, etc) | 20,000 |

| | |
|---|---|
| $110,826 | Subtotal (Labor) |
| $97,415 | Subtotal (Supplies and equipment) |
| $17,253 | Overhead |
| **$225,494** | TOTAL |

***Full Mark-Recapture Study Implementation***
Traps will be deployed in the Sacramento River. The trapping period should be scheduled to include the majority of steelhead migration period (August through November). The number of traps needed will depend on the results of the pilot mark-recapture study. Cost estimates are based on the assumption that four traps are sufficient for the study. A crew of four technicians will be needed to tend at least four traps on the Sacramento River. Traps will need to be operated on weekends. In addition, additional time will be needed for the preparation of the study, constructing traps, repairing equipment, data entry and data quality assurance quality control (QAQC), and report writing.

| *Labor – Mark-Recapture Studies* | *Personnel Needs* |
|---|---|
| Trap installation (4 traps) | 1 Week, 4 Technicians |
| Tending traps (4 traps) | 4 Months, 4 Technicians |
| Trap removal (4 traps) | 1 Week, 4Technicians |
| End of year trap repair | 1 Month, 4 Technicians |
| Trap construction (from scratch) | 2 Weeks, 4 Technicians |
| Data QA/QC | 1 Month, 1 Technician |
| Project Lead and Reporting | 11 Months, 1 Biologist |

Estimates for personnel include, 25 technician person months, and one biologist will be needed for 11 months. Total labor costs for one project year are estimated to be $149,557.

Supplies, equipment, and operating costs for the full implementation study are estimated to be the same as the pilot study costs described above, $97,415. Costs could be reduced if the same traps, vehicles, boat and trailer can be used from the pilot study. However, travel costs will be higher for the extra month of trapping.

Overhead was estimated to be $22,086.

| | |
|---|---|
| $149,557 | Subtotal (Labor) |
| $97,415 | Subtotal (Supplies and equipment) |
| $22,086 | Overhead |
| **$269,058** | TOTAL |

**Central Valley Wide Steelhead Distribution Surveys**

Cost estimates for the distribution surveys will depend on how much effort is needed to survey the randomly selected sample units. The number and reach length of the sample units is unknown. Sample units should be surveyed in random order; therefore travel costs will depend on the location of the sample units. To generate a cost estimate for the distribution survey, the reach length of the sample unit was assumed to be 2 miles, and the number of sample units selected annually was 75. Each unit was assumed to need surveying twice. Surveying one sample unit (2 miles) likely can be completed in one day. To complete this work, a crew of six people is recommended to travel the Central Valley and conduct the surveys. Depending on the river conditions, two to four person crews may be needed to conduct the surveys.

Extensive GIS work and ground survey work will be needed to identify the sample frames, sample units, and survey method to be used. Developing cost estimates to survey twice a subset of the sample units (20%) is difficult without knowing the number of sample units. The cost estimates presented below were developed based on surveying 75 sample units twice annually during steelhead spawning (November-March), and a crew of two to four people can survey one sample unit a day. Some sample units will only require two people to complete the survey, therefore for some days three sample units can be surveyed.

| *Labor – Distribution Surveys* | *Personnel Needs* |
|---|---|
| Pre-project GIS work | 12 Months, 1 GIS Specialist |
| Snorkel surveys | 6 Months, 6 Technicians |
| Project Lead and Reporting | 12 Months, 1 Biologist |

Estimates for personnel include 24 months of a biologist's rate and 36 months of technician time. Total labor costs are estimated to be $267,450.

| *Supplies, Equipment, and Operating costs – Distribution Surveys* | *Cost* |
|---|---|
| Dry suit (per person) | 1,500 |
| GPS unit (3) | 1050 |
| Wading boots (per person) | 70 |
| Dive hood (per person) | 30 |
| Neoprene socks (per person) | 15 |
| Neoprene gloves (per person) | 20 |
| Mask and snorkel (per person) | 35 |
| Dive slates or data recording devices (per person) | 10 |
| Dry bag/box (per person) | 15 |
| Vehicle (4WD Crew cab pickup) (6) | 180,000 |
| Operating costs (gasoline, misc. equipment, maintenance) | 160,000 |

Supply, equipment, and operating expenses for a crew of seven people are estimated to be $352,915. Equipment cost estimates per person are $1,695. Six trucks are needed for traveling to stream reach locations, crews working in teams of two will need to leave a truck at the downstream end of the survey reach. The bulk of the operating costs are for travel. The crew will need to travel throughout California's Central Valley to conduct the distribution surveys. The remaining operating costs are for miscellaneous supplies, equipment, computer, and unforeseen costs.

| | |
|---|---|
| $267,450 | Subtotal (Labor) |
| $352,915 | Subtotal (Supplies and equipment) |
| $54,958 | Overhead |
| **$675,323** | TOTAL |

**Video/DIDSON Monitoring**

***Cottonwood Creek –*** *Northwestern California Diversity Group*

***Cow and Bear creeks –*** *Basalt and Porous Lava Diversity Group*
***Antelope, Deer and Mill Creeks –*** *Northern Sierra Nevada Diversity Group*

This plan recommends that a dedicated crew carry out the video/DIDSON monitoring on Cottonwood, Cow, Bear, Antelope, Mill, and Deer creeks. One crew dedicated to video/DIDSON monitoring can effectively and efficiently monitor steelhead in these six rivers. If separate crews were established, costs would increase due to a need for more personnel and higher operating costs.

Cost estimates for monitoring stations will depend on site characteristics, site location and personnel experience. Video monitoring stations are less expensive if installed in existing structures because the cost of a weir is unnecessary. The width of the stream at a selected site has a large effect on video monitoring station costs, as a wide stream requires more weir panels to span the stream. Power is much cheaper if a site has access to a power grid than solar panels. Experienced personnel can install, maintain, and remove a video monitoring station more quickly than less experienced personnel.

Dedicated personnel in the field will be needed to install, maintain, repair, and remove each monitoring station. In addition, dedicated personnel will be needed for project management, reviewing video and DIDSON footage, data management, and report writing. The monitoring stations will operate during the steelhead migration period (September through June). Personnel will need to build and repair weir panels and equipment, and report results during July and August. Potentially, the crew could be used to monitor Chinook salmon during July and August (see cost sharing opportunities in Chapter 15).

Below are the estimated labor needs to conduct the tasks described above for the six monitoring stations. Total costs for personnel to oversee all six monitoring stations are estimated to be $444,392.

| *Labor –Video Monitoring* | *Personnel Needs* |
|---|---|
| Field work | 12 months, 4 Technicians |
| Video analysis, Data Management, Reporting | 12 months, 3 Technicians |
| Project Lead and Reporting | 12 months, 1 Biologist |

All equipment and cost estimates for a horizontal bar weir, video equipment, and labor needs are from experience building and operating video monitoring stations on Mill, Battle, Cow, Bear, and Cottonwood Creeks (Doug Killam, CDFG, pers. comm., 2009).

Equipment cost estimates presented below are for the equipment needed to construct one video monitoring station with a partial horizontal bar style weir. Cost estimates are based on 2009 costs (Doug Killam, CDFG, Pers. Comm., 2009). Solar power is assumed to be needed for each monitoring station, sites are unknown and this will prevent underestimating the cost of a monitoring station. In addition, each station is assumed to need 12 weir panels.

Total costs for a horizontal bar weir and video/sonar equipment for one monitoring station is estimated to be $152,210. Therefore the total cost for six video/sonar monitoring stations is estimated to be $913,260.

Total cost operating cost estimates are $278,000, details are described below. The bulk of the operating costs will be for travel and a spare DIDSON. Daily maintenance is required for each weir. These monitoring stations will likely be located in remote locations, therefore require extensive travel. A spare DIDSON unit is needed if another unit needs to be repaired. The remaining costs will be for vehicle and trailer maintenance, computers, training, miscellaneous equipment (e.g. welding equipment for building weirs, waders, DIDSON housing, cables), and unforeseen project costs.

Overhead is estimated to be $76,334.

| *Horizontal Bar Weir Equipment* | *Cost* |
|---|---|
| Weir panel – 10.5 feet in length (12) | 2,500 |
| White plates | 400 |
| Anchoring reinforcement (rebar) | 250 |
| Brace pipes | 400 |
| Overhead cables (support power, coaxial cables, lights, cameras) | 500 |
| Camera frames and attachments | 300 |
| Assorted hardware | 500 |
| Overhead lighting | 50 |

| *Video/Sonar Monitoring Equipment* | |
|---|---|
| Power cables | 200 |
| Coaxial cables | 300 |
| Underwater cameras (3) | 500 |
| Overhead camera | 150 |
| DIDSON | 100,000 |
| Digital video recorders + Storage hard drives (3) | 1,000 |
| Security cabinet | 20 |
| Video analysis equipment (3) | 39,000 |
| Back-up power supply (Batteries; 12) | 1,440 |
| Solar Power Panels (10) | 4,700 |

| *Operating Costs* | |
|---|---|
| Vehicles (4x4,3/4 ton, 1 short bed, 1 long bed, crew cab pickups, with caps) (3) | 90,000 |
| Utility trailer (1) | 3,000 |
| Operating costs (gasoline, misc. equipment, maintenance) | 185,000 |

| | |
|---|---|
| $444,392 | Subtotal (Labor) |
| $1,191,260 | Subtotal (Supplies and equipment) |
| $76,334 | Overhead |
| **$1,711,986** | TOTAL |

***Clear Creek Monitoring*** **–** *Northwestern California Diversity Group*

A fish device counter and weir is being recommended for monitoring steelhead in Clear Creek. Monitoring with a Vaki Riverwatcher System and Alaskan style resistance board weir is being considered by the USFWS in Clear Creek. The weir type and fish device counter that will work best for Clear Creek may change, but cost estimates presented below are for a Vaki Riverwatcher System and Alaskan style resistance board weir. Cost estimates for the weir were obtained by USFWS from Cramer Fish Sciences (M. Brown, USFWS, Pers. Comm. 2010). Personnel costs are a rough estimate for using USFWS employees (M. Brown, USFWS, Pers. Comm. 2010). Existing USFWS trucks can be used, therefore gasoline costs were based on USFWS rate ($0.18/mile) and traveling 80 miles per day. Costs are described below.

| *Fish Device Counter Monitoring Clear Creek* | *Costs USD* |
|---|---|
| Labor costs | 150,000 |
| Alaskan Style Weir | 105,000 |
| Vaki Riverwatcher System with digital cameras | 50,000 |
| Equipment (solar panels, security box, batteries, etc) | 10,000 |
| Contingency costs | 15,000 |
| Gasoline costs | 5,256 |

| | |
|---|---|
| $150,000 | Subtotal (Labor) |
| $185,256 | Subtotal (Supplies and equipment) |
| $22,496 | Overhead |
| **$357,752** | TOTAL |

***Butte Creek Monitoring** - Northern Sierra Nevada Diversity Group*

Monitoring with a Vaki Riverwatcher system in the fish ladder at Durham Mutual Diversion Dam is a new program. Personnel needs are described below and costs are estimated to be $90,840.

| *Labor - Video Monitoring Butte Creek* | *Personnel Needs* |
|---|---|
| Weir installation | 3 days, 4 Technicians |
| Weir removal | 1 day, 4 Technicians |
| Repair, Daily Maintenance, Video Analysis, and QC | 10 months, 1 Technician |
| Planning and Reporting | 2 months, 1 Technician |
| Supervisor | 6 months, 1 Biologist |

The monitoring station will require the installation of two weir panels (each approximately 10 $ft^2$), hardware, white plates and video equipment. The existing fish ladder and power grid supply reduces the cost of the weir. Weir equipment costs for Butte Creek are $3,900. Vaki Riverwatcher equipment costs are estimated to be $56,140 (details described below).

Operating costs are estimated to be $45,000.

Overhead costs are estimated to be $15,460.

| *Butte Creek Weir Estimates* | *Cost* |
|---|---|

| | |
|---|---|
| Panels (2) | 3,000 |
| Hardware (to attach panels to ladder) | 500 |
| White plates (provides contrasting background for video) | 400 |

| *Butte Creek Vaki Riverwatcher Equipment Cost Estimates* | *Cost* |
|---|---|
| Vaki Riverwatcher System | 50,000 |
| Back-up power supply (Batteries; 12) | 1,440 |
| Solar Power Panels (10) | 4,700 |

| *Butte Creek Operating Costs* | *Cost* |
|---|---|
| Vehicle | 30,000 |
| Operating costs (gas, maintenance, misc. equipment, computer, etc) | 15,000 |

| | |
|---|---|
| $90,840 | Subtotal (Labor) |
| $105,040 | Subtotal (Supplies and equipment) |
| $15,460 | Overhead |
| **$219,340** | TOTAL |

***Merced River**– Southern Sierra Nevada Diversity Group*

This plan recommends an Alaskan style weir be constructed on the Merced River. The site for the weir on the Merced River is unknown, therefore total cost for the weir is unknown. This plan recommends allocating $200,000 to build and install the weir and Vaki Riverwatcher system on the Merced River, and allocating $212,500 per year to monitor at the weir (assuming costs are similar to those reported for monitoring on the Stanislaus and Tuolumne Rivers described below). These costs will need to be re-evaluated during the implementation phase. FishBio and Cramer Fish Sciences construct and install these weirs in the CV and could provide their cost estimates once the site has chosen.

| | |
|---|---|
| $212,500 | Subtotal (Labor) |
| $200,000 | Subtotal (Supplies and equipment) |
| **$412,500** | TOTAL |

***Calaveras River**– Southern Sierra Nevada Diversity Group*

This plan recommends an Alaskan style weir be constructed on the Calaveras River. The site for the weir is unknown, therefore total cost for the weir is unknown. An existing fish ladder or a fish ladder constructed in the future potentially could be used to hold the Vaki Riverwatcher system, therefore reducing project costs. An allocation of $200,000 is recommended to build and install the weir and Vaki Riverwatcher system on the Calaveras River, and allocating $212,500 per year to for monitoring (assuming costs are similar to those reported for monitoring on the Stanislaus and Tuolumne Rivers described below). These costs will need to be re-evaluated during the implementation phase. FishBio and Cramer Fish Sciences construct and install these weirs in the CV and could provide their cost estimates once the site has chosen.

| | |
|---|---|
| $212,500 | Subtotal (Labor) |
| $200,000 | Subtotal (Supplies and equipment) |
| **$412,500** | TOTAL |

**Total Estimated Costs**

Below are the total estimated costs for each recommend new steelhead monitoring program. Annual cost estimates were calculated by summing start-up costs in year 1 for personnel costs, operating costs, and overhead costs. These annual cost estimates should be evaluated annually.

| | **Start-up Cost Year 1** | **Annual Cost Year 2+** |
|---|---|---|
| *New Steelhead Monitoring Programs* | *Cost in USD* | *Cost in USD* |
| **Sacramento Mainstem mark-recapture** | | |
| Pilot Study (3 months) | 237,935 | 148,079 |
| Full Implementation (4 months) | 269,058 | 191,643 |
| **Central Valley Steelhead Distribution Surveys** | 675,323 | 482,408 |
| **Cottonwood, Cow, Bear, Antelope, Deer, and Mill Creeks –** Video/DIDSON Monitoring | 1,711,986 | 705,726 |
| **Clear Creek** – Vaki Riverwatcher System and a Alaskan style weir | 357,752 | 191,504 |
| **Butte Creek –** Vaki Riverwatcher System | 219,340 | 121,300 |
| **Merced River** – Vaki Riverwatcher System and a Alaskan style weir | 412,000 | 212,000 |
| **Calaveras River** – Vaki Riverwatcher System and a Alaskan style weir | 412,000 | 212,000 |
| *Total cost estimates for new monitoring programs* | **4,295,394** | **2,264,660** |

**Total Costs for Recommended Implementation Staff**

A full-time database architect, plan coordinator, and statistician are recommended for implementation of the monitoring plan (Chapter 13). Annual costs are described below.

| | |
|---|---|
| $70,689 | Database Architect |
| $86,030 | Biologist/Plan Coordinator |
| $102,180 | Statistician |
| **$258,899** | TOTAL |

**Costs of Existing Steelhead Monitoring Programs**

Cost estimates were obtained for the existing steelhead monitoring programs described in Chapters 5, 6, 7, and 8 from project leaders.

***Clear Creek Monitoring –*** *Northwestern California Diversity Group*
The redd survey in Clear Creek is an existing monitoring program that is funded by USFWS at $75,000 annually. A detailed estimate of costs for this monitoring program is available from the USFWS Red Bluff office.

***Battle Creek Monitoring -*** *Basalt and Porous Lava Diversity Group*
Monitoring steelhead in Battle Creek is completed through an existing monitoring program (fish trap and video monitoring system) that is funded at $130,000 annually. A detailed estimate of costs for this monitoring program is available from the USFWS Red Bluff office.

***Feather River Monitoring -*** *Northern Sierra Nevada Diversity Group*
Funding for the Feather River Alaskan style weir and device counter equipment is secured by the CDWR. The costs to build and install with all necessary operating equipment are estimated to be between $350,000 and $375,000 (J. Kindopp, CDWR, Pers. Comm., 2010). The weir will include PIT tag readers. Electricity will be run to the site, and a field office and bunker will be built. Operating costs and data reporting are estimated to be $160,000 annually. A detailed estimate of costs for this monitoring program is available from the CDWR Oroville office.

***Yuba River Monitoring -*** *Northern Sierra Nevada Diversity Group*
Monitoring steelhead in the lower Yuba River using a Vaki Riverwatcher system in the North and South fish ladders at Daguerre Point Dam is an existing monitoring program funded by the Yuba County Water Agency (YCWA) through the Lower Yuba River Accord at approximately $75,000 annually. A detailed estimate of costs for this monitoring program is available from the YCWA office in Marysville.

***American River Monitoring –*** *Northern Sierra Nevada Diversity Group*
The American River steelhead redd survey is an existing program. Redd surveys are currently funded by the USBR on a yearly basis. The annual cost to monitor and write the report is $45,000 (J. Hannon, USBR, Pers. Comm., 2010). A detailed estimate of costs for this monitoring program is available from the USBR office in Sacramento.

***Mokelumne River Monitoring –*** *Southern Sierra Nevada Diversity Group*
The redd survey on the Mokelumne River is an existing monitoring program by EBMUD. Both Chinook salmon and steelhead redds are monitored weekly from October through March. Depending on the amount of spawning, three or two person crews survey the entire survey area in two days using a canoe. The annual cost of this survey, data processing and data analysis is about $45,000. A detailed estimate of costs for this monitoring program is available from the EBMUD office in Lodi.

***Stanislaus and Tuolumne Rivers –*** *Southern Sierra Nevada Diversity Group*
Monitoring on the Stanislaus River and the Tuolumne River with an Alaskan style weir and Vaki Riverwatcher system are existing programs. The weir on the Stanislaus River is owned by USFWS and the weir on the Tuolumne River is owned by Turlock Irrigation District. Operation and maintenance of the weirs is contracted to FishBio, a fisheries and ecological consulting group. Total costs for building the Tuolumne weir with the Vaki Riverwatcher system and solar

panels was approximately $145,000 (C. Sonke, FishBio, Pers. Comm., 2010). However, costs to build a weir and maintain a weir depend on the width of the river (length of the weir) and distance traveled to maintain the weir daily. Planning/permitting for the Tuolumne weir was budgeted for $31,000; although a little less was spent. Monitoring costs for one weir from September through January is about $20,000 per month during periods of normal flow/debris loads, and $30,000 per month during periods of high flow/debris loads (C. Sonke, FishBio, Pers. Comm., 2010). Monitoring costs for one system from February through June is about $15,000-$18,000 per month. Therefore, total annual monitoring costs for one weir from September through June is about $212,500 (assume 2 months of low flow, 3 months of high flow, and 5 months at an average of $16,500 per month). Depending on funding, operation of the monitoring station may be terminated in December (focus on Chinook salmon only). Therefore additional funds may be needed from December through June for steelhead monitoring. Detailed estimate of costs for these monitoring programs is available from the FishBio office in Oakdale.

**Total Costs for Existing Steelhead Monitoring Programs**

The total cost estimates for each of the existing monitoring programs is described below. These programs may need additional funds to incorporate the recommended protocols for device counters and redd surveys into their programs. During the implementation phase of this plan, these costs should be identified and additional funds obtained.

| *Annual costs for existing steelhead monitoring* | *Cost* |
|---|---:|
| **Clear Creek** – Redd survey | 75,000 |
| **Battle Creek** – Video monitoring | 130,000 |
| **Feather River –** Alaskan weir and device counter | 160,000[1] |
| **Yuba River** – Vaki Riverwatcher Systems | 75,000 |
| **American River** – Redd Survey | 45,000 |
| **Mokelumne River** – Redd Survey | 45,000 |
| **Stanislaus River** – Vaki Riverwatcher System | 215,500 |
| **Tuolumne River** – Vaki Riverwatcher System | 215,500 |
| *Total annual costs for existing steelhead monitoring* | **961,000** |

[1] The CDWR has dedicated funds ($375,000) to build and install the weir and a fish device counter. The program is anticipated to begin in 2010-2011.

# CHAPTER 15

# COST SHARING OPPORTUNITIES

## STEELHEAD AND CHINOOK SALMON MONITORING

With the exception of the recommended redd survey for the American River, all of the recommended steelhead monitoring programs include Chinook salmon monitoring. Overlap in these monitoring programs for steelhead and Chinook salmon present cost sharing opportunities. Therefore the estimated costs described in Chapter 14 for steelhead monitoring could be reduced if costs are shared with other funding sources. Cost sharing opportunities are recommended to be addressed during the implementation of this monitoring plan (Chapter 13).

All of the proposed video monitoring projects described in this plan also benefit Chinook salmon escapement monitoring, as Chinook salmon abundance can also be estimated, run timing examined, and length approximated. However, the survey period for steelhead is from at least September through June, and would likely be extended into July and August for Chinook salmon escapement monitoring. Therefore, the video monitoring stations would monitor year round.

In the Basalt and Porous Lava Group, video monitoring fish passage in Cow, Bear and Battle Creek would provide a primary abundance estimate for both fall-run and spring-run Chinook salmon. Currently, spring-run, fall-run and winter-run are monitored in Battle Creek using video monitoring. Only fall-run Chinook salmon are currently monitored in Cow and Bear Creek using video monitoring.

In the Northern Sierra Nevada Diversity Group, video monitoring of Mill, Deer, Antelope and Butte Creeks and the Feather and Yuba River will provide primary or secondary abundance estimates of fall-run or spring-run Chinook salmon. These estimates could be compared to estimates obtained from current survey techniques (mark-recapture carcass surveys, redd surveys or snorkel surveys) and potentially improve precision of abundance estimates. Video monitoring would provide a comparison for abundance estimates for fall-run Chinook salmon in Mill and Deer Creeks (mark-recapture carcass surveys), and spring-run Chinook salmon in Antelope Creek (snorkel survey), Mill Creek (redd survey), Deer Creek (snorkel survey) and Butte Creek (snorkel survey and mark-recapture survey). Video monitoring at the segregation weir in the Feather River would likewise help establish a population estimate for spring-run Chinook salmon, where the current mark-recapture carcass survey produces an estimate for Chinook salmon and is reported as fall-run. Chinook salmon are already monitored year round at Daguerre Point Dam (DPD) on the lower Yuba River, and these fish passage counts can be compared to the mark-recapture carcass survey estimate for above DPD (Chinook salmon spawn below DPD).

In the Northwestern California Diversity Group, video monitoring is already being conducted on Cottonwood Creek for fall-run Chinook salmon and Beegum Creek (tributary to Cottonwood Creek) for spring-run Chinook salmon escapement monitoring. A fish device counter on Clear Creek could be used to monitor steelhead and spring-run, fall-run, late-fall, and any winter-run Chinook salmon.

In the Southern Sierra Nevada Diversity Group, fall-run Chinook salmon escapement is currently being monitored using mark-recapture carcass surveys in the Mokelumne, Stanislaus, Tuolumne, and Merced Rivers. In addition, escapement is being monitored using video monitoring on the Mokelumne, Stanislaus, and Tuolumne Rivers. Video monitoring on the Merced River would be a new escapement monitoring program for Chinook salmon. Restoration of the San Joaquin River has goals of self-sustaining Chinook populations and restoration of spring-run Chinook salmon to the San Joaquin River and its tributaries. Monitoring of the San Joaquin River and its tributaries (Stanislaus, Tuolumne, and Merced Rivers) is the only way to assess progress towards these goals.

The recommended kayak and snorkel-based redd survey for Clear Creek is an existing monitoring program. The survey monitors both steelhead and late-fall run Chinook salmon.

Another cost sharing opportunity between steelhead and Chinook salmon monitoring would be the development of a salmonid data management system, including the development of a centralized database (Chapter 12). Recommended monitoring programs for steelhead will collect Chinook salmon data, and vice versa. Video monitoring, redd surveys, snorkel surveys, and juvenile monitoring programs could collect data for both species. In addition, the database can be designed to maintain data collected from monitoring programs that target only steelhead or Chinook salmon (i.e., steelhead pilot mark-recapture study, distribution surveys, Chinook salmon mark-recapture carcass surveys, etc.).

Staff/Personnel recommended for the implementation of the steelhead monitoring program (Chapter 13) could be used for the implementation of the forthcoming Adult Chinook Salmon Escapement Monitoring Plan. Again, the data management system could be designed to accommodate both plans. The biologist/plan coordinator would be working with many project leaders that monitor both steelhead and Chinook salmon, potentially using the same monitoring program (e.g. redd survey on Clear Creek). The statistician would provide technical assistance to help implement recommended studies and estimate steelhead abundance and Chinook salmon escapement using the recommended procedures in the monitoring plans.

# LITERATURE CITED

[BCWP] Butte Creek Watershed Conservancy. 1999. Butte Creek Project: existing conditions report, California State University Chico. Available at: [http://battlecreekwatershed.org]

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for detecting and estimating the size of migrating salmon. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Data Series 07-44, Anchorage.

[CDWR] California Department of Water Resources. 2002. Emigration of juvenile Chinook salmon in the Feather River, 1998-2001. Oroville, CA.

[CDWR and PG&E] California Department of Water Resources and Pacific Gas and Electric Company. 2009. Habitat expansion plan for Central Valley spring-run Chinook salmon and California Central Valley steelhead – draft habitat expansion plan (ICF J&S 0085408). Sacramento, CA. November.

CH2MHILL. 2007. Cottonwood Creek Watershed Management Plan. September 2007. Available at: [http://www.cottonwoodcreekwatershed.org/nodes/aboutwatershed/reports/documents/ccwmp.pdf]

Crawford, B. A. and S. Rumsey. 2009. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act (Idaho, Oregon, and Washington). NOAA's National Marine Fisheries Service Northwest Region.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observation. B. R. Murphy and D. W. Willis, *editors*. Fisheries Techniques, Second edition. American Fisheries Society, Bethesda, Maryland.

Eilers, C. D. 2008. Review of present steelhead monitoring programs in the California Central Valley. Sacramento, California. Report to California Department of Fish and Game Contract # P0685619. Available at: [http://www.nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=6499]

Earley, J. T., D. J. Colby, and M. R. Brown. 2009. Data draft of juvenile salmonid monitoring in Clear Creek, California from October 2008 through September 2009. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Redd Bluff, California.

FAO. 1999. Guidelines for the routine collection of capture fisheries data. FAO Fisheries Technical Paper No. 382. Rome, FAO. Available at: [ftp://ftp.fao.org/docrep/fao/003/x2465e/x2465e00.pdf]

FishBio. 2010. Calaveras River monitoring. Available at: http://sanjoaquinbasin.com/calaveras-river.html. Accessed on June, 15 2010.

Ford, T. and S. Kirihara. 2009. 2008 Lower Tuolumne River annual report. Report 2008-5. Federal Energy Regulatory Commission.

Ford, T. and S. Kirihara. 2010. Tuolumne River *Oncorhynchus mykiss* Monitoring Report. Submitted in compliance with ordering paragraph (C) (5) of the April 3, 2008 FERC order on ten-year summary report under Article 58 for Project No. 2299.

Galbreath, P. F. and P. E. Barber. 2005. Validation of a long-range dual frequency identification sonar (DIDSON_LR) for fish passage enumeration in the Methow River. Columbia River Inter-Tribal Fish Commission Technical Report 05-4. Portland, Oregon.

Garman, C. E. and T. R. McReynolds. 2008. Butte and Big Chico Creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha* life history investigation 2006-2007. California Department of Fish and Game, Inland Fisheries Administrative Report No. 2008-1, Chico, CA.

Garza, J. C., and D. E. Pearse. 2008. Population genetic structure of *Oncorhynchus mykiss* in the California Central Valley. Final Report for California Department of Fish and Game Contract # P0485303.

Hallock, R. J., D. H. Fry, Jr., and D. A. LaFaunce. 1957. The use of wire fyke traps to estimate the runs of adult salmon and steelhead in the Sacramento River. California Fish and Game Quarterly 43(4):271-298. U.S. Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (Salmo gairdnerii gairdnerii) in the Sacramento River system. Fish Bulletin No. 114. California Department of Fish and Game.

Hallock, R.J. 1989. Upper Sacramento River steelhead, *Oncorhynchus mykiss*, 1952-1988. Report to the Fish and Wildlife Service.

Hannon, J., and B. Deason. 2005. American River steelhead (*Oncorhynchus mykiss*) spawning 2001-2005. Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

Holmes, J. A., G. M. W. Cronkite, H. J. Enzenhofer, and T. J. Mulligan. 2006. Accuracy and precision of fish-count data from a "dual-frequency identification sonar" (DIDSON) imaging system. ICES Journal of Marine Science 63: 543 – 555.

[IEPSPWT] Interagency Ecological Program Steelhead Project Work Team. 1998. Monitoring, assessment, and research on Central Valley steelhead: status of knowledge, review of existing programs, and assessment of needs. In: Comprehensive monitoring, assessment, and research program plan technical appendix VII–A–11.

Johnson, P., B. Nass, D. Degan, J. Dawson, M. Johnson, B. Olson, and C. Harvey-Arrison. 2006. Assessing Chinook salmon escapement in Mill Creek using acoustic technologies in 2006. Report submitted to USFWS Anadromous Fish Restoration Program.

Kennedy, T. and T. C. Cannon. 2002. Stanislaus River salmonid density and distribution survey report (2000-2001). United States Fish and Wildlife Service, Central Valley Project Improvement Act Program.

Killam, D. and M. Johnson. 2008. The 2007 Mill Creek video station steelhead and spring-run Chinook salmon counts. SRSSAP Technical Report N0. 08-01. California Department of Fish and Game.

Kimmerer, W., B. Mitchell, and A. Hamilton. 2001. Building models and gathering data: can we do this better? California Department of Fish and Game Contributions to the Biology of Central Valley Salmonids, Volume 2, Fish Bulletin 179:305.

Kucera, P.A. 2009. Use of dual frequency sonar to determine adult Chinook salmon (*Oncorhynchus tshawytscha*) escapement in the Secesh River, Idaho in 2007-2008. Nez Perce Tribe Department of Fisheries Resources Management, Lapwai, ID.

Lindley, S. T., R. S. Schick, A. Agrawal, M. Goslin, T. E. Pearson, E. Mora, J. J. Anderson, B. May, S. Greene, C. Hanson, A. Low, D. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science 4(1) Article 3. Available at: [http://repositories.cdlib.org/jmie/sfews/vol4/iss1/art3]

Lindley, S. T., R. S. Schick, E. Mora, P. B. Adams, J. J. Anderson, S. Greene, C. Hanson, B. P. May, D. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science. 5(1) Article 4. Available at: [http://repositories.cdlib.org/jmie/sfews/vol5/iss1/art4]

Low, A. 2007. Existing program summary Central Valley salmon and steelhead monitoring programs. CDFG, Sacramento, California.

Mackey, E. 2005. Trends in Atlantic salmon: the role of automatic fish counter data in their recording. Scottish Natural Heritage Commissioned Report No. 100.

Maxell, B. A. 1999. A prospective power analysis on the monitoring of bulltrout stocks using redd counts. North American Journal of Fisheries Management 19:860 – 866.

Maxwell, S. L. and N. E. Gove. 2004. The feasibility of estimating migrating salmon passage rates in turbid rivers using a dual frequency identification sonar (DIDSON) 2002. Alaska Department of Fish and Game Report No. 2A04-05, Anchorage.

McDonald, T. L. 2003. Review of environmental monitoring methods: survey designs. Environmental Monitoring and Assessment 85:277 – 292.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42,156 p.

McEwan, D. R. 2001. Central Valley Steelhead. Pages 1-44 in R. L. Brown (ed). Contributions to the biology of Central Valley salmonids. Volume 1. California Department of Fish and Game. Sacramento, California.

McEwan, D. R. and T. A. Jackson. 1996. Steelhead restoration and management plan for California. California Department of Fish and Game, Sacramento, CA.

McHugh, P., P. Budy, and H. Schaller. 2004. A model-based assessment of the potential response of Snake river spring-summer Chinook salmon to habitat improvements. Transactions of the American Fisheries Society 133:622-638.

Mitchell, W. T. 2010. Age, growth, and life history of steelhead rainbow trout (*Oncorhynchus mykiss*) in the lower Yuba River, California. ICF International. Sacramento, CA.

Moussalli, E. and R. Hilborn. 1986. Optimal stock size and harvest rate in multistage life history models. Can. J. Fish. Aquat. Sci. 43:135-141.

Mueller, A., D. L. Burwen, K. M. Boswell, and T. Mulligan. 2010. Tail-beat patterns in dual-frequency identification sonar ecograms and their potential use for species identification and bioenergetics studies. Transactions of the American Fisheries Society 139:900-910.

Newton, J. M. and M. R. Brown. 2004. Adult spring Chinook salmon monitoring in Clear Creek, California, 1999-2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Nielsen, J. L., S. A. Pavey, T. Wiacek, and I. Williams. 2005. Genetics of Central Valley *O. mykiss* populations: drainage and watershed scale analyses. San Francisco Estuary and Watershed Science 3(2) Article 3. [http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art3]

[NMFS] National Marine Fisheries Service. 2009. Public draft recovery plan for the evolutionary significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon, and the distinct population segment of Central Valley steelhead. Sacramento Protected Resources Division. October 2009.

[NPS] National Park Service. 2008. Data management guidelines for inventory and monitoring networks. Natural Resources Report NPS/NRPC/NRR – 2008/035. National Park Service, Fort Collins, Colorado.

Pipal, K. A. 2005. Summary of monitoring activities for ESA-listed salmonids in California's Central Valley. NOAA-TM-NMFS-SWFSC-373.

Pipal, K., M. Jessop, G. Holt, and P. Adams. 2010. Operation of dual-frequency identification sonar (DIDSON) to monitor adult steelhead (*Oncorhynchus mykiss*) in the central California coast. NOAA-TM-NMFS-SWFC-454.

Rible, E. 2009. Lower Mokelumne River fall-run Chinook salmon and winter-run steelhead redd survey report: October 2008through July 2009. East Bay Municipal Utility District, Lodi, CA.

Stevens, D.L. 2002. Sampling design and statistical analysis methods for the integrated biological and physical monitoring of Oregon streams. U.S. Envir. Prot. Agen., West. Ecol. Divi., Corvallis, OR.13 p + append.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262 – 278.

Stillwater Sciences. 2004. Lower Calaveras River Chinook salmon and steelhead limiting factor analysis first year report (revised). Prepared for Fishery Foundation of California by Stillwater Sciences. Berkeley, CA.

StreamNet. 2009. Considerations for regional data collection, sharing, and exchange. White paper. Bruce Schmidt.

[USFWS] United States Fish and Wildlife Service. 2001. Final restoration plan for the anadromous fish restoration program. A plan to increase natural production of anadromous fish in the Central Valley of California. Available at: [http://www.fws.gov/Stockton/afrp/restplan_final.ctm#25]

[USFWS] United States Fish and Wildlife Service. 2007. Central Valley steelhead and late fall-run Chinook salmon redd surveys on Clear Creek, California. Prepared by Sarah Giovannetti and Matt Brown, Red Bluff, California.

[USFWS] United States Fish and Wildlife Service. 2008a. Steelhead and late-fall Chinook salmon redd surveys on Clear Creek, California. 2008 Annual Report. Red Bluff Fish and Wildlife Office. Red Bluff, California. December 2008.

[USFWS] United States Fish and Wildlife Service. 2008b. Draft rotary screw trap protocol for estimating production of juvenile Chinook salmon. Comprehensive Assessment and Monitoring Program, Sacramento, CA.

[FR] Office of the Federal Register. 1998. Endangered and threatened species: threatened status for two ESUs of steelhead in Washington, Oregon, and California. Federal Register 63:53(19 March 1998):13347-13371.

[FR] Office of the Federal Register. 2000. Designated critical habitat: critical habitat for 19 evolutionarily significant units of salmon and steelhead in Washington, Oregon, Idaho, and California. Federal Register 65:32(16 February 2000):7764-7787.

[FR] Office of the Federal Register. 2005. Endangered and threatened species; designation of critical habitat for seven evolutionarily significant units of Pacific salmon and Steelhead in California; final rule. Federal Register 70:170(2 September 2005):52488-52627.

[FR] Office of the Federal Register. 2006. Endangered and threatened species: final listing determinations for 10 distinct population segments of west coast steelhead; final rule. Federal Register 71:3(5 January 2006):834-862.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. *In* Salmonid Field Protocols Handbook, Techniques for Assessing Status andTrends in Salmon and Trout Populations. D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons, Editors. American Fisheries Society, Bethesda, Maryland.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2008. Juvenile salmonid monitoring in Battle Creek, California, November 2007 through June 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Williams, J. G., J. J. Anderson, S. Greene, C. Hanson, S. T. Lindley, A. Low, B. P. May, D. McEwan, M. S. Mohr, R. B. MacFarlane, and C. Swanson. 2007. Monitoring and research needed to manage the recovery of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin Basin. NOAA Technical Memorandum, NMFS-SWFSC-399.

Zimmerman, C. E., G. W, Edwards, and K. Perry. 2009. Maternal origin and migratory history of steelhead and rainbow trout captured in rivers of the Central Valley, California. Transactions of the American Fisheries Society 138:280-291.

Zimmerman, C. E., G. W. Edwards, and K. Perry. 2008. Maternal origin and migratory history of *Oncorhynchus mykiss* captured in rivers of the Central Valley, California. Final Report. Prepared for California Department of Fish and Game, Contract P03853006. March 2008. [http://www.delta.dfg.ca.gov/AFRP/documents/Zimmerman_et_al.pdf]

## PERSONAL COMMUNICATION

Azat, J., CDFG, Pers. Comm., Central Valley Chinook salmon escapement monitoring summary reports and Grand Tab, 2010.

Bellmer, R. and J. Nelson., CDFG, Pers. Comm., CDFG steelhead restoration and management plan for California, 2009.

Brown, M., USFWS, Pers. Comm., Clear Creek rotary screw trap monitoring for steelhead, 2010

Brown, M., USFWS, Pers. Comm., Weir and fish device counter for Clear Creek, 2010.

Carlson, R., PSMFC, Pers. Comm., CALFISH, 2010.

Del Real, S., EBMUD, Pers. Comm., Video monitoring at Woodbridge Dam on the Mokelumne River, 2010.

Garman, C., CDFG, Pers. Comm., Monitoring steelhead in Big Chico and Butte Creeks, 2010.

Garza, J. and Anderson., NOAA, Pers. Comm., Parentage based tagging for steelhead in the California Central Valley, 2010.

Gingras, M., CDFG, Pers. Comm.., Large fyke traps, 2008.

Gingras, M. and M. Harris., CDFG, Pers. Comm., Large fyke traps, 2009.

Hannon, J., USBR, Pers. Comm., American River redd survey, 2010.

Harvey-Arrison, C., CDFG, Pers. Comm., rotary screw traps, 2010.

Heyne, T., CDFG, Pers. Comm., Stanislaus weir, 2008.

Killam, D., CDFG, Pers. Comm., Video monitoring for steelhead in the upper Sacramento River basin and cost estimates, 2009 and 2010

Kindopp, J., CDWR, Pers. Comm., Proposed weir for the Feather River, 2010.

Sonke, C., FishBio., Pers. Comm., Weir and Vaki Riverwatcher system on the Stanislaus and Tuolumne Rivers, 2010.

Threloff, D., USFWS, Pers. Comm., CAMP program and data management, 2010.

**APPENDIX A**

**PILOT MARK-RECAPTURE PROGRAM SIMULATION STUDY**

# Sacramento River Mark-Recapture Steelhead Abundance Estimation: A Simulation Study

By

WEST, Inc.


**Western EcoSystems Technology**

2003 Central Avenue, Cheyenne, WY 82001
Phone: 307-634-1756 Fax: 307-637-6981

Jim Griswold
jgriswold@west-inc.com
Ryan Nielson
rnielson@west-inc.com


For

**Pacific States Marine Fisheries Commission**

May 26, 2010

## INTRODUCTION

A mark-recapture study will be used to estimate the number of adult steelhead (*Oncorhynchus mykiss*) migrating up the mainstem of the Sacramento River. Historic mark-recapture efforts have included marking fyke-trap catches in the Sacramento River above the confluence of the Sacramento River and the American and Feather Rivers from 1953 – 1959 (Hallock 1989). In the earlier study, fish were recaptured at upstream weirs and a diversion dam. This fyke trap effort was considered to be successful while dependent on strategic placement of the traps for optimal catchability. We will attempt to repeat this earlier study at a location in the Sacramento River downstream of the confluence of the American River, but upstream of the Sacramento-San Joaquin River Delta (Figure 1). Prior to full implementation of this technique, a pilot program will be carried out to evaluate trapping success and the degree to which fish will be injured during the trapping process. As part of the pilot program we developed a computer simulation to estimate the potential variability in mark-recapture population estimates. The objective of this simulation was to estimate the precision and bias of an estimator for the total abundance of wild and hatchery adult steelhead migrating up the Sacramento River using hypothetical data and a mark-recapture model that allows for temporally stratified estimates. The simulation explored the characteristics of abundance estimates over a range of population sizes, number of traps fished and probability of capture, with an assumed run-timing based on recent angler surveys and historic trapping records.

## METHODS

The mark-recapture technique investigated in this simulation is a temporally stratified design where sampling at multiple river locations is used to estimate the abundance of the migrating adult steelhead population in discrete time segments. Hypothetically, these time segments may correspond to possible variations in passage rates during the migration period. This stratified approach was used since steelhead may migrate in pulses of high, medium and low run abundance over the migration period (Hallock 1989). The method consists of counting adult steelhead captured at designated trapping sites and releasing tagged fish (floy tags for hatchery steelhead and caudal-fin clips for wild fish) back into the population at sites downstream from recapture sites. The temporal segments of the hatchery run and the wild run are estimated separately then summed to achieve total abundance estimates.

### *Assumptions of the Mark-Recapture Model*

- There is constant capture probability within strata (time segments) and equal probability of capture for marked and unmarked fish.
- Hatchery fish and wild fish have the same capture probability within each stratum.
- Fallback of fish captured at a downstream site and released upstream occurs at the same rate for wild fish as for hatchery fish within each stratum. Fallback is the event where a fish drops back downstream of the marking site after marking and release.
- Fish do not lose their tags, and fin clips are visible throughout the study.

- Mortality is the same for all fish, regardless of marking or origin (wild vs. hatchery).

***Description of the Mark-Recapture Model***

Floy-tagged hatchery fish with individual ID numbers recaptured at the upstream fyke traps are counted to estimate capture probability (trap efficiency) for both wild and hatchery fish, which is used to estimate abundance for that temporal segment of the population. The method is temporally stratified such that each trap efficiency trial is paired with one capture period, with a small probability of recaptured fish occurring in later strata. This strategy accounts for potential temporal changes in capture probability over the study period assuming a constant capture probability within a stratum and equal probability of capture for tagged fish and untagged fish (Carlson et al. 1998). It is also assumed that capture probability is the same for marked and unmarked fish regardless origin, and that fish do not lose their marks or tags (Carlson 1998, Amstrup et al. 2005). When all assumptions are met the stratified design allows for nearly unbiased population estimates of hatchery fish abundance in each stratum (Schwarz and Dempson 1994, Carlson et al. 1998).

Wild steelhead will not receive individual tags with unique ID numbers (just a caudal fin clip), so the estimated total number of hatchery fish in each stratum, along with an estimate of the ratio of wild to hatchery fish in the migration will be used to estimate the total number of wild fish. This method requires that stratum specific capture probabilities are the same for wild and hatchery fish, that fallback of fish captured at a downstream site and released upstream occurs at the same rates for wild and hatchery fish within each stratum, and that mortality is the same for all fish.

The method of capturing fish for both marking and recapture in the pilot study will employ multiple wire fyke traps set with the catch openings facing downstream (Hallock et al. 1961, Hallock 1989). Four or more traps will be used during the pilot study. The trap set furthest downstream will be reserved for marking fish only while the upstream-most trap will only involve recapture efforts. Both marking and recapture will occur at traps located between the extreme lower and upper traps. Traps will be set far enough apart to allow complete mixing of marked and unmarked fish so that the probability of capture is most likely to be similar for marked and unmarked fish. Marked fish will need to be ferried by boat or trucked upstream far enough that fallback is minimized and complete mixing between the released marked fish and unmarked fish will have occurred. In addition, all wild and hatchery fish captured will be marked in some fashion so that the total number of unique fish captured can be identified.

### *Computer Simulation*

### *Mark-recapture Statistical Analysis Methods*

The following notation is defined for the mark-recapture model when wild fish are clipped:

$L$ = number of strata or temporal migration periods

$h$ = stratum index (capture period and a corresponding trap efficiency trial) $(h = 1, 2, \ldots, L)$,

$M_{Hh}$ = number of tagged hatchery fish released in stratum $h$,

$M_{Wh}$ = number of clipped (genetic tissue sampled) wild fish released in stratum $h$,

$m_{Hh}$ = number of tagged hatchery fish recaptured in $h$,

$m_{Wh}$ = number of clipped wild fish recaptured in $h$,
$u_{Hh}$ = number of unmarked hatchery fish captured in $h$,
$u_{Wh}$ = number of unmarked wild fish captured in $h$,
$n_{Hh}$ = total number of hatchery fish captured in $h$ $\left(= m_{Hh} + u_{Hh}\right)$,
$n_{Wh}$ = total number of hatchery fish captured in $h$ $\left(= m_{Wh} + u_{Wh}\right)$,
$N_{Hh}$ = total hatchery steelhead population size in $h$,
$N_{Wh}$ = total wild steelhead population size in $h$,

As mentioned above, all wild and hatchery fish captured need to be marked in some fashion so that a tally of the total number of unique individual hatchery and wild fish caught can be obtained. However, this does not mean that 100% of hatchery fish need to be fitted with floy tags. Sick or injured fish may be caudal-fin clipped to mark that they have already been captured and included in the tally of unique hatchery steelhead caught. Thus, $u_{Hh}$ represents the number of steelhead not marked for the mark-recapture portion of the study, but these fish will be marked in some manner to identify that they have already been tallied as a unique fish. We assume that all genetic samples will be taken for all wild fish and thus $u_{Wh}$ will equal zero.

The objective of the mark-recapture study is to estimate $N_W$ and $N_H$; the total population sizes of wild and hatchery steelhead migrating past the trap sites, respectively. For each stratum, $h$, the estimate for the abundance of hatchery fish is

$$\tilde{N}_{Hh} = \frac{n_{Hh} M_{Hh}}{m_{Hh}}. \tag{1}$$

The distribution of $m_{Hh}$, conditional on $M_{Hh}$ and $n_{Hh}$, is hypergeometric (Schwarz and Dempson 1994). Chapman (1951) provides an approximately unbiased estimator for $\tilde{N}_{Hh}$:

$$\hat{N}_{Hh} = \frac{(n_{Hh}+1)(M_{Hh}+1)}{(m_{Hh}+1)} - 1. \tag{2}$$

An approximately unbiased estimator for the variance of $\hat{N}_{Hh}$ (Seber 1970) is

$$V\hat{a}r\left(\hat{N}_{Hh}\right) = \frac{\left(M_{Hh}+1\right)\left(n_{Hh}+1\right)\left(M_{Hh}-m_{Hh}\right)\left(n_{Hh}-m_{Hh}\right)}{\left(m_{Hh}+1\right)^2\left(m_{Hh}+2\right)}. \tag{3}$$

Using the estimated abundance of hatchery fish in stratum $h$ and the ratio of unique wild to hatchery fish captured we can estimate the total number of wild steelhead using

$$\hat{N}_{Wh} = \frac{n_{Wh}\hat{N}_{Hh}}{n_{Hh}}. \tag{4}$$

The variance of $\hat{N}_{Wh}$ can be calculated using

$$V\hat{a}r\left(\hat{N}_{Wh}\right) = V\hat{a}r\left(\hat{N}_{Hh}\right)\left(\frac{n_{Wh}}{n_{Hh}}\right)^2.$$

(5)

The total hatchery steelhead abundance estimate for the migration period can then be calculated using

$$\hat{N}_H = \sum_{h=1}^{L} \hat{N}_{Hh}. \tag{6}$$

The total wild steelhead abundance estimate is given by

$$\hat{N}_W = \sum_{h=1}^{L} \hat{N}_{Wh}. \tag{7}$$

The variance estimate for the total hatchery steelhead abundance estimate is

$$V\hat{a}r\left(\hat{N}_H\right) = \sum_{h=1}^{L} V\hat{a}r\left(\hat{N}_{Hh}\right). \tag{8}$$

The variance estimate for the total wild steelhead abundance estimate is

$$V\hat{a}r\left(\hat{N}_W\right) = \sum_{h=1}^{L} V\hat{a}r\left(\hat{N}_{Wh}\right). \tag{9}$$

An asymptotic approximate 90% confidence interval for total wild steelhead abundance is

$$\hat{N}_W \pm 1.645\sqrt{v\left(\hat{N}_W\right)}. \tag{10}$$

An asymptotic approximate 90% confidence interval for total hatchery steelhead abundance is

$$\hat{N}_H \pm 1.645\sqrt{v\left(\hat{N}_H\right)}. \tag{11}$$

Since $m_{Hh}$ and $m_{Wh}$ are hypergeometric random variables (Schwarz and Dempson 1994), $m_{Hh}$ was simulated from a hypergeometric distribution with parameters $M_{Hh}$ and $n_{Hh}$ and $m_{Wh}$ was simulated from a hypergeometric distribution with parameters $M_{Wh}$ and $n_{Wh}$. The simulation also used a binomial distribution with parameters $n$ (steelhead abundance for stratum $h$) and $p$ (capture probability for stratum $h$) to generate value of $M_{Hh}$, $M_{Wh}$, $n_{Hh}$ and $n_{Wh}$.

Hypothetical simulation data for run-timing and capture probability was based on values taken from the results of the 1950's mark-recapture studies (Hallock 1989). Run-timing consisted of $L$ = 9 temporal strata. Capture probability values were adjusted for 2007 – 2008 flow levels in the Sacramento River just below the confluence of the Sacramento River with the American River, since we believed that higher flows will reduce capture probability at the new trap site(s). Capture probability was fixed at 0.037 and 0.075 under a 7 trap level of effort with the 0.075 value based on the reported capture probability of 0.10 – 0.20 in Hallock (1989). The lower value of 0.037 is conservative and is meant to reflect a least favorable case scenario for capture probability. Trapping effort used for simulation included two scenarios consisting of four traps and seven traps each. Thus the effective probabilities of capture for the four trap scenario are 0.037 × 4/7 = 0.022 and 0.075 × 4/7 = 0.043.

Starting values for total steelhead abundance were based on a hypothetical stocking rate of 1,480,000 hatchery yearlings – the sum of the production goals for the Feather River Hatchery, Nimbus Hatchery and Coleman National Fish Hatchery. The simulation used two hypothetical values (0.005 and 0.015) for the smolt-to-adult ratio (SAR). These SAR values for hatchery steelhead are approximate values based on Nimbus Hatchery and Feather River Hatchery returns and are intended to represent expected low and high values for this survival parameter. No published estimates of hatchery SAR or wild SAR were available from Central Valley studies due to the lack of comprehensive Coded Wire Tag (CWT) tagging studies. The proportion of wild steelhead in population used the simulation was set to either 0.01 or 0.05. These estimates of the proportion of wild fish were obtained from estimates at Nimbus Hatchery.

Ninety-percent confidence intervals (CI) for population estimates were based on the 5$^{th}$ and 95$^{th}$ quantiles of 5,000 simulated estimates of total abundance for each origin group, wild and hatchery. Means and standard errors of estimates for each of the input scenarios were estimated as the empirical means and empirical standard errors of the 5,000 simulated population estimates. Bias of the estimates was defined as the difference between the mean of the 5,000 simulation estimates and the true population value provided as simulation input. Using the approximate steelhead stocking rate of 1,480,000 fish annually and SAR values of 0.005 and 0.015, the number of hatchery fish surviving to migration and passing by the traps in the simulation were 7,400 and 22,200 total fish. Total abundance of wild steelhead in the simulations were either 75, 224, 389 or 1,168 (Table 1).

## RESULTS

Simulation results for wild steelhead given data inputs described above are given in Table 2 and Figure 2. Simulation results for hatchery steelhead given data inputs described above are given in Table 3 and Figure 3. Bias was generally negative (meaning estimates were low) and smallest for simulations involving larger population sizes and higher capture probabilities (Tables 2 and 3). The half widths of estimated 90% CIs for population estimates of wild steelhead expressed as a percentage of the true population total varied from 6.6% to 23.4% with mean of 16.7% (Table 2). The half-widths of 90% CIs for population estimates of hatchery steelhead expressed as a percentage of the true population size varied from 6.6% to 22.3% with a mean of 16.5% (Table 3). The coefficient of variation did not exceed 26% for the estimate of total abundance of wild steelhead (Table 2 and Figure 4).

# DISCUSSION

The simulation indicated there are moderate levels of variability around estimates of wild and hatchery steelhead abundance given hypothetical levels of probability of capture and certain assumptions about the mark-recapture model. However, bias in estimators were relatively low (generally < 7%) unless probability of capture and total abundance was extremely low. The simulation results for scenarios 1 and 5 (Table 2) are likely the result of rare events in the simulation dictated by the random draws from binomial and hypergeometric distributions with extremely low probabilities and sample sizes.

As expected, larger errors were associated with lower trapping effort and reduced probability of capture. Using seven traps instead of four resulted in an average decrease in 90% CI half-widths for wild abundance estimates from 19.7% to 13.7% (Table 2 and Figure 2).

Key assumptions made for the analysis and simulation were that the probability of capture of marked fish will be the same as that of unmarked fish, and that batch marked (clipped) wild fish have the same probability of capture as hatchery fish which will be given a unique tag. Violation of the latter assumption may depend on the run-timing of hatchery and wild fish. A check on this assumption would be to compare the ratio of wild:hatchery recaptures to the ratio of wild:hatchery for marked fish. If these ratios are similar then it is likely the assumption of equal capture probability was met. During the pilot study the assumption of equal capture probabilities for wild and hatchery fish will be tested using chi-squared tests of homogeneity (Agresti 1990).
If a large enough sample of wild fish could be individually tagged the assumption of equal probability of capture for wild and hatchery fish could be more thoroughly tested and an independent estimate of the recapture probability of wild fish could be made. Individual marks on some wild fish of a moderate sample size should allow implementation of a more sophisticated mark-recapture model for which it would be possible to estimate covariates such as steelhead size and age effects on capture probability as well as the effect of flow and day of migration on capture probability. Additionally, tagging some wild fish would allow the possibility of estimating the spawning destination proportions of the wild run at upstream tributaries. One such covariate mark-recapture model is the Huggins model (Amstrup et al. 2005, McDonald and Amstrup 2001, Huggins 1989).

It should be emphasized that the simulation results are limited by our minimal knowledge of the factors affecting the efficiency of the traps, the behavior patterns of migrating steelhead and the consistency of our ability to operate and maintain the traps effectively. There are undoubtedly unknown factors which the simulations do not take into consideration. The simulation studies should therefore be continued once the mark-recapture study is begun and additional data is available. This will allow monitoring of the appropriateness of model assumptions and study operation such that adjustments can be made to achieve more accurate and precise estimates.
Considering the pilot study nature of this first attempt to achieve a fairly precise estimate of the total Sacramento River steelhead migration, the small to moderate differences in bias and precision using only four fyke traps may be an acceptable compromise considering the extra time, maintenance, uncertainty and resources involved in employing additional traps. However, if when using only four traps during the first weeks of the peak migration it appears that the probability of capture is estimated at levels at or below 0.02, additional traps should be considered.

## LITERATURE CITED

Agresti, A.  2002. Categorical data analysis. John Wiley & Sons, Inc., Hoboken, New Jersey, USA.

Amstrup, S. C., T. L. McDonald, and B. F. J. Manly. 2005. Handbook of capture-recapture analysis. Princeton University Press, Princeton, New Jersey, USA.

Carlson, S. R., L. G. Coggins, and C. O. Swanton. 1998. A Simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fishery Research Bulletin 5:88 – 102.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1:131-160.

Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. California Department of Fish and Game Report.

Hallock, R. J. 1989. Upper Sacramento River Steelhead, *Oncorhynchus mykiss*, 1952 – 1988. California Department of Fish and Game report to the Fish and Wildlife Service.

Huggins, R. M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133 – 140.

McDonald, T. L., and S. C. Amstrup. 2001. Estimation of population size using open capture-recapture models. Journal of Agricultural, Biological, and Environmental Statistics 6:206 – 220.

Schwarz, C. J. and J. B. Dempson. 1994. Mark-recapture estimation of a salmon smolt population. Biometrics 50:98 – 108.

Seber, G. A. F. 1970. The effects of tag response on tag-recapture estimates. Biometrika 26: 12 – 22.

Table 1. Mark-recapture simulation input values for the population abundance, probability of capture, number of traps, smolt-to-adult ratios (SAR), and proportion of wild steelhead.

| Population Abundance | | Probability | Traps | SAR | Proportion |
|---|---|---|---|---|---|
| Wild | Hatchery | of Capture | Fished | Hatchery | Wild |
| 75 | 7,400 | 0.022 | 4 | 0.005 | 0.01 |
| 224 | 22,200 | 0.037 | 7 | 0.015 | 0.05 |
| 389 | | 0.043 | | | |
| 1,168 | | 0.075 | | | |

Table 2. Simulation results for mark-recapture estimation of the number of wild adult steelhead migrating up the Sacramento River.

| Scenario | Probability of Capture | Wild Population | Hatchery Population | No. of Traps | Mean Wild Est. | % Bias Wild | SE Wild | 90% CI Low | 90% CI High | 90% CI Half-width | Coef. of Variation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.022 | 75 | 7,400 | 4 | 53 | -28.8 | 13.5 | 38 | 73 | 23.3 | 0.25 |
| 2 | 0.038 | 75 | 7,400 | 7 | 70 | -6.1 | 14.3 | 55 | 88 | 22.0 | 0.20 |
| 3 | 0.022 | 224 | 22,200 | 4 | 212 | -5.4 | 45.6 | 164 | 266 | 22.6 | 0.21 |
| 4 | 0.038 | 224 | 22,200 | 7 | 223 | -0.6 | 27.0 | 192 | 257 | 14.3 | 0.12 |
| 5 | 0.022 | 389 | 7,400 | 4 | 278 | -28.6 | 70.6 | 201 | 383 | 23.4 | 0.25 |
| 6 | 0.038 | 389 | 7,400 | 7 | 366 | -5.9 | 74.8 | 288 | 456 | 21.6 | 0.20 |
| 7 | 0.022 | 1,168 | 22,200 | 4 | 1,097 | -6.1 | 232.1 | 851 | 1,370 | 22.2 | 0.21 |
| 8 | 0.038 | 1,168 | 22,200 | 7 | 1,167 | -0.1 | 138.2 | 1,007 | 1,349 | 14.6 | 0.12 |
| 9 | 0.043 | 75 | 7,400 | 4 | 73 | -2.4 | 13.4 | 59 | 90 | 20.9 | 0.18 |
| 10 | 0.075 | 75 | 7,400 | 7 | 75 | 0.1 | 7.1 | 66 | 84 | 12.0 | 0.10 |
| 11 | 0.043 | 224 | 22,200 | 4 | 224 | -0.1 | 22.4 | 198 | 253 | 12.3 | 0.10 |
| 12 | 0.075 | 224 | 22,200 | 7 | 224 | 0.0 | 11.5 | 210 | 239 | 6.6 | 0.05 |
| 13 | 0.043 | 389 | 7,400 | 4 | 379 | -2.6 | 69.4 | 305 | 464 | 20.3 | 0.18 |
| 14 | 0.075 | 389 | 7,400 | 7 | 390 | 0.2 | 36.8 | 347 | 439 | 11.8 | 0.09 |
| 15 | 0.043 | 1,168 | 22,200 | 4 | 1,168 | 0.0 | 119.7 | 1,029 | 1,321 | 12.5 | 0.10 |
| 16 | 0.075 | 1,168 | 22,200 | 7 | 1,168 | 0.0 | 60.3 | 1,093 | 1,247 | 6.6 | 0.05 |
| Mean | | | | | | -5.4 | | | | 16.7 | 0.15 |

Table 3. Simulation results for Sacramento River hatchery steelhead adults based on input values from Table 1.

| Scenario | Probability of Capture | Hatchery Population | No. of Traps | Mean Hatch Est. | % Bias Hatchery | SE Hatchery | 90% CI Low | 90% CI High | 90% CI Half-width | Coef. of Variation |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.022 | 7,400 | 4 | 5,242 | -29.2 | 1,298 | 3,836 | 7,138 | 22.3 | 0.25 |
| 2 | 0.037 | 7,400 | 7 | 6,956 | -6.0 | 1,432 | 5,476 | 8,672 | 21.6 | 0.21 |
| 3 | 0.022 | 22,200 | 4 | 20,779 | -6.4 | 4,332 | 16,281 | 26,123 | 22.2 | 0.21 |
| 4 | 0.037 | 22,200 | 7 | 22,107 | -0.4 | 2,692 | 18,961 | 25,458 | 14.6 | 0.12 |
| 5 | 0.043 | 7,400 | 4 | 7,234 | -2.2 | 1,299 | 5,808 | 8,847 | 20.5 | 0.18 |
| 6 | 0.075 | 7,400 | 7 | 7,406 | 0.1 | 685 | 6,591 | 8,289 | 11.5 | 0.09 |
| 7 | 0.043 | 22,200 | 4 | 22,226 | 0.1 | 2,266 | 19,560 | 25,126 | 12.5 | 0.10 |
| 8 | 0.075 | 22,200 | 7 | 22,208 | 0.0 | 1,148 | 20,786 | 23,727 | 6.6 | 0.05 |
| Mean | | | | | -5.5 | | | | 16.5 | 0.15 |

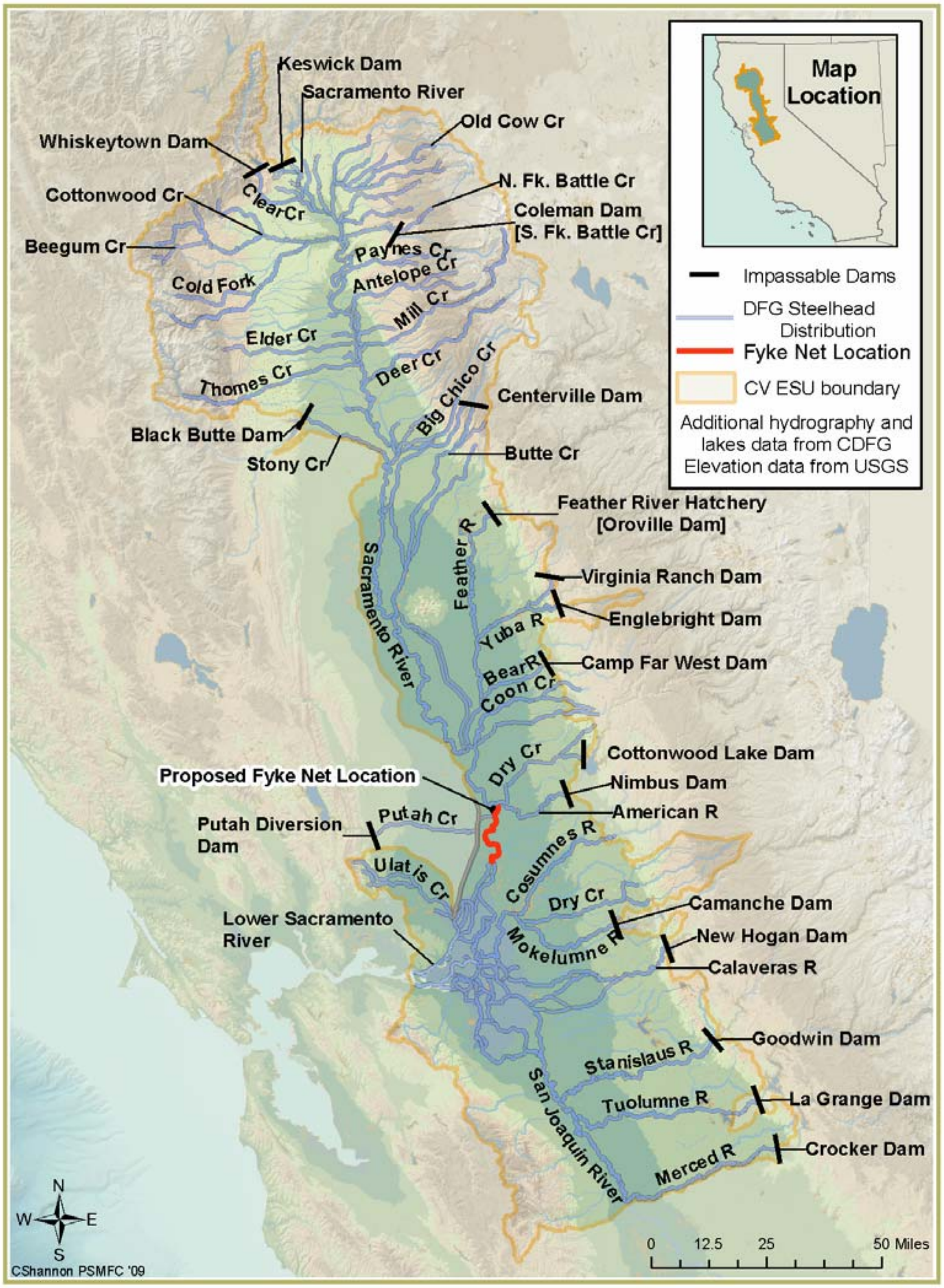


Figure 1. Proposed fyke trap locations in the Sacramento River just below confluence of the Sacramento River and the American River.

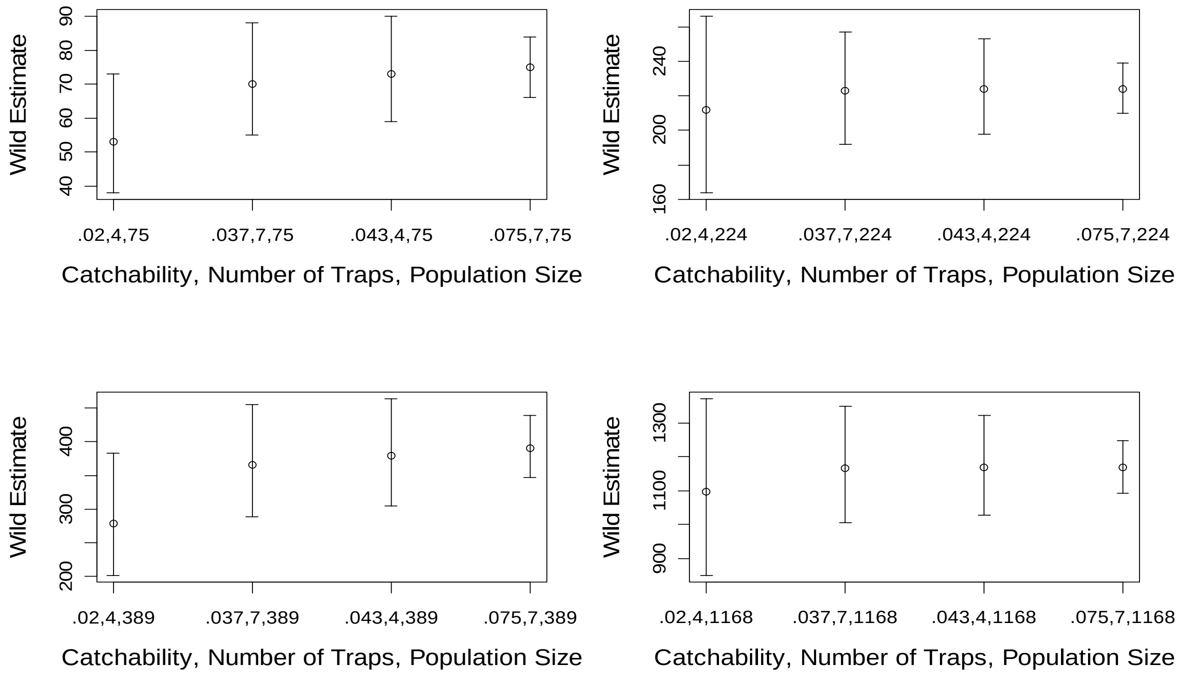


Figure 2. Simulated wild population estimates with 90% confidence intervals for variable catchability (0.037 and 0.075), number of traps (4 and 7) and population sizes (75, 224, 389 and 1,168).

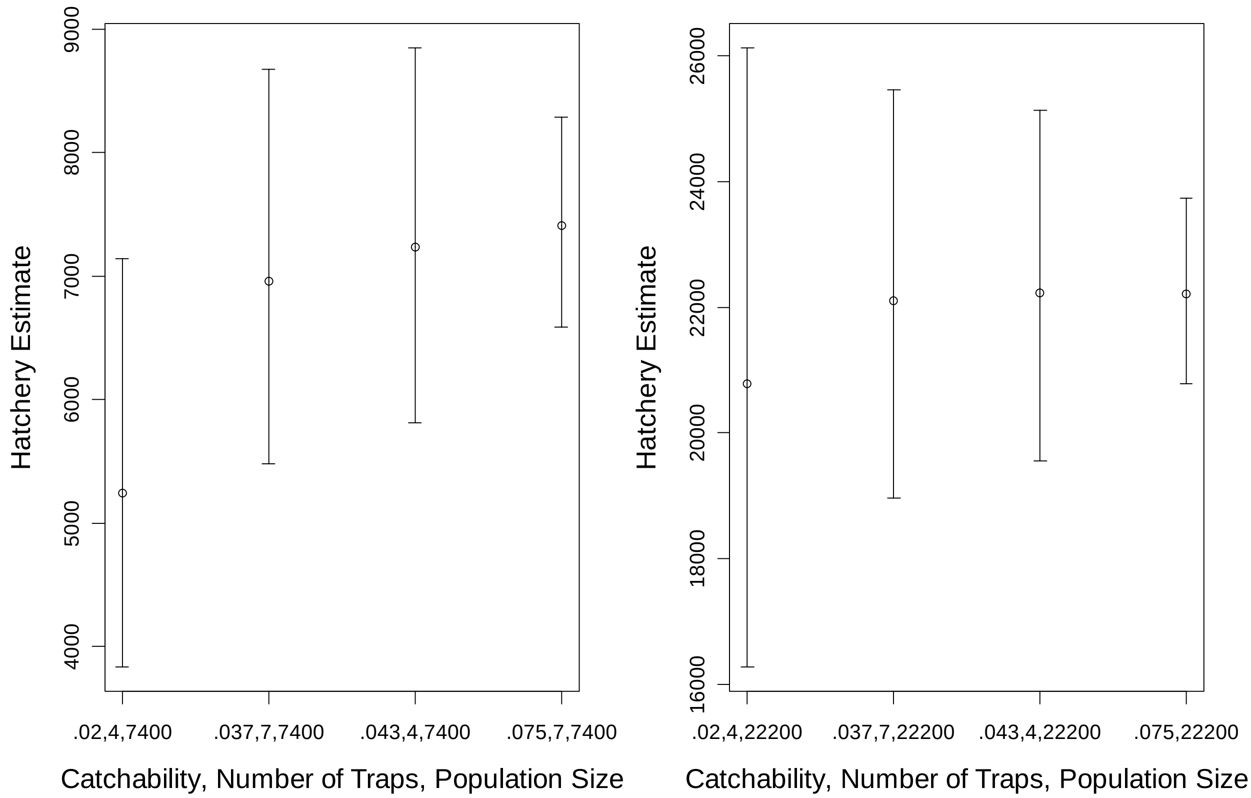


Figure 3. Simulated hatchery population estimates with 90% confidence intervals for variable catchability (0.037 and 0.075), number of traps (4 and 7) and population sizes (7,400 and 22,200).

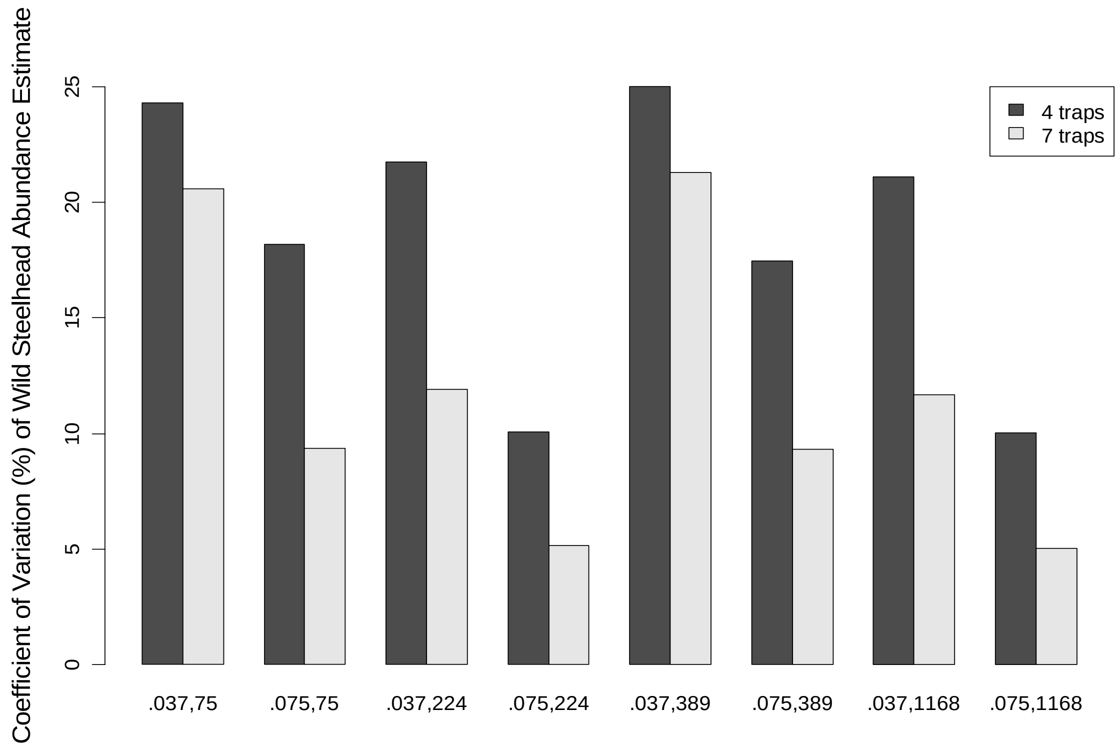


Figure 4. Coefficient of variation (%) of simulated wild steelhead abundance estimates with 4 and 7 trap effort levels and two levels of probability of capture (0.037, 0.075).

**APPENDIX B**

**RECOMMENDED PROCEDURES FOR ESTIMATING STEELHEAD ABUNDANCE USING DEVICE COUNTEERS**

# Estimating Steelhead Escapement Using Device Counters

By

WEST, Inc.

Western EcoSystems Technology
2003 Central Avenue, Cheyenne, WY 82001
Phone: 307-634-1756 Fax: 307-637-6981

Jim Griswold
jgriswold@west-inc.com

Ryan Nielson
rnielson@west-inc.com

For

Pacific States Marine Fisheries Commission

May 25, 2010

## INTRODUCTION

We describe methods for estimating the accuracy and precision of three fish device counters that could be used to estimate total escapement within a watershed or stream: the Vaki Riverwatcher®, the dual frequency identification sonar (DIDSON), and traditional optical video cameras. These devices provide enumeration data which are subject to a number of sources of error. The objective of the report is to describe procedures by which these errors can be quantified and incorporated into estimates of total escapement.

The Vaki Riverwatcher, DIDSON and video fish counters have advantages and disadvantages over traditional methods of collecting data to be used for estimating total fish escapement. The devices are expensive to buy and install, are vulnerable to vandalism and theft, and must be installed at an appropriate in-river structure (Mackey 2005). The devices require regular monitoring, maintenance and servicing to maintain reliable operation and to insure that the data are of high quality. Damage by flooding of the in-river structure is always a possibility. Nevertheless, these devices have a number of strengths: they provide a fairly accurate and consistent count, they can function all year round, and they can operate with minimal impact on individual fish which is an important consideration when the status of the population is threatened or endangered. Moreover, a permanent record is obtained for fish passage which can be reviewed and corrected for error and used for future training personnel that process the images.

The Vaki Riverwatcher uses a linear sensory array to measure the height (ventral-dorsal) of a fish breaking infrared light beams emitted from a series of diodes positioned opposite a series of sensors. As a fish swims in a linear fashion (e.g., upstream or downstream) it breaks a second array of infra-red light beams. From the height of the fish and the rate it moves between the two arrays the counter is able to reconstruct an outline of the fish. This outline is then stored to be validated by the operator (Mackey 2005, Figure 1).

A video camera add-on is available for the Vaki Riverwatcher (Figure 2) to limit the rate of false counts. The Vaki Riverwatcher has the advantage of being less costly than the DIDSON. However, the DIDSON forms near-video-quality images based on sound instead of light and has the advantage of being able to collect images in near zero-visibility water (Maxwell and Gove 2004, Tiffan and Rondorf 2004). The range of imaging for the DIDSON depends on the frequency used. The traditional video camera is the least expensive of the three devices but probably the least accurate when visibility is poor. When water clarity is high a traditional video camera has the advantage of being able to identify fish by species and origin (wild vs. hatchery) (Gates and Boersma 2009, Figure 3).

This report describes methods which will be used to quantify uncertainty in Vaki Riverwatcher, DIDSON, and traditional video count data and obtain estimates of total escapement from the device counts. Hereafter the three device counters will be referred to generally as “device counter”, since each of the three devices will be subjected to the same methodology for error measurement, except when noted otherwise.

***Types of Counting Errors***

There are at least six types of counting errors that may affect estimates of the number of fish passing by a device counter:

7) **Missed counts**: A missed count occurs when a fish passes the device counter but is not recognized. The fish may pass the device too quickly for an image to be recorded or turbidity may cause the sensors to fail. A missed count may also occur when two fish cross the device counter but only one fish is recorded. Periods when the device counter is malfunctioning or inoperative will result in missed counts.

8) **False counts**: A false count occurs when another object is mistaken for a fish (e.g., waterfowl, muskrats, leaves, sticks, or bubbles).

9) **Mixed counts**: A mixed count can occur when a species other than the target species is recorded and is not correctly identified.

10) **By-passed counts:** By-passed counts are the result of the target fish swimming around the device counter and are never in the range within which the fish can be recorded. This type of error can occur during high water events or when the device counter has not been installed in a constricted enough area and the range of the counter is not adequate to detect all fish which migrate past the device. The range of accurate counts will depend on correct installation and aiming the device counter at the correct tilt angle for a given bottom topography, depth and stream width.

11) **Double counts**: Double counts occur when fish which have been counted once drop back below the device counter, and then again enter the range of the device counter and are counted for a second time.

12) **Observer or technician errors**: Errors can be made by the individual(s) processing the images or device counter data. For example, a file may become corrupted or lost, or the observer may under- or over-count fish. Both within and between observer errors are possible.

Three methods will be used to assess the accuracy and variability of the device counter data. The first methods relies on comparing device counts to paired visual counts from a counting tower, using groups of fish allowed to pass through a weir (Holmes et al. 2006). The second method relies on comparing device counts to paired visual counts from a counting tower using unconstrained steelhead (*Oncorhynchus mykiss*, Holmes et al. 2006, Figure 4). The third method for assessing device counter accuracy and variability involves the use of artificial targets or tethered fish that can be passed across the recording field at measured turbidity, depths and distances from the device in order to evaluate the error rate. Alternatively, a DIDSON unit could be paired with another device counter for a certain number of trials. Since the DIDSON is not limited by the range of turbidity expected for Central Valley streams the counts from the two devices can be compared, using the DIDSON count as truth. Staging trials in which target-species and non-target species, either free or tethered, are released through the range of a video camera will be used to assess video performance in recognizing the target species and presence/absence of an adipose fin.

## FIELD METHODS

When passage can be constrained using an enumeration fence, weir or trap (e.g., Cousens et al. 1982) just downstream from the device counter, timed releases of fish will be used to test the device counter. An observer will be positioned on a counting tower to monitor and visually count fish through the period of time when all fish have moved upstream of the device counter. Counts from the device counter recordings will be compared to the visual counts (e.g., the number of fish released from the weir).

When fish passage cannot be constrained, timed comparisons of visual and device counts will be made by stationing an observer on an observation tower overlooking the counter site. A visual marker will be placed on the bottom of the river to mark the device counter's maximum fish recording distance, if this distance is less than the entire stream width. Care should be taken to insure that the visual marker does not disturb fish and prevent them from entering the device counter range. The observer will count all fish passing between the distance reference and the near bank over a pre-specified time period. Again, counts from the device counter recordings will be compared to the visual counts.

Some streams may experience extreme environmental effects which cannot be corrected by simultaneous visual counts of live fish. These include situations during extreme turbidity and high flow. Monitoring on the Thorsa River (Iceland) suggested that the Vaki Riverwatcher is expected to provide correct counts up to a secchi depth of at least 4 inches (Vaki-DNG 2000). Maxwell and Gove (2004) found that in DIDSON images a plastic target sphere roughly the volume of a sockeye salmon was visible within 17 m at turbidity levels of 800 NTU's (Figure 5), while in clear water (secchi 4.0 -5.5 m) the plastic sphere was visible at 26 m. For almost all conditions in Central Valley steelhead streams the DIDSON's ability to provide accurate counts is not expected to be limited by turbidity. Assuming the DIDSON can provide a true count under turbid conditions, a DIDSON counter should be paired with either of the other two device counters during high turbidity conditions to provide a means of measuring device counter error rates due to turbidity. By constraining fish passage immediately below device site and using staged releases of fish (known numbers) for passage through the device we could compare the known numbers to the device counts. Here the DIDSON would be assumed to provide the true count. Alternatively, fish could be towed through the counting site during various conditions.

Measurements of environmental conditions (e.g., flow, turbidity, lighting conditions, device operator ID) will be made during the validation tests as well as for every day of the migration period. These potential explanatory covariates will be used during modeling and prediction (see below) to account for variations in error rates. All fish counting towers will be covered and include a light source beside the gate to the upstream barrier so that continuous counts can be made regardless of weather or time of day. Fish which fall back below the device counter range during validation tests will be noted as having been possibly double counted by the device. Fish that are clearly moving upstream but have not disappeared from the field of view when the device film/files have ended will be included in the upstream count. These 'event' based approaches are necessary to assess the accuracy and precision of the device counter over a range of fish densities and water visibility conditions (Maxwell and Gove 2004, Holmes et al. 2006). The decision as to which streams are to be tested depends on the frequency and extent to environmental conditions are expected to change. These field methods just described represent the minimum field tests that are necessary to produce valid estimates of total escapement. However, more field testing will be necessary if other conditions exist. For instance, if species misidentification is a potential issue or the device counter is not operational for an extended period of time. These additional protocols are described below.

## STATISTICAL ANALYSIS

### *Estimating Detection Rates for a Device Counter*

As mentioned above, error rates for a device counter could involve missed detections or false detections. Normal linear regression (Kutner et al. 2005) will be used to estimate the probability of detection for each device counter over the range of environmental conditions when the visual/DIDSON counts are obtained during the trials were considered to have been made without error. The data taken from each validation trial will consist of a series of paired counts from the counting towers, tethered fish or DIDSON counts, and the estimates from the device counter being tested. Each set of paired counts correspond to one validation trial and will have a set of covariate information (e.g., flow, turbidity, lighting conditions, device operator ID). The response values in the model will be the number of device counts for each trial divided by what is considered the true count (i.e., visual or DIDSON count) for that trial. The normal linear regression modeling may require identification of a suitable transformation of the proportion of counts to meet the model assumptions. This method allows for estimating adjustment terms that incorporate for missed counts, false counts, mixed counts, and double-counts. Here the estimated detection rates will be specific to each covariate combination.

Identification of the best covariates for modeling detection rates will be carried out using the small sample version of Akaike's information criterion (AICc, Burnham and Anderson 2002). The use of covariates for counting conditions will provide information on river conditions affecting accuracy and precision of counts. The observer ID covariate will allow for an estimate of the importance of variation between individual device counter operators.

### *Sample Sizes for Estimating Detection Rates*

In order to estimate the error rates of device counters at acceptable levels of precision an adequate number of paired trials will need to be conducted. Sample sizes required for given levels of effect size (difference between visual counts and device counts), statistical significance (alpha), and statistical power can be estimated via linear regression analysis of the device counts versus visual/DIDSON counts as paired trials are being conducted. The method proceeds as follows. The variance of the regression slope (*b*) of device count versus visual/DIDSON counts is given by

$$s_b^2 = \frac{MSE}{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2} \tag{1}$$

where MSE is the mean square error estimated from the linear regression of device counts on visual/DIDSON counts, $X_i$ is the visual/DIDSON count for the $i^{th}$ paired trial, and $n$ is the number of paired events (sample size) during which $X_i$ fish were counted. Power $(1-\beta)$ where $\beta$ is the probability of a type II error, can be calculated using

$$t_{1-\beta} = t_\alpha + \frac{\delta}{s_b}, \tag{2}$$

and

$$Power = 1-\beta = P\left(t \geq t_{1-\beta}\right), \tag{3}$$

where $\delta$ is the detectible effect size or difference between the Vaki count and the true count. Sample sizes which provide power of at least 0.80 are recommended. Gamma ($\delta$) should be set so that $\frac{\delta}{MSE} \leq 0.10$. This will insure that there is minimal sampling variability contributed by estimated detection rate.

***Estimating Daily Escapement***

Assuming either flow, turbidity or both are selected as important variables in explaining the variation in detection rates, the estimated expected values of those detection rates will be used to adjust the device counts. Recall that detection rates ($\hat{p}$) are estimated from linear regression analysis and can be less than 1 or greater than 1, depending if under-counting or over-counting dominates during certain environmental conditions. For the case where both flow and turbidity are included as explanatory covariates in the final linear regression model for detection rates, the adjusted count for the $i^{th}$ day of the counter enumeration which experienced flow level *j* and the turbidity level *k* is

$$\hat{C}_i = \frac{C_{i,\,flow_j,turbidity_k}}{\hat{p}_{flow_j,turbidity_k}}. \tag{4}$$

Bootstrapping (Davison and Hinkley 1996) will be used to estimate the standard error (SE) and a 90% confidence interval (CI) for total escapement within a day. Two thousand bootstrap samples will provide 2000 additional estimates of total escapement for each day. The standard deviation (SD) of the 2000 estimates for each day will be used as an estimate of the SE, and the 5th and 95th percentiles of the $B$ = 2000 estimates will be used for the lower and upper 90% confidence interval limits, respectively. The bootstrap algorithm proceeds as follows:

1. For each bootstrap replicate, indexed $b = 1,\ldots,B$:

   (a) Generate bootstrap sample $X^{*(b)} = \begin{pmatrix} y_1^* & x^*_{11} & \cdots & x^*_{1p} \\ \vdots & \vdots & & \vdots \\ y_n^* & x^*_{n1} & \cdots & x^*_{np} \end{pmatrix}$ by sampling with replacement from the $n$ rows of the observed dataset for the selected detection rate model.

   (b) Compute the $b^{th}$ replicate estimates of $\bar{p}^{(b)}$ from the $b^{th}$ bootstrap sample in (a).

2. Calculate the $b^{th}$ replicate estimates of the daily estimated escapements, $\hat{C}_i^b$ using (4).

3. The SE is the sample standard deviation of the replicates $\hat{C}_i^{(1)},...,\hat{C}_i^{(B)}$. The bootstrap 90% confidence interval is the 5$^{th}$ and 95$^{th}$ percentiles of the replicates $\hat{C}_i^{(1)},...,\hat{C}_i^{(B)}$.

***Estimating Seasonal Escapement***

The total escapement for the spawning migration period will be estimated using the sum of the $n$ daily escapement estimates

$$\hat{E}_{total} = \sum_{i=1}^{n} \hat{C}_i . \tag{5}$$

With the assumption of independence of adjusted counts over all days of the spawning migration period the variance of the total escapement can be estimated as the sum of the variances of the individual daily adjusted counts

$$\hat{\mathrm{var}}\left(\hat{E}_{total}\right) = \sum_{i=1}^{n} SE\left(\hat{C}_i\right) . \tag{6}$$

An approximate 90% asymptotic confidence interval for the total escapement over the entire $t$ days of the spawning migration is

$$CI = \hat{E}_{total} \pm 1.65 \times \sqrt{\hat{\mathrm{var}}\left(\hat{E}_{total}\right)} . \tag{7}$$

***Estimating Error in Species and Stock of Origin***

If species other than steelhead (e.g., Chinook, resident rainbow trout, pikeminnow) are expected to result in false counts, or it is necessary to estimate escapement by stock of origin (wild or hatchery), it will be necessary to estimate detection rates for target species and/or origin group for each location where a device counter is used. Both the Vaki Riverwatcher and the DIDSON may have low reliability for correctly identifying adipose fins, fish length, or species identification (Holden and Struthers 1997, Miller et al. 2003, Stanislaus weir email summary 2005, Baumgartner 2010) (Figures 1, and 5 – 7). However, Vaki Riverwatcher and DIDSON have been shown to be both accurate and precise with accuracy in the range of mid to high 90$^{th}$ percentile for fish passage rates generally encountered in the Central Valley, and can operate at a greater detection range than a video device counter (Holmes et al. 2006, Maxell and Gove 2007). When completely submersed in a plexi-glass box of clear water video device counters have been shown to give good discrimination of species and adipose fin recognition (Gates and Boersma 2009). If video camera images have acceptably high discriminatory ability, video cameras will be paired with the Vaki Riverwatcher or DIDSON when non-target species (or origin) are present and at random intervals throughout the migration period. This will allow for independent estimates of the proportions of the target species (or origin) during each temporal segment of the spawning migration period. To assess video reliability in identifying target species and presence or absence of an adipose fin, video counts will be used to estimate the ratio of the target species to the rest of the fish in the stream across a range of environmental conditions (e.g., turbidity and flow).

If species other than steelhead result in false counts, or it is necessary to estimate escapement by stock of origin, the escapement estimation procedure described above will need to be modified as follows:

1. Carry out calibration trials to obtain the best device settings for the video for optimal discrimination of the target species and adipose fin recognition.

2. Estimate the video detection rate of the target species, $\bar{\hat{R}}_{jk}$ (equation [8] below) and the rate of fish identified as wild (adipose fin recognition) using trials with known targets.

3. Calculate the proportion of total video fish that are the target fish using a video device counter across a range of days during the migration period and a range of environmental conditions, $\hat{P}_{video_{jk}}$ (equation [9] below).

4. Estimate escapement of the target species (and origin) for a survey day from paired video and device survey counts for a given set of environmental conditions. This is done by estimating the number of target fish comprising the device counts by multiplying the device counts adjusted for detection rate, $\hat{C}_i$ (equation [4] above), by the proportion ($\hat{P}_{video_{jk}}$) of target fish counted in the video images. Finally, obtain the corrected estimate of escapement, $\hat{E}_{ijk}$ (equation [10] below), by dividing the estimated number of target fish by the estimated video detection rate ($\bar{\hat{R}}_{jk}$) obtained in step 2.

In order to calibrate the video and train image processing personnel to minimize false counts, calibration trials in which pikeminnow, Chinook and steelhead (the latter two with and without adipose fins) can be allowed to pass through the recording range of the counting device. Target fish will be presented at a range of distances from the video over a range of water depths, turbidity and flow conditions to obtain video settings and installation setup which allow for optimal discrimination of target species and origin groups (Maxell and Gove 2004). Those video settings giving the highest proportion of correct counts by species and origin group will be used for all escapement estimates. If fish cannot be tethered or manipulated to pass by the device counter, it could be assumed that during clear water conditions the video camera could provide 'true' estimates and be used to calibrate the DIDSON.

The second step in the process involves a series of trials used to estimate the rate of target fish counts by releasing through the imaging field of the video individual fish of known species/origin over river conditions having a range of flow and turbidity levels. For the case in which the trials use only steelhead and Chinook, the estimated rate of steelhead discrimination is the ratio of the count of fish identified as steelhead in the video image to the true number of steelhead in the trials for the given environmental conditions. The mean ratio over *n* trials with varying turbidity and flow levels is

$$\bar{\hat{R}}_{jk} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_{video,ijk}}{C_{steelhead,ijk}}, \tag{8}$$

where $C_{video,ijk}$ and $C_{steelhead,ijk}$ are the counts of fish identified as steelhead in the video and counts of the true number of steelhead for the $i^{th}$ trial during turbidity level $j$ and flow level $k$ respectively.

The estimated proportion of target fish counted in the video for the $i^{th}$ day of the survey when the video camera is paired with the device (Vaki or DIDSON) is

$$\hat{P}_{video,ijk} = \frac{C_{video(steelhead),ijk}}{C_{video(total),ijk}}, \tag{9}$$

where $C_{video(steelhead)ijk}$ is the count of steelhead for turbidity level $j$ and flow level $k$, and $C_{video(total),ijk}$ is the total fish count for the video for turbidity level $j$ and flow level $k$ when the video camera is paired with the device (Vaki or DIDSON) on the $i^{th}$ day of the survey.

Estimated escapement for the $i^{th}$ survey day during the $j^{th}$ turbidity level and $k^{th}$ flow level is estimated in the third step as

$$\hat{C}_i' = \frac{\hat{P}_{video,ijk}}{\bar{\hat{R}}_{jk}} \times \hat{C}_i, \tag{10}$$

where $\hat{C}_i$ was estimated using equation (4) above, and $\hat{C}_i'$ is the new adjusted estimate.

Standard errors for the daily total escapement estimates adjusted for species or origin misidentification can be calculated using the bootstrap method described above. However, the bootstrap procedure will need to be amended to include new bootstrap estimates for equations (8) and (9). Following the bootstrap, new estimates of the total escapement during the migration period, along with a 90% confidence interval, can be obtained using equations (5) – (7) above (recognizing the need to switch from $\hat{C}_i$ to $\hat{C}'_i$ in those equations).

False identification of Chinook as steelhead will depend on the degree of overlap in the migration of the two species. The period and extent to which both steelhead and Chinook are expected to be migrating past a site will vary by river but should be minimal (Hannon and Deason 2005, Pagliughi 2008). However, this time may extend for as long as a month in some waters (Hannon and Deason 2005). Intensive sampling using fyke nets or weirs set downstream or upstream from the device counter will be used to provide an independent estimate of the true proportions and run-timing of target species, non-target species and origin groups. Additionally, the sampling will collect scale and tissue samples and record lengths from steelhead to determine the proportion of resident non-anadromous stream rainbow trout in the migrating population information that will be used to adjust final steelhead escapement estimates.

***Imputation of Missing Data: Extended Periods of Missing Data***

Missing data can occur for a number of reasons. We expect that the test analyses and regression results described above will provide unbiased estimates of escapement at a range of turbidity and flow conditions when the device counter is in operation. However, extreme high water, excessive turbidity or malfunctioning of equipment may result in a device counter being non-operational for extended periods from several hours to several days. These are considered to be missing at random. Missing data due to malfunctioning of equipment is the condition of data missing completely at random. That is the condition of being missing is not dependent on the number of fish present on any day and not dependent on any other variable. While device counts will be dependent on turbidity levels, actual fish passage or the true count may not be dependent on turbidity or high flow events. The exception to this would be when fish are staging at a downstream location due to lower than normal flows or behind a partial barrier just before a high flow event. Data from Clear Creek, Mokelumne River and the American River do not indicate a general relationship between fish passage rate and discharge (Hannon and Deason 2005, Giovannetti and Brown 2007, Pagliughi 2008).

Generalized additive regression models (GAM) using either spline fitting (LOESS) or locally weighted regression (LOWESS; Hastie and Tibshirani 1990, Zanobettie et al. 2000, Woods 2006) will be used to predict missing counts during these extended periods. Standard errors and 90 % confidence intervals will be computed for the predictions. The autocovariance function will be computed for the GAM model to test for autocorrelation in the counts. Distributed lag terms will be included in the model according to the method described in Zanobettie et al. (2000) if autocorrelation is found to be significant at the alpha = 0.1 level (equivalent to a 90% CI).

A second Bayesian method is also recommended. This method involves estimating a posterior predictive distribution from which the missing values are predicted (Gelman et al. 2004, Ntzoufras 2009). Variances and 90% credible intervals of the counts for the missing days can be computed by sampling from the posterior predictive distribution.

Which of these two methods is best to use may depend on the degree to which prior information exists on the correct distribution of the data.

Both recommendations described above provide methods to impute the missing data for each period of time, along with methods for calculating variances for those imputations. If data imputation is necessary, simply include those imputed escapement estimates in and their estimated variances in equations (5) – (7) to obtain a total escapement estimate and 90% for the spawning migration period.

*Generalized Additive Modeling (GAM) of Missing Values*

Likely distributions for the count data can be Poisson, binomial, negative binomial or approximately Gaussian if the counts are large (say median count > 25). The day of the missed count is used as an explanatory covariate potentially along with other covariates if these are found to be related to the period of missing data. Then, a generalized additive model (GAM) can be used to predict the missing count data using splines or locally weighted regression.

The additive model applied on the estimated daily escapement (response variable $Y_i$) and day (explanatory variable $X_i$) variable is

$$Y_i = \alpha + f\left(X_i\right) + \varepsilon_i \,, \tag{20}$$

where $\varepsilon_i \sim N\left(0, \sigma^2\right)$.

Writing $f\left(x_i\right)$ as a linear regression model in terms of basis functions $b_j\left(X_i\right)$ we get

$$f\left(X_i\right) = \sum_{j=1}^{p} \beta_j \times b_j\left(X_i\right). \tag{21}$$

Suppose that p = 4. This gives

$$f\left(X_i\right) = \beta_1 \times b_1\left(X_i\right) + \beta_2 \times b_2\left(X_i\right) + \beta_3 \times b_3\left(X_i\right) + \beta_4 \times b_4\left(X_i\right). \tag{22}$$

For a cubic polynomial where

$$b_1\left(X_i\right) = 1, b_2\left(X_i\right) = X_i, b_3\left(X_i\right) = X_i^2 \;, b_2\left(X_i\right) = X_i^3$$

we have

$$f\left(X_i\right) = \beta_1 + \beta_2 \times X_i + \beta_3 \times X_i^2 + \beta_3 \times X_i^3 \,, \tag{23}$$

which can give a wide range of possible shapes, depending on the values of the coefficients (Zuur et al. 2009).

Models with more than one explanatory variable can also be fitted:

$$Y_i = \alpha + f_1\left(X_i\right) + f_2\left(Z_i\right) + \varepsilon_i \tag{24}$$

where $\varepsilon_i \sim N\left(0,\sigma^2\right)$, where $f_1\left(X_i\right)$ and $f_1\left(Z_i\right)$ are functions of covariates. In this case $Z$ could represent sex, water temperature or discharge if these were expected to be implicated in run timing.

Since the LOESS smoother and the polynomial and cubic regression splines are local regression models they can be written in the same form as the linear regression model:

$$\hat{Y} = S \times Y \quad and \quad \operatorname{var}\left(\hat{Y}\right) = \sigma^2 \times S \times S', \tag{25}$$

where S is analogous to the hat matrix, $X\left(X'X\right)^{-1}X'$ in multiple linear regression where X is the design matrix of 1's and covariates and $\sigma^2$ is the variance of the response (counts) and the expressions $\hat{Y}, Y, X, and\ S$ are vectors and matrices.

An estimated standard error for the $i^{th}$ missing value is given by:

$$s\hat{e}\left\{\hat{Y}_i\right\} = \sqrt{\hat{\sigma}^2\left(1 + x_i^{'}S\left(S'S\right)^{-1}S'x_i\right)}, \tag{26}$$

where $x_i$ is the $p \times 1$ vector of $i^{th}$ row ($i^{th}$ observation) of the design matrix X containing the covariate values. A 90% confidence interval for the $i^{th}$ predicted value is

$$\hat{Y}_i \pm t_{n-p-1,\alpha/2} \cdot s\hat{e}\left\{\hat{Y}_i\right\}. \tag{27}$$

*<u>Estimating Missing Values Within a Bayesian Framework</u>*

Estimates of missing values are based on predictive distributions, or the distribution of the data averaged over all possible parameter values (Gelman et al. 2004, Ntzoufras 2009). Distributions may be Gaussian, Poisson, negative binomial or binomial. The choice of which distribution to use will depend on goodness of fit tests and posterior predictive checking and sensitivity analyses (Gelman et al. 2003, pgs 157–176). Therefore, when say, Gaussian data $y$ (estimated daily escapement), (substitute summations for integrals for discrete data) have not been observed yet, predictions are based on the marginal likelihood

$$f(y) = \int f(y \mid \theta) f(\theta) d\theta, \tag{28}$$

which is the likelihood averaged over all parameter values backed up by our prior beliefs. In this example $f(y)$ is also called the prior predictive distribution. After having observed data $y$, we can find the prediction of missing data $y'$. We then compute the posterior predictive distribution

$$f(y' \mid y) = \int f(y' \mid \theta) f(\theta \mid y) d\theta, \tag{29}$$

which is the likelihood of the future data averaged over the posterior distribution $f(\theta \mid y)$. Another way to view missing data $y'$ is as additional parameters under estimation for which the joint posterior distribution is given by $f\left(y',\theta \mid y\right)$. Inference on the future observations $y'$ can be based on the marginal posterior distribution $f\left(y' \mid y\right)$ by integrating out all nuisance parameters. One such nuisance parameter is the parameter vector $\theta$. Now, the predictive distribution is given by

$$f\left(y' \mid y\right)=\int f\left(y',\theta \mid y\right)d\theta=\int f\left(y',\theta \mid \theta, y\right)f\left(\theta \mid y\right)d\theta, \tag{30}$$

since known and missing observations ($y$ *and* $y'$ respectively) are conditionally independent given the parameter vector $\theta$ (Ntzoufras 2009).

The Poisson regression model assumes that $y$ (daily count data) is Poisson with mean $\mu$ (and therefore variance $\mu$). The link function is typically chosen to be the logarithm, so that $\log \mu = X\beta$. The distribution for count data $y=\left(y_{1,\ldots,}y_n\right)$ is therefore

$$p\left(y \mid \beta\right)=\prod_{i=i}^{n}\frac{1}{y_i!}e^{\exp(\eta_i)}\left(\exp\left(\eta_i\right)\right)^{y_i}, \tag{31}$$

where $\eta_i=\left(X\beta\right)_i$ is the linear predictor for the $i^{\text{th}}$ case (McCullagh and Nelder 1989). The initial one covariate model will have the following structure:

$$\begin{aligned} &count_i \sim Poisson\left(\lambda_i\right) \\ &\log \lambda_i=\beta_1+\beta_2 day_i \quad for\ i=1,2,\ldots,n. \end{aligned} \tag{32}$$

The prior distributions for the $\beta$'s are

$$\begin{aligned} &\beta_1 \sim N\left(0,0.0001\right) \\ &\beta_2 \sim N\left(0,0.0001\right). \end{aligned} \tag{33}$$

If we consider a missing observation $Y_i$ with known covariate value $x_i$ then we can estimate its expected value $E\left(Y_i \mid y, x_i\right)$ using the predictive distribution

$$p\left(y_i \mid \underline{y}, x\right)=\sum p\left(y_{i|} \mid \beta, x_i\right)p\left(\beta \mid \underline{y}\right), \tag{34}$$

and $Y_i$ can be considered as an additional parameter under estimation. Therefore, it can be generated within an MCMC algorithm from the conditional posterior distribution and we can generate $y_i$ in the iteration of the algorithm by

$$\overset{(t)}{y_i} \sim P\left(\overset{(t)}{\log\left(\lambda\right)_i}\right) with \overset{(t)}{\log \lambda_i}=E\left(Y_i \mid \overset{(t)}{\log \lambda_i}, x_i\right)=\beta_1^t+\beta_2 x_i^{(t)}. \tag{35}$$

In WinBUGS (Lunn et al. 2000) we can define an additional stochastic node ynew ($y_i$)

$$\begin{aligned} &ynew \sim dnorm(munew) \\ &munew <- beta1 + inprod(beta[], xnew[]) \end{aligned}, \tag{36}$$

where xnew[] is the vector with element(s) of the explanatory value(s) for the missing (to-be-estimated) response. It is important to note that we need to specify *xnew* in the data of the WinBUGS model code. We also need to specify that the value of *ynew* (missing value for a given day) is not available by setting *ynew*=NA in the list data format. *Ynew* is treated in a way similar to that used for parameters that are to be estimated. Otherwise we substitute specific missing count data elements with NA values in the list format. After compiling and running the model, posterior summaries of y will provide standard errors and credible intervals for the missing (i.e., stochastic) counts of the vector *ynew*.

***Estimating Within- and Between-observer Variability***

Within-observer (device operator) variability consists of individual-specific observer errors in the assignment of counts to device images. This includes all activities undertaken by the observer which affect a given count. Within-observer variability can be minimized by extensive observer training and conducting test trials prior to analysis of the device counter images. If results from the test trials indicate unacceptable levels of variability, either within- or between-observers, additional training and testing will be conducted prior to analysis the current season's device counter images.

Test trials will involve each observer processing the same sample of device counter images/files multiple times. We recommend using a sample of 10 images/files from previous years. Each sample will consist of 20 minutes of device counter operation. The sample of images/files will be chosen so as to best represent the variable environmental conditions and fish passage rates. Each observer will view each of the 10 files 5 times.

The coefficient of variation for an individual observer *i* for file *j* is a measure of within-observer precision (Jones et al. 1998)

$$CV_{W-O,ij} = \frac{\sqrt{\sum_{k=1}^{n_k} \left(X_{ijk} - \overline{X}_{ij}\right)^2 / \left(n_k - 1\right)}}{\overline{X}_{ij}}, \qquad (37)$$

where $X_{ijk}$ is the $k^{\text{th}}$ replicate count for observer $i$ viewing file $j$, $n_k$ is the number of replicate counts for the $i^{\text{th}}$ recording (we recommend a minimum of 5), and is the mean count for observer *i* across the replicate counts for file *j*. An average of the coefficient of variation estimates for an individual observer across the sample of image files will be used as the measure of within-observer variability for each individual. As a general rule of thumb, a coefficient of variation greater than 0.10 will be cause for concern as larger values can be expected to result in substantial errors in escapement estimates.

Another source of error that is often overlooked in escapement estimation of all types is the variability of counts among observers (Cousins et al. 1982, Symons and Waldichuk 1984, Jones et al. 1998). The variability between observers will also be assessed using the same methods described above (i.e., replicate viewings of 10 files by each observer). An assessment of the device counts among observers who process the data, stratified by file, can be accomplished using the coefficient of variation (CV) and the average percent error (APE), where

$$CV_j = \frac{\sqrt{\sum_{i=1}^{R_j} \left(\overline{X}_{ij} - \overline{X}_j\right)^2 / \left(R_j - 1\right)}}{\overline{X}_j}, \tag{38}$$

*R* is the number of observers that viewed file *j*, $\overline{X}_{ij}$ is the average count by observer *i* for file *j*, and $\overline{X}_j$ is the average count for file *j* across observers. Here the CV is a measure of the precision of counts from different observers for a particular file. Again, these estimates can be averaged across the sample of files to get an overall assessment across various environmental conditions and fish passage rates. If the CV exceeds 0.10 additional training should be provided until observer variability is at or below 10%.

## Conclusions

Estimating total escapement using fish enumeration counters requires identifying and accounting for a number of sources of error and variability which may be dependent on a variety of factors involving the river environment, the device itself, the species present in the spawning run and the observers who process the recorded count data. We assume in this report that the proper device counter is chosen for each stream location and that the device is installed in an optimal place in the stream where fish are confined to pass within the recording range of the device during normal operating conditions. It is also imperative that the device settings are optimal for maximum counting accuracy and precision again given the specific geometries of the location, bottom profile, depth etc. Methods available for validating and assessing the accuracy of device counters are relatively new in the fisheries literature and not well tested over a full range of field conditions. Thus, some considerable experimentation, exploration and resources may be required to carry out the validation and calibration trials described above as each stream's field location and river parameters are different. However, this work will be justified since the reward will be more accurate and precise estimates of total escapement necessary for effective monitoring trends and abundance in Central Valley steelhead.

### LITERATURE CITED


Baumgartner, L., M. Bettanin, J. McPherson, M. Jones, B. Zampatti and K. Beyer. 2010. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Muray-Darling Basin. Industry & Investment NSW-Fisheries Final Report Series, No. 116.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.

Cousens, N. B. F., G. A. Thomas, C. G. Swann, and M. C. Healey. 1982. A review of salmon-escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences: 1108.

Davison, A. C., and D. V. Hinkley. 1996. Bootstrap methods and their application. Cambridge University Press, Cambridge, New York, USA.

Gates, K. S., and J. K. Boersma. 2009. Abundance and run timing of adult Chinook salmon and steelhead in the Funny River, Kenai Peninsula, Alaska, 2009. Alaska Fisheries Data Series Number 2009-16, U.S. Fish and Wildlife Service.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. Chapman & Hall/CRC, Boca Raton, Florida, USA.

Giovannetti, S. L., and M. R. Brown. 2007. Central Valley steelhead and late fall Chinook salmon redd surveys on Clear Creek, California. U.S. Fish and Wildlife Service; Red Bluff Fish and Wildlife Office.

Hannon, J., and B. Deason. 2005. American River steelhead (*Oncorhynchus mykiss*) spawning 2001 – 2005. Central Valley Project, American River, California, Mid-Pacific Region.

Hastie, T. J., and R. J. Tibshirani. 1990. Generalized additive models. Chapman & Hall/CRC, Boca Raton, Florida, USA.

Holden, A. V., and G. Struthers. 1997. Fish counters seminar: proceedings of a one-day seminar held at A K Bell Library, Perth. The Atlantic Salmon Trust and The Institute of Fisheries Management (Scottish Branch).

Holmes, J. A., G. M. W. Cronkite, H. J. Enzenhofer, and T. J. Mulligan. 2006. Accuracy and precision of fish-count data from a "dual-frequency identification sonar" (DIDSON) imaging system. ICES Journal of Marine Science 63: 543 – 555.

Jones, E. L., and T. J. Quinn. 1998. Observer accuracy and precision in aerial and foot survey counts of pink salmon in a southeast Alaska stream. North American Journal of Fisheries Management 18:832 – 846.

Kutner, M. H., C. J. Nachtsheim, J. Neter, and W. Li. 2005. Applied linear statistical models. McGraw-Hill, Boston, Massachusetts, USA.

Lauver, E.D. 2007. Priest Rapids project video fish-counting program annual report 2007. Public Utility District No. 2 of Grant County, Ephrata, WA 98823. Page 2 of Appendix C.

Lunn, D.J., A. Thomas, N. Best, and D. Spiegelhalter. 2000. WinBUGS - a Bayesian modelling framework: concepts, structure, and extensibility. Statistics and Computing 10:325 – 337.

Mackey, E. 2005. Trends in Atlantic salmon: the role of automatic fish counter data in their recording. Scottish Natural Heritage Commissioned Report No. 100.

Maxwell, S. L., and N. E. Gove. 2004. The Feasibility of estimating migrating salmon passage rates in turbid rivers using a dual frequency identification sonar (DIDSON). Regional Information Report No. 2A04-05, Alaska Department of Fish and Game.

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Second edition. Chapman & Hall, Boca Raton, Florida, USA.

Miller, J. D., D. L. Burwen and S. J. Fleischman. 2003. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2001. Alaska Fishery Data Series No. 03-03.

Ntzoufras, I. 2009. Bayesian modeling using WinBUGS. Wiley & Sons, New York, New York, USA.

Pagliughi, S.W. 2008. Fall-run Chinook salmon and winter-run steelhead redd survey report: October 2007 through March 2008. East Bay Municipal District, 1 Windemasters Way, Lodi, CA 95240.

Santos, J. M., P. J. Pinheiro, P. J. Ferreira, and J. Bochechas. 2008. Monitoing fish passes using infrared beaming: a case study in an Iberian river. Journal of Applied Ichthyology 24:26 – 30.

Stanislaus weir email summary 2005. http://www.sanjoaquinbasin.com/resources/stanweir_archives/Postcards04/postcard8.htm

Symons, P. E. K., and M. Waldichuck, editors. 1984. Proceedings of the workshop on stream indexing for salmon escapement estimation, West Vancouver, B.C. Canadian Technical Report of Fisheries and Aquatic Science 1326.

Tiffan, K., F., and D. W. Rondorf. 2004. Imaging fall Chinook salmon redds in the Columbia River with a dual-frequency identification sonar. North American Journal of Fisheries Management 24:1421 – 1426.

Woods, S. N. 2006. Generalized additive models: an introduction with R. Chapman & Hall/CRC, Boca Raton, Florida, USA.

Vaki-DNG Ltd. 2000. Letter from B. Traustason (Vaki-DNG Ltd.) to T. McCarthy (Water Management Technologies) regarding turbidity levels. December 13, 2000. Quoted from Biological Opinion – Authorization from the construction and future operation of the Robles diversion Fish Passage Facility.

Zanobetti, A., M. P. Wand, J. Schwartz, L. M. Rayan. 2000. Generalized additive distributed lag models: quantifying mortality displacement. Biostatistics 1: 279 – 292.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effect models and extensions in ecology with R. Springer, New York, New York, USA.

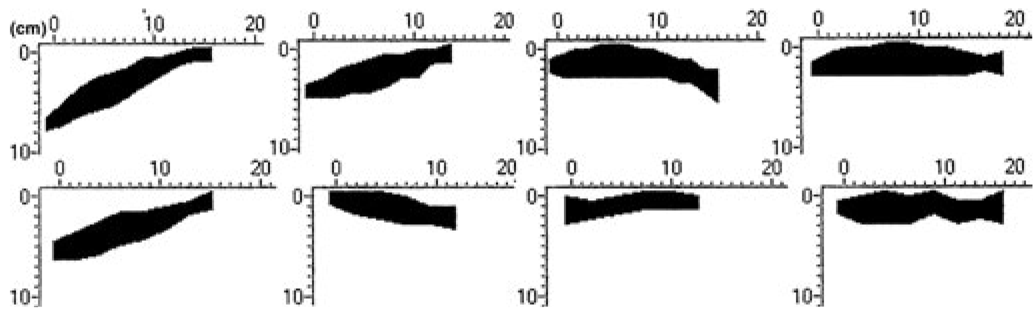


Figure 5. Silhouette examples recorded by the Vaki River-Watcher system (from Santos et al. 2007). Note the lack of defining characteristics, including dorsal and anal fin.

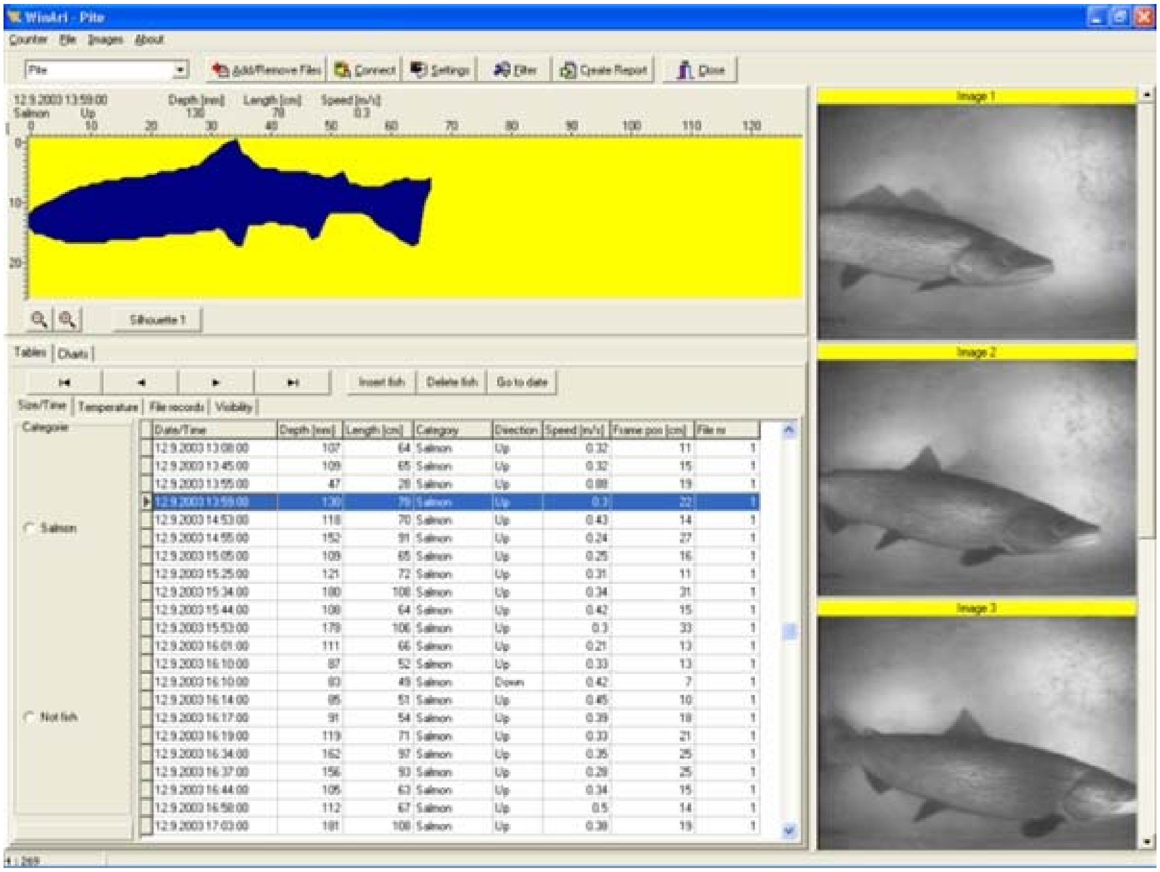

Figure 6. The Riverwatcher can be supplied with a digital camera system to record video or still images of fish passing through the scanner. The scanner triggers the camera to capture between 1 and 5 digital photos or a short video clip of each fish. The computer then automatically links the digital images to the other information contained in the database for that individual fish such as size, passing hour, speed, silhouette image, temperature etc. Image taken from Vaki, Inc. website:

http://www.vaki.is/Products/RiverwatcherFishCounter/CameraRW/.

Figure 7. Example of an image from the video fish counter system at Priest Rapids on the Columbia River, taken from Lauver (2007).

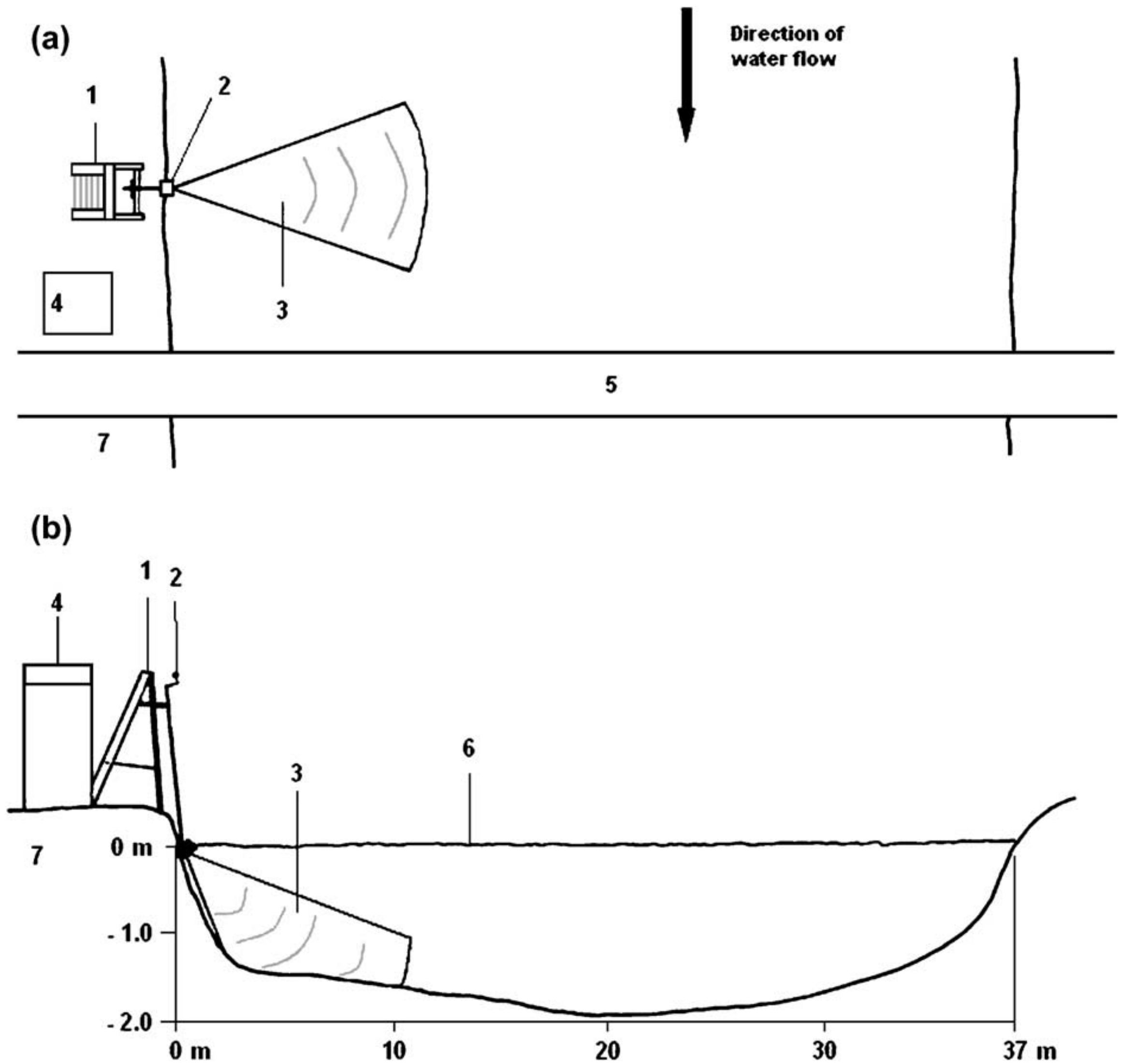


Figure 8. A schematic overhead (a) and side view (b) of a study area showing the deployment of the DIDSON imaging system and the water volume ensonified by the beams using a 1, counting tower; 2, DIDSON transducer mounted to adjustable pole mount; 3, ensonified water volume; 4, topside equipment shed; 5, bridge deck; 6, water surface; 7, right river bank. Note that the vertical and horizontal scales differ. River banks are labelled right and left relative to an observer facing downstream. Image taken from Holmes (2006).

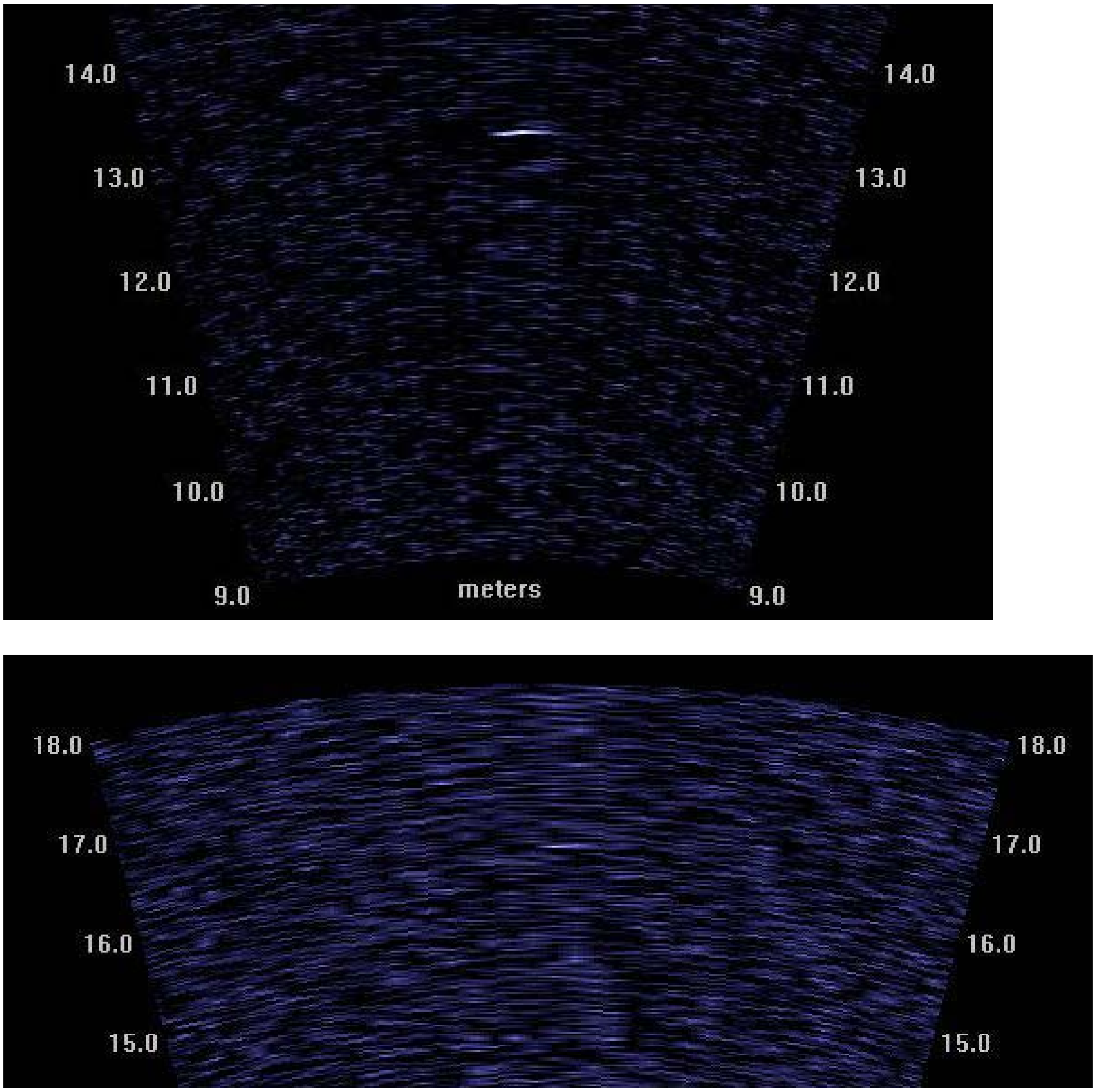


Figure 9. DIDSON image of the 10.16 cm plastic sphere shown at 13 m (top) and at 16.5 m (bottom) in turbid water. Image taken from Maxwell and Gove (2004).

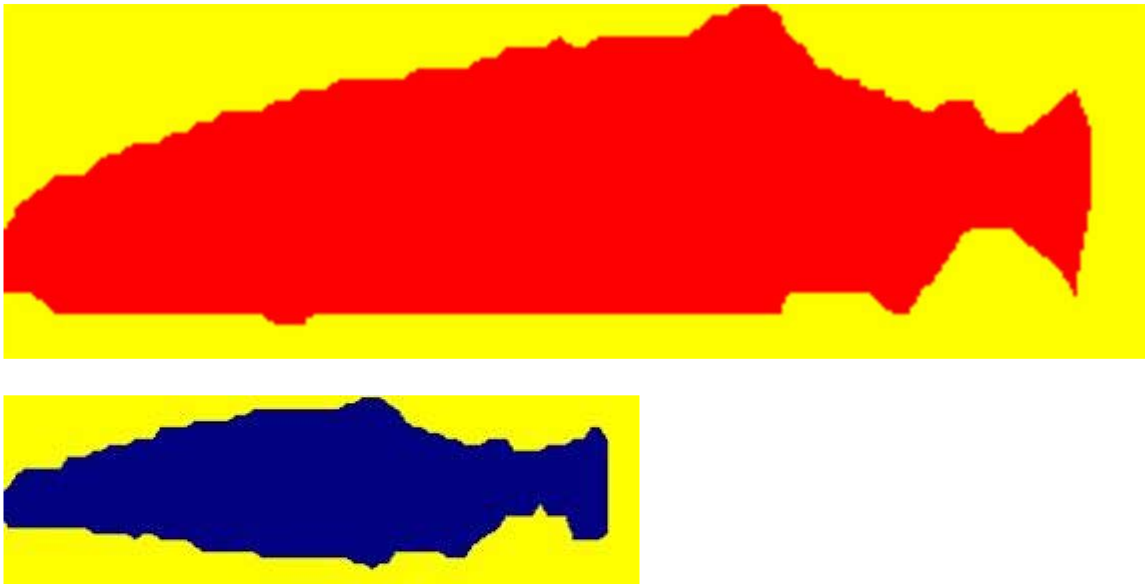

Figure 10. Above are the infrared silhouettes created from the *O. mykiss* as it passed through the Vaki scanner and into the trap. These silhouettes are very similar to the Chinook silhouettes and without a digital photograph could have easily been mistaken for a Chinook. Images obtained from Stanislaus weir e-mail summary (2005).

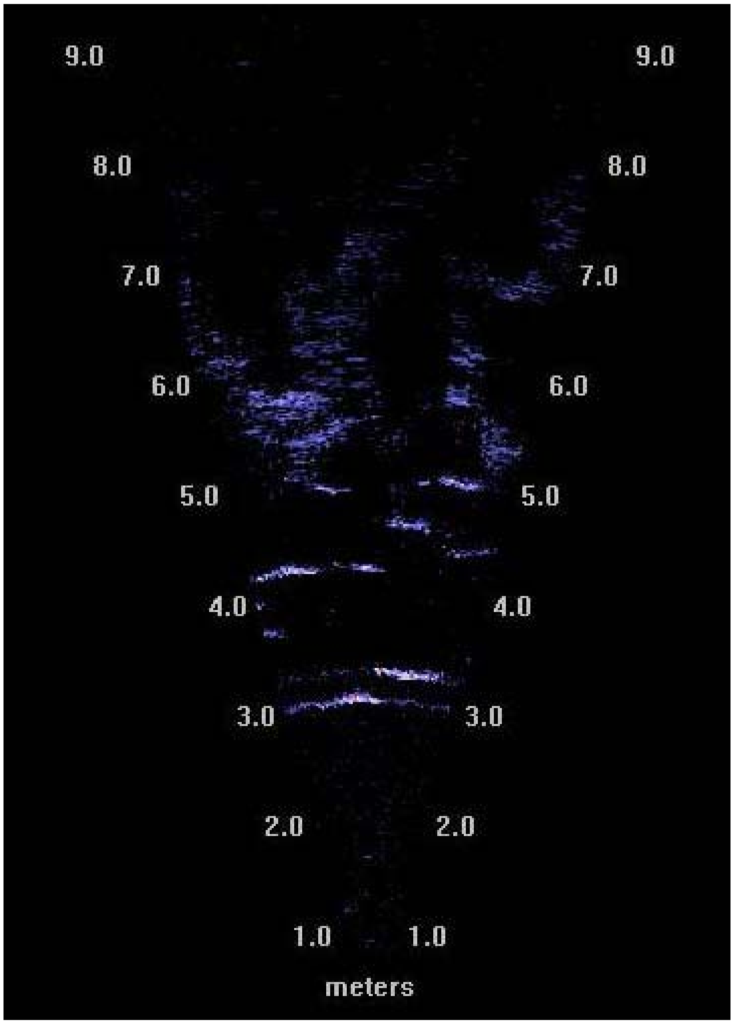


**Figure 11. DIDSON image of migrating sockeye salmon with the salmon images outlined. The remaining signal comes from a combination of river bottom and volume reverberation, Wood River, July 2, 2002. Image was taken from Maxell and Gove (2004)**

**APPENDIX C**

**RECOMMENDED PROTOCOLS FOR ESTIMATING STEELHEAD ABUNDANCE BASED ON REDD COUNTS**

# Central Valley Steelhead Monitoring Protocol: Escapement Estimation Based on Redd Counts

By

WEST, Inc.


**Western EcoSystems Technology**

2003 Central Avenue, Cheyenne, WY 82001

Phone: 307-634-1756  Fax: 307-637-6981

Jim Griswold

jgriswold@west-inc.com

Ryan Nielson

rnielson@west-inc.com


For

**Pacific States Marine Fisheries Commission**

May 25, 2010

# INTRODUCTION

Redd counts are commonly used for monitoring annual trends in the abundance of spawning salmonids. However, if redds are not detected with 100 percent accuracy, counting errors may obscure important population trends (Maxell 1999). In addition, in order to estimate escapement using redd counts corrected for observer error one must also estimate the number of females per redd and the ratio of females to males in the population. This document contains our recommendations for obtaining a total steelhead (*Oncorhynchus mykiss*) redd count for a watershed and using this count to estimate total escapement.

# METHODS

## Estimating the Total Number of Redds

Since spawning occurs over a period of months and redds can become obscured by scouring, fines and/or algae after just a few days, information from just a few repeated surveys within the spawning season cannot be used to obtain reliable estimates of the total number of redds for that season. Alternatively, even if the redd is not obscured by scouring or other conditions observers may fail to detect the redd. In this situation the redd is available to be seen but probability of detection is less than 1.0. In addition, we occasionally expect false positive identifications of steelhead redds – something that is not a steelhead redd is counted as one. These three situations need to be accounted for when estimating the number of steelhead redds within a watershed.

### *Estimating Redd Retention for Repeated Surveys*

Estimating the total number of steelhead redds present in a watershed during a spawning season requires multiple surveys in all or a sample of sub-reaches where potential spawning habitat exists. These repeated surveys will be conducted in order to minimize and adjust final estimates for the number of redds missed and number of false identifications by the survey crew. In order to accurately estimate the number of redds within a watershed the number and timing of repeated surveys should depend on the length of the spawning season and the length of time an individual redd can be detected. For example, if a high percentage of redds remain visible for no more than two weeks, surveys should be repeated at least every 14 days throughout the season until no new redds are observed and new steelhead are not expected to enter the system. An estimate of the duration of redd visibility will be obtained by returning to a sample of newly constructed and marked redds on a daily basis and determining the last day on which each redd was visible (Giovannetti and Brown 2007). The number of days over which at least ninety-five percent of redds are still visible will be used as the survey recurrence time. Using this method, all redds need to be marked with flagging and their positions recorded using a Geographic Information System (GPS). Estimating necessary survey recurrence intervals based on redd retention will ensure that the number redds present but not available to be seen during spawning season is low and does not substantially effect redd abundance estimates. If a moderate to large number redds are not available to be seen during the spawning surveys final estimates of redd abundance will be biased low.

The estimation of redd retention rates is necessary for precise and accurate determination of survey recurrence time and will allow the final estimator to account for missed redds due to scheduled surveys that were not conducted. Clear Creek and the lower Yuba River sampling designs already incorporate redd aging studies which have provided some guidance in establishing the maximum length of time between scheduled surveys. More accurate and precise estimates of redd retention rates will allow for measures of uncertainty in estimated survey recurrence intervals as well as estimates of missed counts and their standard errors. An example of the procedure for estimating recurrence time and missed counts is given in Appendix I.

The redd retention rate ( $R(t)$ ) is the probability of a redd being observable a minimum of *t* days (Appendix I; Kalbfleisch and Prentice 1980). Redd retention rate is estimated as

$$\hat{R}(t) = 1 - \frac{\sum_{j=1}^{t} d_j}{N}, \qquad (1)$$

where *t* is the number of days after identification (and flagging) of the redd, $d_j$ is the number of redds which were no longer detectable on the $j^{th}$ day after their construction, and *N* is the total number of redds followed daily in the study. The required data for estimating (1) are consecutive daily observations on a sample of newly constructed redds. Each day an observer will visit each redd and record the date and the status of each redd as being detectable or not detectable. This daily monitoring will occur until all redds in the sample are no longer visible. Then (1) is calculated for each value of *t*.

The asymptotic variance of the Kaplan-Meier estimate (1) is given by (Kalbfleisch and Prentice 1980),

$$V\hat{a}r\left[\hat{R}(t)\right] = \left[\hat{R}(t)\right]^2 \sum_{j<t} \frac{d_j}{n_j(n_j - d_j)}, \qquad (2)$$

$n_j$ is the number of redds still visible at time *j*.

The minimum survey recurrence interval should target the number of days for which the redd retention rate ≥ 0.95. The number of tagged redds to be used in the redd retention survey should be sufficiently large to allow the estimated coefficient of variation (CV) of estimated retention time to be less than 0.05;

$$CV = \frac{\sqrt{V\hat{a}r\left(\hat{R}(t)\right)}}{\hat{R}(t)} < 0.05\,. \qquad (3)$$

This will ensure that the estimate of the survey recurrence time provides a retention rate of between 0.90 and 1.0 95% percent of the time. The estimation of redd retention need only be done once for each study stream since it is a reasonable assumption that hydrological conditions which determine average retention rate should be fairly constant over time. However we also recommend that redds be aged according to the method used in Giovannetti and Brown (2007) so that the appropriateness of this assumption can be monitored.

### *Estimating Observer Error*

Estimation of observer error in redd counts (i.e., missed redds or incorrect identifications) requires repeated, independent surveys along a probabilistic-based (e.g., random, stratified random sampling) sample of sub-reaches during a short period of time (e.g., one day) when it can be assumed that no new redds were created and none were destroyed by scouring or obscured by silt or algae. In addition, one of the surveys must be conducted by expert observers

who produce survey results that can be considered 'truth' (no missed redds or incorrect identifications). To meet this assumption, the first team of surveyors should be well trained, experienced, and viewed as 'experts' by their peers. Directly following the first survey of a sample of sub-reaches by the expert team, the sampled sub-reaches will then be re-surveyed by a 2nd team of observers ("survey team") made up of a random sample from the pool of observers who will complete the surveys throughout the spawning period (Muhlfeld et al. 2006). In this scenario, the proportion of the total number of redds identified by the expert survey team that is also identified by 2nd survey team will be used as the estimated probability of detection.
Under this sampling design, all stream reaches with potential steelhead spawning habitat are divided into sub-reaches. Sub-reaches will be delineated with the objective of reducing the variation in habitat features within each sub-reach. For example, one sub-reach might be classified as a riffle with low canopy cover and a narrow riparian zone. A sub-reach length of 250 m was found to be suitable in the study of observer variability conducted by Gallagher and Gallagher (2005). The upper and lower limits of each sub-reach will be marked with flagging on both banks, and detailed maps of each reach will be constructed to scale, and key channel and habitat features will be noted (e.g., debris jams, large boulders, islands, side channels, braids, and bars) (Gallagher and Gallagher 2005). The expert team of observers will then survey all or a probabilistic-based sample of the sub-reaches and mark all redd locations using a GPS. The survey team will then re-survey the same sub-reaches later that same day or the following day and in the same manner as the first team. It is important that little time elapse between the two surveys so that the survey sub-reaches can be considered 'closed' during the two independent surveys – i.e., no new redds are created and none are destroyed between the survey by the experts, and the subsequent survey.

Each team, whether during a repeated trial survey or for a regular seasonal survey, should consist of at least one experienced observer. Team members should consult one another when redd identification is uncertain. A 'test' category should be used to categorize possible false redds or redds under construction so that subsequent surveys may render the assignment of each 'test' redd with more certainty (Gallagher and Gallagher 2005, Johnson et al. 2007).
It is possible that probability of detection and misidentification rates are dependent on redd densities, which are usually related to habitat features (e.g., substrate, gradient, depth and other hydrological conditions). Probability of detection also may depend on survey conditions which affect visibility (e.g., flow, turbidity and precipitation) (Gallagher and Gallagher 2005, Muhlfeld 2006). High flows and increased turbidity will most likely result in an increase in the observer error rate (for examples see Jones and Quinn 1998, Gallagher and Gallagher 2005, and Muhlfeld et al. 2006). To account for non-constant errors probability of detection will be modeled using the appropriate explanatory variables. Thus, flow, depth, water visibility, and other habitat/survey information should be collected on all surveys. Logistic regression (Agresti 2002) will be used to model probability of detection by the survey team, given detection by the expert team. The appropriate logistic function for the redd survey data is

$$p_i = E\left[y_i\right] = \frac{\exp(\beta_0 + \beta_1 x_{i1} + ... + \beta_p x_{ip})}{1 + \exp(\beta_0 + \beta_1 x_{i1} + ... + \beta_p x_{ip})}, \quad (4)$$

where $p_i$ is the probability of detection, $y_i$ is an indicator variable (taking a value of 1 or 0) identifying whether redd *i* observed by the expert team was detected during the second survey by 'the survey team', *E* represents the expected value, $\beta_0, \beta_1, ..., \beta_p$ are unknown coefficients to be estimated, and $x_{i1}, ..., x_{ip}$ are measured values of *p* covariates representing habitat characteristics for redd *i* or survey conditions experienced when the second team surveyed the sub-reach containing redd *i*. Identification of the best covariates for modeling probability of detection will be carried out using the small sample version of Akaike's information criterion (AICc, Burnham and Anderson 2002). It may be necessary to use estimated relationships between probability of detection and habitat or survey conditions for observer detectability during years or surveys when efficiency trials cannot be performed. However, the recommended procedure is to construct the logistic model annually since stream conditions and observer competence may vary.

Misidentification rates (i.e., the number of false redds counted per km of stream) can be modeled using Poisson regression

$$\ln\left[E\left(\lambda_j\right)\right] = \alpha_0 + \alpha_1 x_{j1} + ... + \alpha_p x_{jp} + offset_j, \tag{5}$$

where *ln* is the natural logarithm, $\lambda_j$ is the number of false redds identified in sub-reach *j* during the second survey, $offset_j$ is an offset term representing the natural logarithm of the total length (km) of sub-reach *j*, $\alpha_0, \alpha_1, ..., \alpha_p$ are unknown coefficients to be estimated, and $x_{i1}, ..., x_{ip}$ are measured values of *p* covariates representing habitat characteristics or survey conditions for sub-reach *j*. Identification of the best covariates for modeling misidentification rates will also be based on AICc values.

If Chinook salmon spawning is known to be concurrent with a scheduled steelhead redd survey the logistic regression equation in Gallagher and Gallagher (2005) will be used to classify redds as steelhead or Chinook when redd species is uncertain. The species classification equation using date of observation and redd size as predictor variables was estimated using data from Northern California coastal streams. The model misclassified only 3 of 44 observed steelhead redds in the American River during 2002 – 2003 (Gallagher and Gallagher 2005). The logistic model for classifying redds based on the 2002 – 2003 study is:

$$\hat{P} = \frac{1}{1 + \exp\left[-4.074 + 0.13(day) - 0.918(red\ area)\right]}, \tag{6}$$

where *day* is day of the run. A redd is classified as a steelhead redd if $\hat{P} \geq 0.5$.

Redds made by resident rainbow trout occur in many of the Central Valley streams, and it is possible that resident rainbow trout redds can be misclassified as steelhead redds. However Zimmerman and Reeves (2000) found that in the Deschutes River in Oregon only 9 to 15 percent of sampled rainbow trout redds occurred during the steelhead spawning period. Despite these results, overlap may be greater in the Central Valley. The Oregon study also found that steelhead redds were larger than resident rainbow trout redds (p-value < 0.001), substrate size was larger for steelhead (p-value < 0.001) and steelhead redds were at greater depths than rainbow trout redds (p-value < 0.001). Similar studies have yet to be conducted for Central Valley streams. In order to assess the potential magnitude of redd misclassifications sampling should be conducted throughout the spawning season and sex and stage of maturity should be recorded on all fish. A scale sample should be taken so that the proportion of spawning resident rainbow trout can be estimated. Sampling could be achieved using a variety of methods including hook-and-line, trapping or hatchery collections. After 2 to 3 years, sample data should be adequate to determine whether misclassification of rainbow trout redds is likely to be an issue. Differentiating resident rainbow trout redds from steelhead redds should be an area of ongoing investigation, especially with regard to evaluating the extent to which this source of redd misclassification. Ultimately, it may be necessary to classify redds as steelhead or rainbow trout by discriminant function analysis (Johnson and Wichern 2002) or logistic regression models (Hosmer and Lemeshow 2000) using covariates so that this error can be accounted for in the final escapement estimates.

***Estimating Total Redd Abundance***

Following estimation of detection probabilities and misidentification rates the total potential redd count (*R*) will be partitioned into the number of actual redds (*A*) and the number of false counts (*F*), or misidentifications:

$$R = A + F. \quad (7)$$

If detection probabilities are estimated to be constant across all sub-reaches the total number of correct redd detections (*A*) can be viewed as a binomial random variable,

$$A \sim Binomial(T, p), \quad (8)$$

where *T* is the true total number of redds, and *p* is the probability of detection. If the number of false counts is the same for all sub-reaches, then the number of false redds (*F*) can be viewed as a Poisson random variable with a mean rate of false counts per km of stream reach ( $\lambda$ ). Based on this model, the expected number of potential redds counted during a survey is

$$E[R] = Tp + \lambda d \ , \quad (9)$$

where *d* is the total length (km) of stream reaches surveyed. The variance of the total count can be calculated using

$$Var[R] = Tp(1-p) + \lambda d \ . \quad (10)$$

Under a model which assumes that $\lambda$ and *p* are constant, a pseudo-likelihood (Hall 1990) estimate of the expected value of the true number of redds given an observed count *R* is

$$\hat{T} = \left(R - \lambda d\right) / \ p \ , \quad (11)$$

which has a variance estimated by

$$\left[\hat{T}p\left(1-p\right)+\lambda\right] / \ p^2 . \quad (12)$$

If probability of detection is found to vary across sub-reaches then equation (10) above can be used to estimate total redd abundance within a season for a system of *n* reaches using the regression estimates for *p* (Equation 4) and $\lambda$ (Equation 5):

$$\hat{T} = \left(\sum_{r=1}^{n} R_r - \bar{\hat{\lambda}} d\right) / \ \bar{\hat{p}} \ , \quad (13)$$

where $R_r$ is the total count of unique potential redds identified by the survey crew in reach $r$ across all repeated surveys, beginning with the second survey if the expert crew surveyed the reach, $\bar{\hat{\lambda}}$ is the average predicted false error rate across all survey conditions and habitat types, $d$ is the total length (km) of reaches surveyed, and $\bar{\hat{p}}$ is the average probability of detection.

For example, consider a situation where the available spawning habitat in a system can be divided into 67 sub-reaches totaling 17 km in length. Then, a random sample of 40 sub-reaches is surveyed by an expert team of observers on day 1 and again by the survey team on day 2. Finally, all 67 sub-reaches are surveyed by the survey team on days 3, 16, 29, 42, 55, 68, 81, 94, and 107 through the entire spawning season. Equations (4) and (5) are then applied to the survey data collected on the first 2 survey days and these analyses result in an estimated average probability of detection of $\bar{\hat{p}} = 0.8$ and an estimated average of one false redd identified per km of stream surveyed ($\bar{\hat{\lambda}}$). Finally, if a total of 160 unique potential redds are counted by the survey crew during the 9 surveys (not including the survey by the expert team) the final estimate for the total number of redds in the system during the season would be (160 – 1(17))/0.8 = 179.

Bootstrapping (Davison and Hinkley 1996) will be used to estimate a variance and confidence interval (CI) for the total number of redds. Using 2000 bootstrap samples from the data used to estimate probability of detection (Equation 4) and the misidentification rate (Equation 5), new estimates of the total number of redds in a system can be estimated for each sample. The standard deviation (SD) of the 2000 estimates represents the standard error (SE) of the total estimate, and the 5th and 95th percentiles of the 2000 estimates are the lower and upper 90% confidence interval limits, respectively. The algorithm proceeds as follows

3. For each bootstrap replicate, indexed $b = 1, \ldots, B$:

   (c) Generate bootstrap sample $X^{*(b)} = \begin{pmatrix} y_1^* & x^*_{11} & \cdots & x^*_{1p} \\ \vdots & \vdots & & \vdots \\ y_n^* & x^*_{n1} & \cdots & x^*_{np} \end{pmatrix}$ by sampling with replacement from the $n$ rows of the observed dataset for the selected detection probability model. Generate a similar bootstrap sample from the n rows of the final observed covariate dataset for the misidentification covariates for the selected misidentification rate model.

   (d) Compute the $b^{th}$ replicate estimates of $\bar{\hat{p}}^{(b)}$ and $\bar{\hat{\lambda}}^{(b)}$ and $\bar{\hat{T}}^{(b)}$ from the $b^{th}$ bootstrap sample in (a).

4. The SE($\hat{T}$) is the sample standard deviation of the replicates $\hat{T}^{(1)}, \ldots, \hat{T}^{(B)}$. The bootstrap 90% confidence interval is the 5th and 95th percentiles of the replicates $\hat{T}^{(1)}, \ldots, \hat{T}^{(B)}$.

**Estimating Total Escapement from Estimates of Total Redd Abundance**

A number of studies have shown that steelhead redd counts are highly correlated with the number of reproductive adults (for examples see Beland 1996, Susac and Jacobs 1999, Rieman and Allendorf 2001, Gallagher and Gallagher 2005, and Muhlfeld et al. 2006). In fact, Gallagher and Gallagher (2005) report a correlation of 0.82 (p-value = 0.003) between redd counts and area-under-the-curve (AUC) escapement estimates. However, in order to estimate total escapement using estimates of redd abundance the number of females per redd and the ratio of females to males in the population need to be known or estimated.

***Estimating the Number of Females per Redd***

Gallagher and Gallagher (2005) found that the average number of steelhead redds per female was 1.93 (SE = 0.47, range from 1.02 to 2.43) based on capture-recapture estimates, but it was 3.46 (range from 1.80 to 6.91) based on AUC estimates. The Gallagher and Gallagher (2005) study involved a three year survey of five Northern California coastal streams. Susac and Jacobs (1999) found steelhead redds per female varied from 0.5 to 4.5 for Oregon streams. In addition, Gallagher and Gallagher (2005) documented a relationship between redd size and the number of females per redd – smaller redds were more likely to be representative of fewer females.

Mark-recapture methods, video cameras or trapping weirs can be used to estimate the total number of females in a watershed. These estimates can then be used to estimate the number of females per redd. If it is believed that the ratio of females per redd is constant across streams the estimated ratio from one stream might be used for similar, neighboring streams. If precise estimates of the number of females per redd can be obtained on a periodic basis, these estimates can be applied to redd counts in years when the number of females per redd is not expected to vary.

An alternative to using mark-recapture methods or trapping weirs to estimate the number of females per redd is the redd area method (Gallagher and Gallagher 2005). This method, which has been developed and evaluated for steelhead in five coastal northern California streams, assumes the number of redds a female makes is related to the area ($m^2$) of the redd, and that steelhead redds per female range from 1 to 4 (Susac and Jacobs 1999, Gallagher and Gallagher 2005). First a systematic sample of redds are measured, say every 5$^{th}$ redd, using the method described by Johnson et al. (2007) to measure redd area. Redds larger than 4.6 $m^2$ are assumed to represent one female. Each redd between 3.05 and 4.6 $m^2$ is assumed to represent three quarters of a female, redds between 1.52 and 3.04 $m^2$ are assumed to represent one half of a female, and redds smaller than 1.52 $m^2$ are assumed to represent one quarter of a female. The total number of females in the sample is then estimated as the sum of the number of redds in each size group multiplied by its corresponding representation as number of females. This number is then expanded by 5 to obtain the estimate of total females since the sampling fraction for this example was 1/5. If the redd area method is to be used it should be validated with additional studies using another method.

***Estimating the Proportion of Females in the Population***

It may be possible to estimate the proportion of females in the population using angler survey data or steelhead report card data for each watershed. Regardless, sex ratios will be collected from live fish sampling for a minimum of three temporal portions of the run (e.g., early, middle and late), since the sex ratio may be related to run-timing. After a number of years such data should allow for an assessment of whether sex ratios are consistent within a season, between streams or across years.

***Estimation of Total Escapement***

The total escapement based on redd surveys will be estimated by dividing the estimated total number of females (estimated via redd counts and the number of females per redd) by the estimated proportion of females in the spawning population. Bootstrapping will be used to estimate the SE and a 90% CI for the total escapement estimate. This method will incorporate all sources of uncertainty (i.e., probability of detection, misclassification, redds per female and sex ratio) in the final estimate. The bootstrap algorithm is

1. For each bootstrap replicate, indexed $b = 1, \ldots, B$:

   (a) Generate bootstrap sample $X^{*(b)} = \begin{pmatrix} y_1^* & x^*_{11} & \cdots & x^*_{1p} \\ \vdots & \vdots & & \vdots \\ y_n^* & x^*_{n1} & \cdots & x^*_{np} \end{pmatrix}$ by sampling with replacement from the $n$ rows of the observed dataset for the selected detection probability model (4). Generate a similar bootstrap sample, $X_\lambda^{*(b)}$ from the $n$ rows of the final observed covariate dataset for the misidentification covariates for the selected misidentification rate model (5).

   (b) Compute the $b^{th}$ replicate estimates of $\bar{\hat{p}}^{(b)}$ and $\bar{\hat{\lambda}}^{(b)}$ and $\bar{\hat{T}}^{(b)}$ from the $b^{th}$ bootstrap sample in (a).

   (c) Generate bootstrap sample $X_{redd\ area}^{*(b)}$ by sampling with replacement from the $n$ observed values of measured redd areas (m$^2$).

   (d) Generate bootstrap sample $P_{prop.\ females}^{*(b)}$ of the proportion of the escapement consisting of females by drawing random binomial proportions from a binomial distribution with parameters $\hat{\pi}_{prop\ females}$ and $n$ the number of observed redds.

   (e) Compute the $b^{th}$ replicate estimate of $\hat{E}^{(b)}$ from the $b^{th}$ bootstrap samples from (b) – (e) above.

2. The SE($\hat{E}$) is the sample standard deviation of the replicates $\hat{T}^{(1)}, \ldots, \hat{T}^{(B)}$. The bootstrap 90% confidence interval is the 5$^{th}$ and 95$^{th}$ percentiles of the replicates $\hat{E}^{(1)}, \ldots, \hat{E}^{(B)}$.

***Estimating Redd Counts for Missed Surveys and Estimating Survey Recurrence Time***

If scheduled surveys are missed due to storm events resulting high flow conditions or poor visibility, surveys should be conducted as soon after such events as conditions will allow. If there is sufficient advance notice of storm events surveys should be conducted immediately before the event (Giovannetti and Brown 2007). If a survey is missed and the gap between successive surveys exceeds the value $t$ in the estimated retention rate where $\hat{R}(t) \geq 0.95$ (equation [1]), new redds constructed during that interval may no longer be available for detection during the next survey due to scouring or algae. In these situations an estimate of the number of missed redds not available for detection will be used to the estimate of the number of new redds on the first survey following the missed survey.

If survey *j* was missed due to weather, we will adjust the estimate of the number of new redds present during survey *j*+1. This adjustment begins with estimating $\hat{R}(t)$ (equation [1]) where $t$ = the number of days between successive surveys surrounding the missed survey. For example, if surveys are scheduled to be 7 days apart, and one survey is missed, $\hat{R}(14)$ will be estimated using equation (1). The new estimate of the number of new redds present during survey *j*+1 (those detected + redds not available for detection) is

$$\hat{C}'_{S_{u+1}} = \frac{\left(S_{j+1} - S_{j-1}\right) \times \hat{C}_{S_{j+1}}}{\sum_{j=1}^{S_{j+1}-S_{j-1}} \hat{R}(j)}, \tag{14}$$

where $S_j$ is the day of the $j^{th}$ survey where days are consecutive integers starting with 1 ($S_1 = 1$) for the first survey, $\hat{C}_{S_{j+1}}$ is the estimated count of new redds on the first survey following the missed survey estimated from equation (11), $\hat{C}'_{S_{j+1}}$ is the new estimate of total redds that has been adjusted for those not detectable due to scouring or cover by algae. Thus $S_{j+1} - S_{j-1}$ represents the number of days between surveys immediately before and after the missed survey which is notated to have been scheduled for day $S_j$. The variance of this estimated variance using the delta method (Seber 1982, pg. 7)

$$V\hat{a}r\left(\hat{C}'_{S_{j+1}}\right) \approx \left[\frac{\left(S_{j+1} - S_{j-1}\right) \times \hat{C}_{S_{j+1}}}{\sum_{j=1}^{S_{j+1}-S_{j-1}} \hat{R}(j)}\right]^2 \times \left[\frac{\left[\hat{C}_{S_{j+1}} \hat{p}(1-\hat{p}) + \hat{\lambda}\right] / \hat{p}^2}{\hat{C}^2{}_{S_{j+1}}} + \frac{\sum_{j=1}^{S_{j+1}-S_{j-1}} V\hat{a}r\left[\hat{R}(j)\right]}{\left(\sum_{j=1}^{S_{j+1}-S_{j-1}} \hat{R}(j)\right)^2}\right], \tag{15}$$

where $\hat{p}$ and $\hat{\lambda}$ are the estimated probabilities of detection and misidentification rates estimated from equations (4) and (5), respectively.

An assumption required for use of equation (14) is that new redds during $S_{j+1} - S_{j-1}$ follow a uniform distribution. This may not be an unreasonable assumption if the interval $S_{j+1} - S_{j-1}$ is small compared to the total spawning period. Other distributions such as the normal or exponential may be used if auxiliary run-timing data are available to make such an assessment.

***Estimating Detection Rates During High Flow Conditions and Elevated Turbidity Events***

The ability to see and count redds may degrade significantly during high flows events where increased turbidity may also play a role. When scheduled surveys coincide with these events the investigator must make a judgment whether to proceed with the survey or delay the survey until river conditions return to normal.

When high flow conditions and (or) elevated turbidity coincide with a scheduled survey and the decision is made to conduct the survey under such conditions, probability of detection may fall below the level estimated from the trials. In order to estimate probability of detection for reduced visibility conditions it will be necessary to conduct 'before and after' trials over a range of flow/turbidity conditions. Newly constructed redds will be flagged on the first survey of a sample of sub-reaches conducted under normal visibility conditions and the percentage of known flagged redds observed during the second survey conducted under reduced visibility conditions will be an estimate of probability to be applied to estimates for that survey. Flow and turbidity will be measured and recorded for each probability trial and will be measured for all complete surveys conducted over the spawning period. High flow turbidity trials should be conducted using both an expert observer team and regular survey observer teams to obtain an estimate of adjusted detection rates for a range below average visibility conditions. It will be necessary to schedule such trials when stream conditions are right, and though such flexibility may be difficult to achieve the results will be extremely valuable in reducing bias and improving precision in escapement estimates.

**Sampling Designs for Non-Census Redd Surveys**

Escapement estimates based on redd counts for the American River, Mokleumne River and Clear Creek are complete census surveys for which estimates are based on repeated surveys through the duration of the spawning season the entire spawning portion of the river. If alternative designs which sample sub-reaches of the total spawning area (spatial sampling) can be shown to improve the accuracy and precision of estimates of total escapement by allowing additional resources to be used to conduct surveys more frequently or at varying recurrence time throughout the spawning period, these designs should be adopted. Possible designs that might be considered are stratified index designs, and stratified random sampling. Simulation studies based on historical data may shed light on the feasibility of adopting such alternative sampling designs.

## LITERATURE CITED


Agresti, Alan. 2002. Categorical data analysis. John Wiley, New York, New Jersey, USA.

Beland, K.F. 1996. The relationship between redd counts and Atlantic salmon (*Salmo salar*) parr populations in the Dennys River, Maine. Canadian Journal of Fisheries and Aquatic Sciences 53:513 – 519.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Spring-Verlag, New York, New York, USA.

Davison, A. C., D. V. Hinkley. 1996. Bootstrap methods and their application. Cambridge University Press, Cambridge, Massachusetts, USA.

Gallagher, S.P., and C.M. Gallagher. 2005. Discrimination of Chinook salmon, coho salmon, and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in northern California. North American Journal of Fisheries Management 25:284 – 300.

Giovannetti, S. L., and M. R. Brown. 2007. Central Valley steelhead and late fall Chinook salmon redd surveys on Clear Creek, California. U.S. Fish and Wildlife Service; Red Bluff Fish and Wildlife Office.

Hall, P. 1990. Psuedo-likelihood theory for empirical likelihood. Annals of Statistics 18:121–140.

Hosmer, D.W., and S. Lemeshow. 2000. Applied logistic regression. John Wiley, New York, New Jersey, USA.

Johnson, D.H., B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'neil, and T. N. Pearsons, T. N. 2007. Salmonid field protocols handbook: techniques in assessing status and trends in salmon and trout populations. American Fisheries Society in association with State of the Salmon.

Johnson, R. A., and D. W. Wichern. 2002. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, USA.

Jones, E. L., and T. J. Quinn. 1998. Observer accuracy and precision in aerial and foot survey counts of pink salmon in a southeast Alaska stream. North American Journal of Fisheries Management 18:832 – 846.

Kalbfleish J. D, and R. L. Prentice. 1980. The Statistical analysis of failure time data. John Wiley and Sons, New York, New York, USA.

Manly, B. F. J. 1997. Randomization, bootstrap and Monte Carlo methods in biology. Second edition. Chapman and Hall, Boca Raton, Florida, USA.

Maxell, B. A. 1999. A prospective power analysis on the monitoring of bulltrout stocks using redd counts. North American Journal of Fisheries Management 19:860 – 866.

Muhlfeld, C. C, M. L. Taper, and D. F. Staples. 2006. Observer error structure in bull trout redd counts in Montana streams: Implications for inference on true redd numbers. Transactions of the American Fisheries Society 135:643 – 654.

Rieman, B. E., and F. W. Allendorf. 2001. Effective population size and genetic conservation criteria for bull trout. North American Journal of fisheries Management 21:756 – 764.

Seber, G. A. F. 1982. The estimation of animal abundance. Second edition. Blackburn Press, Caldwell, New Jersey, USA.

Susac, G. L., and S. E. Jacobs. 1999. Evaluation of spawning ground surveys for indexing the abundance of winter steelhead in Oregon coastal basins: annual progress report, 1 July 1997 to 30 June 1998.

Wenger, S. J., M. C. Freeman. 2008. Estimating species occurrence, abundance, and detection probability using zero-inflated distributions. Ecology 89:2953 – 2959.

Zimmerman, C. E., and G. H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous Oncorhynchus mykiss: evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Science 57:2152 – 2162.

# Appendix I: Kaplan-Meir Estimates of Redd Retention Rate

An estimate of the probability of a redd being detectable for at least *t* days since initial identification can be estimated using

$$\hat{R}(t) = 1 - \frac{\sum_{j=1}^{t} d_j}{N}.$$

The following provides an example of a redd longevity survey and how that data can be used to estimate survey recurrence time and redd counts for a missed survey.

Table 1. Example simulated dataset for redd retention survey based on 50 newly constructed redds on day 0. Data in the table include the date, time since redd was first identified ($t_j$), the number of redds not detectable ($d_j$), or lost, the number of redds still detectable ($n_j$), estimated redd retention rates and the SE and CV of the estimates.

| Date | $t_j$ | $d_j$ | $n_j$ | $\hat{R}(t_j)$ | $S\hat{E}[\hat{R}(t_j)]$ | $CV[\hat{R}(t_j)]$ |
|---|---|---|---|---|---|---|
| 12/22/2010 | 0 | ---- | 50 | ------- | ------- | ------- |
| 12/23/2010 | 1 | 0 | 50 | 1.000 | | ------- |
| 12/24/2010 | 2 | 0 | 50 | 1.000 | 0 | ------- |
| 12/25/2010 | 3 | 0 | 50 | 1.000 | 0 | ------- |
| 12/26/2010 | 4 | 0 | 50 | 1.000 | 0 | ------- |
| 12/27/2010 | 5 | 1 | 50 | 1.000 | 0 | ------- |
| 12/28/2010 | 6 | 0 | 49 | 0.980 | 0.020 | 0.020 |
| 12/29/2010 | 7 | 0 | 49 | 0.980 | 0.020 | 0.020 |
| 12/30/2010 | 8 | 1 | 49 | 0.980 | 0.019 | 0.020 |
| 12/31/2010 | 9 | 0 | 48 | 0.960 | 0.028 | 0.029 |
| 1/1/2011 | 10 | 0 | 48 | 0.960 | 0.028 | 0.029 |
| 1/2/2011 | 11 | 1 | 48 | 0.960 | 0.027 | 0.028 |
| **1/3/2011** | **12** | **2** | **47** | **0.940** | **0.032** | **0.034** |
| 1/4/2011 | 13 | 3 | 45 | 0.900 | 0.040 | 0.044 |
| 1/5/2011 | 14 | 5 | 42 | 0.840 | 0.046 | 0.054 |
| 1/6/2011 | 15 | 4 | 37 | 0.740 | 0.055 | 0.075 |
| 1/7/2011 | 16 | 6 | 33 | 0.660 | 0.055 | 0.083 |
| 1/8/2011 | 17 | 4 | 27 | 0.540 | 0.060 | 0.111 |
| 1/9/2011 | 18 | 4 | 23 | 0.460 | 0.058 | 0.127 |
| 1/10/2011 | 19 | 5 | 19 | 0.380 | 0.051 | 0.133 |
| 1/11/2011 | 20 | 6 | 14 | 0.280 | 0.036 | 0.130 |
| 1/12/2011 | 21 | 7 | 8 | 0.160 | 0.006 | 0.041 |
| 1/13/2011 | 22 | 1 | 1 | 0.020 | 0.000 | 0.000 |
| 1/14/2011 | 23 | 0 | 0 | 0.000 | ------- | ------- |
| . | 24 | . | 0 | 0.000 | . | |
| . | . | . | . | . | . | . |

### *Example Calculation for an Estimate of Survey Recurrence Time*

The survey recurrence interval was estimated at 12 days since the fraction of redds still apparent was ~0.95 and the CV for this estimate was 0.03, below the 0.05 cutoff.

### *Example Calculation of Estimated Missed Counts for a Missed Survey*

Consider a missed survey resulting in there being 24 days between surveys, where probability of detection from equation (1) is estimated to be $\hat{p} = 0.85$ and misidentification rates are expected to be $\hat{\lambda} = 0.07$. Suppose the next survey after the missed survey counted 33 redds not observed in the previous survey (survey before the missed one), the estimate of total counts of redds constructed during the missed survey would consist of redds still visible (33 redds) plus redds no longer apparent during the survey following the missed survey. Using equation (14),

$$\hat{C}'_{S_{u+1}} = \frac{\left(S_{j+1} - S_{j-1}\right) \times \hat{C}_{S_{j+1}}}{\sum_{j=1}^{S_{j+1}-S_{j-1}} \hat{R}(j)},$$

and assuming for this example a uniform distribution of construction of new redds over the 24 days between surveys, the estimated redd count for the missing survey would be

$$\hat{C}'_{S_{j+1}} = \frac{24 \times 33}{\sum_{j=1}^{20} \hat{R}(j)} = 47.3 \text{ redds},$$

with an approximate standard error of

$$s\hat{e}\left(\hat{C}_j\right) = 8.65 .$$

### *Explanation of the Estimate*

For the example *x* redds were constructed each day of the 24 days between surveys (uniform distribution). Each redd has an estimated probability of lasting long enough to be observed into the next survey. For example this would be $\hat{R}(24)$ for each redd made on day 1 of the 24 days between surveys and $\hat{R}(20)$ would be the probability of observing a redd for at least 20 days for redds seen on day 4 of the 24 days between surveys. Summing the products of *x* with its retention time equals the number of redds remaining visible into the next survey which for our example is 33. Solving this equation for *x* gives the number of redds constructed on one day of the 24 days between surveys. Multiplying the estimate x for a single day's new redds by 24 gives the estimated total:

$$x \cdot \hat{R}(24) + x \cdot \hat{R}(23) + \ldots + x \cdot \hat{R}(1) = 33$$

$$x = \frac{33}{\sum_{i=1}^{24} \hat{R}(i)}$$

$$\hat{C}_{S_j} = 24x = 24 \cdot \frac{33}{\sum_{j=1}^{24} \hat{R}(j)}$$

Appendix II. Giovannetti, S. L., and M. R. Brown. 2007. Central Valley Steelhead and Late Fall Chinook Salmon Redd Surveys on Clear Creek, California. U.S. Fish and Wildlife Service; Red Bluff Fish and Wildlife Office.

## APPENDIX D

## DETAILS: DATA MANAGEMENT PLAN OUTLINE, DATA CAPTURE, CENTRALIZED DATABASES, POTENTIAL DATA FIELDS AND REPORTING FUNCTIONS

### Data Management Plan

This plan recommends that a detailed data management plan be developed in conjunction with a database to assure that all people involved in creating or using a data set understand how the data will be managed. StreamNet (2009) developed an outline for the components needed in a data management plan. Development of a data management system for managing steelhead and Chinook salmon data will need to address at least these components for a data management system (StreamNet 2009):

1. Project Description
    - 1.1. Title
    - 1.2. General description
2. Contacts
    - 2.1. Project leader
    - 2.2. Person(s) responsible for collecting data in the field
    - 2.3. Person(s) responsible for entering the data
    - 2.4. Person(s) responsible for managing (maintaining, changing, updating, correcting, disseminating) the data after collection and entry
3. Data
    - 3.1. General description
    - 3.2. Collection methods description.
    - 3.3. Data capture (e.g., paper data sheets or electronic tools)
    - 3.4. Standards for data management (e.g., standard coding schemes, formats, etc.)
    - 3.5. Data dictionary (e.g., data definitions, codes, units, data is optional or required)
    - 3.6. Data quality control and assurance procedures to be employed
    - 3.7. Data storage process and format (e.g., backup procedures, database structure)
    - 3.8. Where data is stored (e.g., centralized or distributed type database)
    - 3.9. Data "ownership" or control
    - 3.10. Data analysis (how data is analyzed)
    - 3.11. Access to data (who has access to the data)
    - 3.12. Sensitive data (how will this be handled)
    - 3.13. Long term data storage and dissemination
4. Schedules
    - 4.1. Description of data pathway and operations
    - 4.2. Schedule for data flow (flow diagram of data)
    - 4.3. Methods for tracking data status
    - 4.4. How and when will data be made available to others
5. Metadata
    - 5.1. Provide metadata

5.2. Describe who will develop metadata and where and when will the metadata be available.

## Data Capture

This plan recommends investigating the feasibility of using an electronic device to improve the efficiency of data recording, data entry and data quality checking. Two examples are the rugged tablet Personal Computer (PC) and the rugged Personal Digital Assistant (PDA) device.

One example of successfully using the rugged tablet PC is with the Minnesota Department of Natural Resources (MNDNR). They changed from using paper field data sheets to a PC to collect fisheries and habitat data from their lake surveys (Xploretech 2007). Prior to the PC, entering data into dozens of distributed databases across the state of Minnesota, methodically analyze databases for entry errors, and consolidate all of the databases into one central database took months. To overhaul their data management system, MNDNR implemented a project that took three years with 40 staff to develop a new data management system. Dozens of field hardware options were examined to capture data, and MNDNR chose Xplore X104C2 rugged tablets. The application of technology significantly improved efficiency for capturing fisheries data, speed of data retrieval, and quality of data stored. A Java client database application was developed and is used on rugged tablets and desktop workstations over the MNDNR intranet to provide statewide access to a single database and dozens of reports. The rugged tablets have eliminated 27 separate copies of the database that previously required weeks of data consolidation annually. The application improves data quality by providing validation when the fish is still in-hand instead of doing the data entry from paper over the winter when the fish was no longer available to recheck. Quick upload of the data from the PC to the central database provide immediate reporting. Since data entry occurs directly onto the rugged tablets while in the field, approximately 8,875 hours of in-office data entry is eliminated. These hours save the Department $195,250 annually. Overall, estimated cost benefits from implementing the application is $216,170 each year. The estimated base price for each tablet PC is USA $2,800.00.

The PDA offers many of the same advantages of a tablet PC and may prove to be a viable option. The PDA is being used successfully to record fisheries field data in California. These devices can increase the accuracy of data capture and provide a significant time savings when compared to paper datasheets. Since data are entered from the PDA directly into the database, less handling is required resulting in fewer data entry errors. Some quality control can be built into the PDA application. Once data are loaded to the main database back at the office, the data can be subjected to a wider range of automated quality control checks. The PDA recommended by CDFG Northern Region is the Meazura Rugged Digital Assistant (Aceeca MEZ1000 RDA Handheld). The Meazura RDA is less expensive than tablet PC. The device has a monochrome screen with adjustable backlighting to allow use in a wide range of lighting conditions. In addition, the device can be adapted to include GPS functionality by connecting to a Garmin Global Positioning Unit (GPS) via Blue Tooth wireless or may be wired to any GPS. The units are stable, reliable, waterproof, and extremely durable. Starting cost for the Meazura RDA is $400.00. The Northern Region also recommends Pendragon Forms 5.1 (Pendragon Software Corporation) for simple field form development although there are more sophisticated options. This software will create forms from access database tables or queries. The forms need modification if pick lists and other options are desired. Software is $300.00 for the first license and $100.00 for additional licenses.

Johnson et al. (2009) has suggested that for most common fisheries estimates, a single entry of data or single entry using a PDA is sufficient and further that the use of automated error checking in both the PDA and a main database helps to ensure an acceptable level of data quality without the time and expense of more traditional error-checking methods such as double data entry and read-aloud proofing (Johnson et al. 2009). Initial startup costs of a PDA are offset by time saved entering data from paper datasheets to a digital format. Additional time savings result from automating error checking. Johnson et al. (2009) noted some difficulties with the PDA including small screen size, poor system navigation, and data loss. However, these difficulties were not reported by CDFG Northern Region.

## Centralized Database Management Systems

### *Highly Centralized Database Management System*

#### Example 1. California Department of Fish and Game Central Valley GrandTab Application

An online database application was created in December, 2009 for the reporting of Chinook salmon escapement estimates in California's Central Valley to GrandTab (J. Azat, CDFG, Pers. Comm. 2010). The GrandTab online database application is an example of a centralized database system, however the purpose of this system is to maintain summarized data and not raw data. Biologists from multiple agencies including: California Department of Fish and Game (CDFG), California Department of Water Resources (CDWR), United States Fish and Wildlife Service (USFWS), and East Bay Municipal District (EBMUD) enter escapement numbers for adult, grilse, and total (adult and grilse) Chinook salmon for the watershed(s) they monitor. Before this online database application was developed, biologists would have to call in their preliminary escapement Chinook salmon escapement numbers, and call in any changes or the final escapement numbers.

Quality control of the data in the GrandTab database application occurs at different levels. With this application, each biologist is given a username and password to enter data into the database (J. Azat, CDFG, Pers. Comm., 2010). Only the biologists entering data and some managers can access the data. Only biologists can edit the data they entered; to edit the data the line must be first deleted, and once the data is finalized the data cannot be changed without contacting the database specialist. The database is constrained to allow for only one instance of any run/area/survey/year. Data entry validation rules include data entry requirements for some fields and formatting rules.

The GrandTab online database application is in an initial stage. The application was created by a biologis/database specialist, who is currently hosting the application on GoDaddy.com. for $5 per month (J. Azat, CDFG, Pers. Comm. 2010). One of the reasons for this effort was to demonstrate the usefulness of on-line data entry. More resources and support are needed to continue development and improvement of the application keep it running. The application is demonstrating that the use of this technology to improve data reporting.

**Example 2. Wisconsin Department of Natural Resources**
An example of a highly centralized database is the Wisconsin Department of Natural Resources (WDNR), Bureau of Fisheries Management Biology Database. The database was developed to manage fisheries and habitat field data collected statewide in Wisconsin lakes and streams (J. Griffin, WDNR, Pers. Comm., 2010). In 2001, the database was implemented and biologists are mandated to enter all data from annual fish and habitat surveys. Since 2001, the database has grown to include data from fish kills, fishing tournaments, and propagation quota and stocking. Currently, the amount of data in the database is extensive. The database contains 13,826 fish surveys conducted at 8,880 sites in 2,917 streams; 7,542 fish surveys conducted at 1,447 sites in 1,226 lakes; and 1,328 fish survey conducted at 457 sites in 109 rivers. Efforts are also under way to include data from the WDNR's Statewide Paradox Database, containing data from 1938-1992. These historic data will provide access to data collected during 18,000 surveys. The Paradox Database was the result of an initiative by WDNR to enter historic data into a centralized database and warehouse (basically a crew of 2-4 data entry specialists traveled to field offices with laptop computers and entered fisheries data (stored on paper field sheets) into a standardized data entry system).

Fish and habitat monitoring surveys by WDNR are conducted using standardized protocols (developed by the Central Office) with data recorded on standardized datasheets (J. Griffin, WDNR, Pers. Comm., 2010). Forms in the database were developed for easy data entry. When the database was first implemented, data entry was a slow process. However, over time problems were addressed to speed the data entry process. Recently a utility was added to allow biologists to enter data into a spreadsheet template directly into the database, which has resulted in a faster data entry process. Additionally, WDNR is planning a pilot study to examine the feasibility of using tablet or PDA devices to capture data in the field which would also speed data entry. The digital PDA data would be uploaded to the central database automatically.

The database is secured; biologists and database coordinators each have a username and password. The WDNR has strict rules about allowing individuals outside of the Department to have access to the database.

Data quality and control is handled at a couple of different levels for the WDNR database (J. Griffin, WDNR, Pers. Comm., 2010). Guidelines for quality control of data were developed by the Central Office and distributed to biologists. Survey data quality control status (i.e., data entry not complete; data entry complete not proofed; and data entry complete and proofed) is reported by biologists in the database. The database has built in quality control checks such as bounds for fish lengths and weights. These prompt the user if measures are outside of reasonable limits. They have also developed some error checking programs that flag records that appear to contain errors. While the flags identify records that need to be verified, they can be also be used to exclude questionable data when summary reports are developed.

WDNR biologists can easily retrieve the data they enter into the database. The database has a program to query data and download data into an Excel spreadsheet (J. Griffin, WDNR, Pers. Comm., 2010). In addition, WDNR uses Oracle Business Intelligence Discoverer, software, to allow biologists to set criteria and generate a custom summary report for mark- recapture data, length frequencies, length-at-age, relative weight, size structure (i.e., proportional stock density and relative stock density), catch-per-unit of effort, and more.

WDNR has contracts with the United States Geological Survey (USGS) in Middleton, Wisconsin to house and maintain the server and database; and has dedicated staff for the database (J. Griffin, WDNR, Pers. Comm., 2010). In addition, USGS developed the database. The program is currently operating with minimal staff. Additional staff would be used to improve the database. The WDNR pays for one full-time and two part-time programmers at USGS, and one part-time contractor and a full-time database coordinator at the WDNR. The programmers at USGS house, maintain, and make improvements to the database. The contractor assists with relaying needs by the WDNR to USGS. The database coordinator functions as a liaison between the biologists and the programmers, and fills custom data requests for statewide data. The biologists fill outside data requests for the water bodies they manage.

WDNR includes the database in their annual budget. Contract costs with USGS are about $200,000 per year. Original development costs were not specified. Costs for the 2001 implementation year were around $250,000. Costs tend to go up over time as salaries increase; however less time is needed for database development each year.

While the WDNR's database is not perfect, they continue to improve the application. The application is currently functional and is used extensively (J Griffin, WDNR, Pers. Comm., 2010).

### *Distributed Type Centralized Database System*

**Example 3. California Department of Fish and Game, Northern Region Field Data Collection Databases**

The databases being developed by CDFG Northern Region to capture field data from several CDFG monitoring programs in the Northern Region are all developed with a goal of standardization (D. Burch, CDFG, Pers. Comm., 2010). While the applications may seem quite different, all of the data within them can be uploaded to a common database. The concept is to base the structure and formatting on a centralized database schema (entity diagram) that, at this point, only exists on paper. The purpose of the database application is to streamline data entry, data management, provide analysis tools, and ease reporting requirements. The distributed type database system is designed to be flexible so that new columns can be added or selected for use. The applications are currently designed to capture data for creel surveys, carcass surveys, and redd surveys. The central database schema was designed to easily add additional survey types (e.g., RST, snorkel surveys, video monitoring).

The database schema is very similar to the CDFG Information Technology Branch's BIOS database schema. The BIOS database schema was developed to capture a broader range of information and is largely in the development stages. There are currently no examples of fisheries monitoring applications in the BIOS Database (P. Gaul, CDFG, Pers. Comm., 2010). The Northern Region database applications have been modified so that data can be uploaded to the BIOS database at some point in the future (i.e. they are BIOS compliant).

The databases were developed in Microsoft Access, some "front end" user interfaces with built in forms and pre-built queries and standardized reports are also in Access. Other user interfaces were developed for use with a PDA. Both the front and back end databases are distributed for installation on the local computer and PDA equipment. Individuals control the data and upload and export the data as needed. There are plans to develop a utility to upload data periodically for archive in a "central data store" most likely an intranet site.

Currently, the Northern Region Database Applications are supported and maintained by one programmer analyst (D. Burch, CDFG, Pers. Comm., 2010). The database applications are developed for biologists that request database/programming assistance. The distributed databases have been in use for over five years, but they are still in the development phase. The spawner survey database, a PDA application, is currently being used by Seth Ricker and Sean Gallagher, CDFG Northern Region fisheries biologists.

As is currently the case in the Central Valley, each biologist establishes protocols and standards for their project and databases must be flexible (include additional columns and code), to accommodate variations in field protocol and personal preference. This requires intensive programmer time.

**Example 4. Interagency Ecological Program Rotary Screw Trap Database Applications with centralized Bay Delta and Tributary Database (BDAT)**

The Bay Delta and Tributaries database (BDAT), including the Rotary Screw Trap (RST) component was created to meet the needs of the Interagency Ecological Program (IEP) (R. Breuer, CDWR, Pers. Comm., 2010). A database specialist with the California Department of Water Resources (CDWR) developed a "one size fits all" database template to capture all RST data and prepare the data for upload into the BDAT. The RST database is a distributed type database where copies of the database were shared with various agencies and programs in the CV. Use of the database and submission of data for upload into BDAT was voluntary. CDWR provided support to local CDWR offices and if other agencies requested assistance, but there was never a plan to maintain databases for all agencies. Dedicated funds were not provided to CDWR to create and maintain the databases or upload data to BDAT. CDWR is not mandated to collect RST data and it is not a priority. The IEP's focus is in the Delta and most of the RSTs are further upstream so most of the RST data is not a priority for the IEP. Providing the IEP- type databases and hosting RST data to BDAT was a service that CDWR provided. The service was not being utilized and so other avenues for sharing data are being explored. The CDWR intends to focus IEP funding toward data collection of a higher priority for the IEP.

**Example 5. Idaho Department of Fish and Game's Stream Database**

The Idaho Department of Fish and Game (IDFG) developed a collection of databases (IFWIS group) to hold raw field data collected from hatcheries (HDMS database), adult salmonid spawning surveys (SGS database), and stream surveys that collect fish (multiple species) and habitat data (SSS database) throughout Idaho (Harrington and Butterfield; IDFG; Pers. Comm., 2010). Originally, the effort was established to collect standardized data for the regional StreamNet database, but it has evolved over time. The hatchery release database was started 11 years ago and is being re-created with additional functionality to include genetics information that is now being used to identify eggs up to release from the hatchery and salmon that move throughout the Snake River basin. The hatchery trapping database was developed 4-5 years ago, the SSS database is older than 4 years old, and the SGS started 4 years ago and was just implemented in the summer of 2009. This database is used by many individuals within multiple agencies including IDFG, two Native American Tribes, United States Forest Service (USFS), and the USFWS.

The IFWIS group consists of a centralized database and several other distributed-type databases (Harrington and Butterfield; IDFG; Pers. Comm., 2010). All databases are hosted on an SQL server. Biologists enter stream survey data online directly into the SSS database on the SQL server. The other databases (HDMS and SGS) are a distributed type, where the databases are distributed in two formats in a Microsoft Windows environment to the field offices and data coordinators. The distributed databases are flexible enough to allow for a variety of installations. The field databases may not even resemble the SQL server database. A database is installed on an individual's computer. After an individual enters data into a field database, the database is periodically uploaded and exported to a coordinator database for review. Data are then uploaded from the coordinator database to the SQL server database. Conversion of formats happens automatically when data is uploaded from a field database to the SQL server database.

Data quality control is implemented for the IFWIS group. For the SGS distributed databases, individuals are instructed to make edits in their own data and then re-submit the data to the coordinator database (Harrington and Butterfield, IDFG, Pers. Comm., 2010). In some cases, established dates are set for the data to be finalized and submitted to the coordinator database or SQL server. Data coordinators also do some quality control procedures on the data prior to upload to the SQL server, where data errors can be tracked.

IDFG plans to continue to maintain and develop these databases. IDFG accepted responsibility for costs, but this program is being managed by mitigation funding (C. Harrington, IDFG, Pers. Comm., 2010). The cost to house and maintain the database was not provided. IDFG has one of the largest IT Departments in the state of Idaho, and the program is wrapped into the IT Department. Staff includes a program manager, one database assistant, three programmer analysts, and at least three data coordinators. They believe that once the programs are completed and people get used to data entry, staffing will decrease to one programmer for a variety of databases. Costs are being lowered by dropping their five physical servers and using virtual servers, where cost savings are in power, maintenance and upgrades. In addition, the costs of the virtual servers will be shared across the Department.

## Summary of Recommendations for Creating and Implementing a Standardized Database System

The managers that were interviewed for the databases described above were asked to share their recommendations for designing and implementing a standardized data management system in the CV for steelhead and Chinook salmon monitoring programs. These recommendations are their opinions based on their experiences with the database applications they work on. Lessons they learned from their experiences may provide useful information in the development and implementation of a standardized data management system for CV steelhead and Chinook salmon monitoring programs.

Unanimously, everyone interviewed agreed that biologists must be included in the development of the database (J. Azat, CDFG, M. Banach, PSMFC, D. Burch, CDFG, R. J. Griffin, WDNR, C. Harrington, IDFG, R. Breuer, CDWR, Pers. Comm., 2010). Biologists need to be included to help identify what they need and want from the database system. Biologists should provide input as to what fields need to be in the database, what reports are needed, and they should be comfortable with the data entry forms, and other functions of the database. Biologists should be asked to test and critique data forms and reports developed prior to production, which will help improve the utility of the database (J. Azat, CDFG, J. Griffin, WDNR, Pers. Comm., 2010). Biologists should not be asked to input data into a database until they can effectively access, query, and export or download their own data (J. Griffin, WDNR, Pers. Comm., 2010). Problems and questions need to be addressed quickly; this builds a trust between the database managers, biologists and database users. The biologists must be confident that they will be supported in order for this effort to be successful (D. Burch, CDFG, Pers. Comm., 2010).

Recommendations were given regarding development of the database. Before a database is created, the desired output need to be well defined, such as queries, reports. The database system needs to accommodate data entry at a variety of levels (e.g., PDA, desktop database, online entry) (D. Burch, CDFG, Pers. Comm., 2010) and allow for fast entry (J. Griffin, WDNR, Pers. Comm., 2010). The more there is agreement on standardize units of measure and other codes the better, however not standardization of units and measure is not necessary. The WDNR and the CDFG Northern Region have worked around dissimilarities by providing descriptive fields. For example one program collects length in inches and another in centimeters. An adjacent column describes the unit of measure. This works for data entry; however lack of standardization can complicate summary and reporting information. Prior to summary these measures must be converted so that they are reported in a similar unit. The more dissimilar the data, the more complex and difficult it is to manage. (J. Griffin, WDNR, D. Burch, CDFG, Pers. Comm., 2010).

A few managers emphasized the importance of selecting the right database programmers and developers (C. Harrington, IDFG, Pers. Comm., 2010). Programmers with a fisheries or other scientific background will have an advantage because they understand the data and how it is collected (J. Azat, CDFG, J. Griffin WDNR, Pers. Comm., 2010). In the 1980s, IDFG hired two contractors at different times and at least one IDFG programmer was assigned to develop a hatchery release database, but nothing resulted from those efforts. A biologist working at the hatchery saw a need and developed the hatchery release database that was successfully implemented and is still in use. In fact, the majority of the programmers working with the example database systems we examined were trained in fisheries or some other natural resource science.

Strong advocacy is also important, the Idaho team is using power point to help convey concepts and new products planned for development (C. Harrington, IDFG, Pers. Comm., 2010). It is much easier to gain support when stakeholders can envision the product. Similar advice was noted by other managers. Stakeholders must be able to envision the finished product if they are to understand and support the effort.

Some managers advised not to try to do too much too quickly; start small and build on success (M. Banach, PSMFC, H. Rook, CDWR, Pers. Comm., 2010). The core structure of the database must be able to accommodate the evolution of new monitoring methods or changes to the methods, and therefore this core structure needs to be well thought out (D. Burch, CDFG, Pers. Comm., 2010). All of the fields should be identified before the creation of the database, and the database must support the various data collection techniques (J. Azat, CDFG, D. Burch CDFG, J.Griffin, WDNR, Pers. Comm., 2010). Adding fields to a table in a database later can make the database structure complex or difficult for upload (D. Burch, CDFG, J. Griffin, WDNR, Pers. Comm., 2010). Watch out for "feature creep". Feature creep is a tendency for product or project requirements to increase during development beyond those originally foreseen, leading to features that weren't originally planned and resulting risk to product quality or schedule. Feature creep may be driven by a client's growing "wish list" or by developers themselves as they see opportunity for improving the product (http://sawaal.ibibo.com/computers-and-technology) (H. Rook, CDWR, Pers. Comm., 2010).

A successful database program is always based on adequate funding and support (R. Breuer, CDWR, Pers. Comm., 2010). This group recommended attending the CV Project Work Team meetings regularly and meeting with the participants individually to garner support. Stable long-term funding sources need to be identified.

**Potential Fields for a CV Steelhead Monitoring Database**

Potential fields were identified that may be included in a centralized database system for the steelhead monitoring programs. The list of fields for redd surveys (Table 1), fish device counters (Table 2), and mark-recapture surveys using fyke traps (Table 3), and for age data estimated from scales (Table 4), should be used for discussion purposes between a database architect and biologists, when determining fields needed in the database for each monitoring program. Additional fields may be identified or fields listed could be excluded from the database. Biologists through meetings will need to identify if certain fields (e.g., length or substrate type) can be standardized regarding units, or if additional fields will be necessary to accommodate different units of measure (e.g., Unit field with options for inches, centimeters, etc.) or definitions (e.g., size of sand, gravel, cobble, boulder, etc.).

Table 1. Potential fields for redd survey for inclusion in a centralized database system.

| | | |
|---|---|---|
| Waterbody | Average Flow | Habitat Type |
| Survey Number | Redd Identification Number | Pot Length |
| Date | Latitude | Pot Width |
| Surveyors Initals | Longitude | Tail Spill Width 1 |
| Survey Section | Species | Tail Spill Width 2 |
| Number of Crews | Number of Fish on Redd | Depth |
| Crew A or B | Superimposition potential | Velocity |
| Weather | Dominant Substrate | Comments |
| Secchi Disk Depth | Subdominant Substrate | |

Table 2. Potential fields for fish device counters for inclusion in a centralized database system.

| | |
|---|---|
| Waterbody | Direction of Passage |
| Survey Site | Date |
| Survey Number | Time |
| Video Method | Length |
| Surveyors Initals | Depth |
| Hours Operated | Speed |
| Fish ID Number | Position in Frame |
| Fish Species | Comments |

Table 3. Potential fields for mark-recapture surveys using fyke traps for inclusion into a centralized database system.

| | | |
|---|---|---|
| Waterbody | Trap Pull Time | Fish Length |
| Survey Number | Trap Set Time | Fish Weight |
| Trap Number | Depth of Trap | Scale Sample ID |
| Date | Water Temperature | Genetic Sample ID |
| Surveyors Initals | Average Flow | Sex |
| Latitude of Trap | Fish ID Number | Floy Tag Number |
| Longitude of Trap | Fish Species | Condition of Fish |
| Time Fished | Fish Marked or Recaptured | Comments |

Table 4. Potential fields for the estimated ages of fish sampled during surveys for inclusion into a centralized database system.

| | | |
|---|---|---|
| Scale Sample ID | Species | Read Age |
| Date | Coded Wire Tag | Sex |
| Scale Reader | Known Age | Length |

**Reporting Functions for a Database System for CV Steelhead Monitoring Data**

Potential reporting functions that could be developed into the front end of the centralized database system (Table 5). Biologists and database programmer(s)/developer(s) can use these identified functions as a start to discussing what biologists need from the reporting functions.

Table 5. Potential reporting functions of a centralized database system for data collected from steelhead monitoring programs.

| | | |
|---|---|---|
| Total Counts | Trap Efficiency | Age Frequency Histograms |
| Abundance Estimates | Probability to Detect Redds | Sex Ratios |
| Confidence Intervals | Length Frequency Histograms | |

## LITERATURE CITED

Johnson, C. L, G. M. Temple, T. N. Pearsons, and T. D. Webster. 2009. An evaluation of data entry error and proofing methods for fisheries data. Transactions of the American Fisheries Society 138:3, 593-601. Available: http://afsjournals.org/doi/abs/10.1577/T08-075.1. (March 2010)

StreamNet. 2009. Considerations for regional data collection, sharing, and exchange. White paper. Bruce Schmidt.

Xploretech, Xplore Technologies Corporation of America [internet], Case Study Field Service Minnesota Department of Natural Resources' Division of Fish and Wildlife, 2007. Xplore Technologies. Available: http://www.xploretech.com/AboutUsSubPages/cspdfs/fieldservicescs/mnndrcs.pdf (March 2010).

## PERSONAL COMMUNICATION

Azat, J., CDFG, Pers. Comm., Central Valley Chinook salmon escapement monitoring summary reports and Grand Tab, 2010.

Banach, M., PSMFC, Pers. Comm., StreamNet, 2009

Breuer, R., CDWR., BDAT data system and associated Interagency Ecological Program's rotary screw trap database., 2010.

Burch, D. CDFG, Pers. Comm., Distributed Access database developed for monitoring programs in CDFG Region 4, 2010.

Harrington, C. and B. Butterfield. IDFG, Pers. Comm., Idaho Department of Fish and Game's Stream database, 2010.

Harrington, C. IDFG, Pers. Comm., Idaho Department of Fish and Game's Stream database, 2010.

Gaul, P., CDFG, Pers. Comm., California Department of Fish and Game BIOS program, 2010.

Griffin, J., WDNR, Pers. Comm., Wisconsin Department of Natural Resources Statewide Fish and Habitat database, 2010.

Rook, H., CDWR, Pers. Comm., BDAT data system and associated Interagency Ecological Program's rotary screw trap database., 2010.