CITY AND COUNTY OF SAN FRANCISCO

DENNIS J. HERRERA
City Attorney

OFFICE OF THE CITY ATTORNEY

DONN W. FURMAN
Deputy City Attorney

Direct Dial: (415) 554-3959
Email: donn.w.furman@sfgov.org

RECEIVED
10-24-12
SWRCB Clerk

Sent via Email (commentletters@waterboards.ca.gov) and U.S. Mail

October 24, 2012

Jeanine Townsend
Clerk, to the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100

Re: Bay-Delta Plan Review – Other Comments: Application of Narrative Objective to Modification of Fish and Wildlife Objectives Phase 2 Review and Update of 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary ("Bay-Delta Plan")

Letter Outside Comment Period on Potential Draft Modifications to San Joaquin River Fish and Wildlife Flow Objectives for Narrative Objective for Salmon Protection in Bay-Delta Plan

Letter Outside Comment Period on Phase 2 Workshop on Bay-Delta Fishery Resources in Bay-Delta Plan

Dear Ms. Townsend:

I write on behalf of the San Francisco Public Utilities Commission to submit a memo on technical difficulties in applying the doubling goal narrative objective for salmon protection in the Bay-Delta Plan. The doubling goal narrative objective appears in the existing Bay-Delta Plan as follows:

> Water quality conditions shall be maintained, together with other measures in the watershed, sufficient to achieve a doubling of natural production of Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and federal law. *Bay-Delta Plan, Table 3, Water Quality Objectives for Fish and Wildlife Beneficial Uses*

The Board has proposed modifying the doubling goal narrative objective for San Joaquin River flow objectives as follows:

> Maintain flow conditions from the San Joaquin River Watershed to the Delta at Vernalis, together with other reasonably controllable measures in the San Joaquin River Watershed sufficient to support and maintain the natural production of viable native San Joaquin River watershed fish populations migrating through the Delta. Specifically, flow conditions shall be maintained, together with other reasonably controllable measures in the San Joaquin River watershed, sufficient to support a doubling of natural production of

Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and federal law. Flow conditions that reasonably contribute toward maintaining viable native migratory San Joaquin River fish populations include, but may not be limited to, flows that mimic the natural hydrographic conditions to which native fish species are adapted, including the relative magnitude, duration, timing, and spatial extent of flows as they would naturally occur. Indicators of viability include abundance, spatial extent or distribution, genetic and life history diversity, migratory pathways, and productivity. *Revised Notice of Preparation and Notice of Additional Scoping Meeting, April 1, 2011, Draft San Joaquin River Fish and Wildlife Flow Objectives.*

It is likely that the Board may propose modifying the narrative objective for Sacramento River flow objectives in a fashion similar to how it now proposes to modify San Joaquin River flow objectives. While the Board and court cases have acknowledged that implementation of the doubling goal narrative objective may be met by a number of different means - including flow - the Board has not yet grappled with the issue of whether the doubling goal narrative objective can be reduced to quantities that allow the SWRCB or an agency responsible for providing flow to know whether the narrative objective is being met.

Water quality objectives may, of course, be expressed as narrative or numeric. While adoption and revision of water quality objectives are exempt from most provisions of the California Administrative Procedures Act, the Office of Administrative Law will review the regulatory provisions of basin plan amendments under section 11353, which includes determining that the regulatory provisions are clear. (Gov. Code §§ 11353, 11349.3(a), 11349.1(a).) "Clarity" is defined to mean "written or displayed so that the meaning of regulations will be easily understood by those persons directly affected by them." (Gov. Code § 11349(c).)

The attached memorandum by Dr. Ron Yoshiyama discusses the challenges of measuring natural production of anadromous salmonids in the Central Valley, and, hence, the challenges of reducing the doubling goal narrative objective and its attainment to specific quantities that would allow the SWRCB and water agencies to determine whether the objective is being met.

Very truly yours,

DENNIS J. HERRERA
City Attorney

Donn W. Furman
Deputy City Attorney

plus: attachment

cc: Charles R. Hoppin, Chairman
State Water Resources Control Board
P.O. Box 2815
Sacramento, CA 95812-2815
San Joaquin Tributaries Association

Commentary on the Salmonid Doubling Goal for the Anadromous Fisheries Restoration Program:

The Challenge of Measuring Natural Production of Anadromous Salmonids in the San Joaquin Basin Tributaries and other Central Valley Rivers

Ronald M. Yoshiyama, Consultant to the City and County of San Francisco
October 20, 2012

INTRODUCTION

The stated goal of current fisheries programs required by statute or adopted by regulatory agencies to recover anadromous salmonids in the California Central Valley drainage is to increase the level of natural production to double the average production levels that occurred during the 1967-1991 period—i.e., the "Doubling Goal" (Central Valley Project Improvement Act section 3406(b)(1) [anadromous fish], Fish and Game Code section 6902(a) [salmon and steelhead trout], Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary 2006 Table 3 [Chinook salmon], USFWS 1995, AFRP-USFWS 2001, USFWS 2005 [anadromous fish]). The purpose of this commentary is to briefly note some of the conceptual and practical impediments to determining or achieving the Doubling Goal for salmonid populations. Several points of ambiguity are noted below in regard to the biological meaningfulness of "naturally produced" fish as currently defined, as well as various practical difficulties that hamper the collective fisheries management efforts to achieve the Doubling Goal—e.g., heavy influence of hatchery production and consequent reduction in population fitness; substantial rates of straying by spawners to non-natal rivers.

This commentary is intended to highlight issues of concern that must be realistically addressed in order to at least increase the populations of naturally produced salmonids to some viable levels, if not to the Doubling Goal levels. Perhaps the most significant implication is that it may not be possible to accurately determine what the past, reference level of natural production actually was during the baseline (1967-1991) period. If that is true, then it becomes unclear what the current target level(s) for the Doubling Goal for Central Valley salmonid populations should be. The point here is to stimulate constructive dialogue among regulatory agencies and fisheries managers regarding the reality of the hoped-for salmonid Doubling Goal and practicable avenues of approaching, if not necessarily reaching, such a goal.

The goal or mandate to increase anadromous salmonid production in the Central Valley region necessitates the provision of adequate river flows, among other environmental requirements, that facilitate the rebuilding of the salmon populations to self-sustainable levels; i.e.,

> " . . . *Specifically, flow conditions shall be maintained, together with other reasonably controllable measures in the San Joaquin River watershed, sufficient to support a doubling of natural production of Chinook salmon from the average production of 1967-1991, consistent with the provisions of State and federal law. . . .*"

The Position Paper of the Anadromous Fish Restoration Program (USFWS 1995: p.2-IX-6) restates the mandate as requiring that ". . . *natural production of anadromous fish in Central Valley rivers and streams be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991* . . . " and provides definitions of the terms used therein.

The focus of the Doubling Goal on naturally produced salmonids—as opposed to artificially produced (hatchery) salmonids—deserves mention. Natural salmonid populations are important to preserve because they are the repositories of genetic and life-history diversity that allow the populations to efficiently exploit a variety of different habitats and to adapt to long-term temporal changes in environmental conditions (e.g., climate-ocean cycles and regional climate trends) (NRC 1996). Hatchery populations, in contrast, tend to be less diverse because they generally are established from small numbers of "founder" taken from natural populations and are reared under relatively constant artificial conditions.

In fact, a number of studies have now shown that natural (wild) fish perform better than hatchery fish--i.e., natural fish may have greater fitness in terms of survival or reproductive success—at least under certain natural environmental conditions (Kostow et al. 2003, Berejikian and Ford 2004, McLean et al. 2004, Araki et al. 2008, 2009, Schroeder et al. 2008, 2010)). For example, eggs spawned by wild spring Chinook females in the Yakima River (Washington) had a 5.6% higher survival rate from egg to fry than did eggs from first-generation hatchery females (which also were from the Yakima River) (Schroeder et al. 2008). Similarly, naturally produced steelhead in the Hood River (Oregon) had higher smolt-to-adult survival than did hatchery steelhead (Kostow 2004). Furthermore, a study on the early marine phase of juvenile Chinook salmon in the Strait of Georgia showed that naturally produced juveniles from the Cowichan River (Vancouver Island, British Columbia) had far higher survival rates (7.8%-31.5%) than did Cowichan River hatchery juveniles (1.3%) even though both types remained in the same marine area during that period (Beamish et al. 2011). The study by Beamish et al. (2011) is especially significant because it was conducted during, and in response to, an extended period of low production levels of Chinook, coho and sockeye salmon populations and ecosystem changes--the latter associated with progressive warming conditions--in the Strait of Georgia. The Cowichan River Chinook salmon serves as an indicator population for the "health of [C]hinook salmon in general" in that region and to gauge the effectiveness of efforts by the International Pacific Salmon Commission to recover salmon abundances (Beamish et al. 2011).

Achievement of the Doubling Goal strictly in terms of naturally produced salmon (and steelhead) requires a knowledge of at least three points; viz.,

(1) The annual levels of natural production during the 1967-1991 period, which serves as the baseline or reference criterion;
(2) The current and recent levels of natural salmonid production;
(3) An understanding of the required amounts of flows and their temporal schedules—e.g., within and between seasons, and over multi-year periods—that will be minimally sufficient to sustain specified levels of natural salmonid production.

Currently, there does not appear to exist adequate knowledge--in terms of both quantity (e.g., time-series data) and accuracy--about these three points that would allow a reliable quantitative prescription of necessary minimum flows and other environmental requirements, as discussed below.

Points (1) and (2) are the subject of the present commentary. Point (3) is highly controversial and presently indeterminate, and so it is not considered in this commentary.

Points (1) and (2) are closely related because their interpretations critically depend on the definition or understanding of the term "natural production." That definition then determines how feasible it will be to achieve the stated objective of doubling "natural production" through the provision of flows as well as other required measures. In this document, the terms “natural” and “wild” fish are considered equivalent, in concordance with the current usage by the resource agencies and other fisheries and aquatic scientists who are collectively involved in the management of fish resources in California.

The current management practice of the resource agencies defines, or assumes, “natural production” to include any anadromous salmonids that were produced from eggs deposited by parental spawners within the in-river spawning areas—i.e., “fish produced to adulthood without direct human intervention in the spawning, rearing, or migration processes” (USFWS 1995: p.2-IX-6). However, those parental spawners could have included both spawners that hatched from in-river (natural) redds and also spawners that originally were produced in hatcheries (USFWS 1995, IR-CVPIA 2008: p.21). Therein lies a fundamental weakness in the current definition of “natural production” because, as such, current levels of natural production may be derived from hatchery production of previous generations of spawners. Hence, it is possible that the observed levels of naturally spawning populations have been artificially bolstered by high levels of hatchery production during much of the previous decades, thereby distorting our perception of past natural production. If that is true, then it is also likely that the continued high levels of hatchery production may be compromising the ability of truly natural stocks to sustain themselves—i.e., those naturally reproducing stocks that are, or otherwise would be, capable of perpetuating themselves over multiple generations without the addition of hatchery-produced fish.

The potential, if not actual, deleterious effects of hatchery rearing of salmonids on wild populations were suggested at least decades ago (e.g., ISG 1996, NRC 1996). The National Research Council’s Review of the Pacific Northwest Salmon succinctly stated the issues (NRC 1996: p.304-305):

> “Traditional approaches of hatchery programs have imposed different types of biological problems on salmon populations, including demographic risks; genetic and evolutionary risks; problems due to the behavior, health status, or physiology of hatchery fish; and ecological problems. One or more of those problems might have affected either the populations that a hatchery program aimed to rebuild, other populations with which they interact, or both . . . Growing scientific evidence supports the notion that hatchery-caused problems cannot be ignored without further threatening the future of depleted salmon populations.”

Although it is often difficult to conclusively prove the occurrence of negative impacts of hatchery production on natural populations, various negative effects have been increasingly demonstrated by published studies (e.g., summaries in JHRC 2001, Levin et al. 2001, ISAB 2003, Williams 2006). The deleterious effects of hatchery introgression may involve the loss of fitness of populations even after very limited amounts of hatchery supplementation (ISAB 2003, Kostow 2004, Araki et al. 2007).

Aside from the aforementioned conceptual problem with applying the current “working definition” of naturally produced fish, there is the practical problem of enumerating past and present levels of natural production. Specifically, it is not possible to accurately determine the levels of natural production during past periods because the relative numbers of natural and hatchery fish are not accurately known for those times. Until very recently, the natal identity of a major proportion of in-river spawners has been uncertain because many individuals that were produced by salmon and steelhead hatcheries in the Central Valley were not marked as such and therefore could be mistaken for natural fish.

Hence, there is considerable uncertainty about the actual levels of natural production for the 1967-1991 baseline period even if the current definition of “natural” is strictly adopted--i.e., whereby natural fish are defined as those that were hatched in-river, whether their parents were produced in-river or from hatcheries. Several aspects of the problem of accurately ascertaining past natural production are further discussed in the following sections.

Much of the issues discussed above have been previously recognized. Specifically, the lack of scientific clarity about the "Doubling Goal" baseline and the high uncertainty about the actual sizes of natural salmon populations and other related aspects were pointedly noted in the Independent Review of the CVPIA Program (IR-CVPIA 2008: p.21-22); viz. (bold text in original),

"The goal has several important limitations that make it difficult to guide and evaluate the implementation of a program to improve anadromous fish in the Central Valley. These include:

- **The scientific rationale for adopting the index and for its magnitude is not clear.**
- **Estimating natural production is inherently problematic** under the conditions present in the Central Valley. The result is that **the baseline is unreliable and natural production levels are actually unknown.** In other words, doubling adult returns is relatively meaningless as a target if the estimated abundance of the base population is unreliable. Estimating changes in the natural production in a meaningful manner is similarly problematic given variances (presumably large) of the population estimates have not been calculated.
- **Continued reliance on hatchery fish to contribute to natural production is not consistent with the CVPIA goal** of sustaining natural production over the long term.
- **Ocean and river harvest practices and production targets to support harvest are not well coordinated with efforts to increase natural production.**
- **The stated goal to increase the production of both native salmonids and exotic predators/competitors (e.g., striped bass and shad) is internally inconsistent.**
- **Many factors beyond control of the CVP affect survival through returning adults,** so that measuring natural production through returning adults may say little about the effectiveness of program activities."

The first two bulleted points above are of special interest here because they pertain specifically to the conceptual meaningfulness and practicality of the Doubling Goal. The Independent Review Panel further elaborated on those aspects (IR-CVPIA 2008: p.22-23):

"*Population Estimates*

A number of factors contribute to the lack of confidence in anadromous fish population numbers. Population estimates for the baseline and current periods are not available for all anadromous fish (e.g., steelhead south of Red Bluff). For most others, the baseline and current population data is scientifically suspect largely due to variability and unreliability of counting methods and lack of variance calculations. Where there is no or unreliable baseline population statistics it is impossible to determine a reliable doubling target. An example of population estimation problems is the low CVPIA 'doubling target' of 13,000 for Central Valley steelhead. The target is derived from a baseline average of a mere 6,500 naturally-produced steelhead, representing populations of steelhead spawning in tributaries above Red Bluff . Historically, at least, there were large amounts of steelhead in other tributaries (Lindley et al. 2006). The goal for steelhead reflects the historical limitations in the ability to count steelhead, rather than any comprehensive estimate of abundance."

"Natural Production Estimates

Natural production of chinook and steelhead is also difficult to estimate because of the substantial straying of adult hatchery throughout the valley. The presence of unmarked hatchery fish on the spawning grounds is problematic both for determining the baseline condition (i.e., the levels of natural production in 1967-1991) and for estimating the current levels of natural production. Reliable numbers for hatchery straying are not available, nor is the percent of hatchery fish in the total population known. In addition, the fraction of hatchery fish derived from the less-than-reliable-information is assumed constant, but recent reports suggest that this fraction has been rising over time, especially for fall-run chinook and steelhead (Good et al. 2004, Barnett-Johnson et al. 2007). It is possible that rising fractions of hatchery fish are masking actual declines in the abundance of natural populations of fall-run chinook. The result of this lack of data is that the estimates of natural production, both baseline and current, may be off by orders of magnitude."

"Natural Production Definition

Another issue is the broad definition of 'natural' production. Using the agencies' operational definition, hatcheries may prop up the abundance of fish spawning in the wild even to levels that are above carrying capacity, in the extreme case maintaining sizable runs of fish in habitats incapable of supporting a self-sustaining run of fish. Thus, the doubling goal could be met in a quantitative sense, but not be sustainable on a long-term basis as required both by the CVPIA and for de-listing under the ESA."

"Levels and Trends in Population Baseline.

The doubling goal also glosses over other important aspects of the baseline. Foremost among these is that any baseline is better characterized in terms of both levels *and* trends. Some populations or runs were declining steadily over the baseline period, and the average abundance over that period is not a complete description of their status. Using an average obscures the fact that before the level can be raised, the decline must be halted. When this declining trend is also recognized, the fact that some populations achieve levels of abundance close to the baseline level could be viewed as success, because this represents a significant increase in abundance for the population compared to its level at the end of the baseline period."

"*Arbitrary Nature of Doubling Goal*

"Besides the data and interpretation problems, the arbitrary nature of the doubling goal is problematic. Doubling some populations may not ensure long-term sustainability or allow for recovery under the ESA. For other populations, doubling may not even be feasible given the tools available through the CVPIA. For example, more than 80% of historical spawning habitat for spring-run chinook and steelhead and nearly 100% of winter-run chinook habitat (Yoshiyama et al. 2001, Lindley et al. 2007) are above impassable dams. It is not clear to the panel whether there is enough spawning and rearing habitat below these barriers to support populations that double even a degraded baseline, much less to take the species out of jeopardy."

"The problematic nature of the doubling goal and the data issues mentioned above pose a number of challenges to creating a successful restoration program and demonstrating its success based on that goal. The CVP facilities and operations have had complex effects on the physical and biological environment of Central Valley streams, while the doubling goal simplistically suggests that these effects can largely be mitigated by finding ways to make this system produce more fish. Ecologists and salmon biologists have increasingly recognized that high population abundance is a property of a species that emerges from other characteristics, especially diversity (McElhany et al. 2000, Hilborn et al. 2004). This evolving viewpoint should shift the focus of CVPIA salmon restoration to restoring ecological function of habitats in order to support life history and genetic diversity. When ecological function is restored, increases in species abundance and production will follow, as will long-term population sustainability."

"Ecological function is best restored by (re)creating the natural processes that create, maintain and disturb habitats. Other provisions of the CVPIA recognize this concept, especially the directive in Section 3406(b)(1)(A) to 'give first priority to measures which protect and restore natural channel and riparian habitat values through habitat restoration actions, modifications to Central Valley Project operations, and implementation of the supporting measures.' But protecting and restoring ecosystem function seems largely ignored by a program targeted, monitored and explained to the panel as focused nearly entirely on doubling the baseline abundance estimates for chinook salmon."

"*Native and Non-native Anadromous Fish Goals*

A related issue is that the CVPIA doubling goal applies to all anadromous species, some of which are non-native such as striped bass. These species are part of a trophic network that prey upon and compete with salmonid species. Doubling all anadromous species may not be a consistent goal. For example, striped bass are highly piscivorous after two years of age (Stevens 1966), and predation by a larger striped bass population on juvenile winter-run chinook may impede recovery of winter-run chinook (Lindley and Mohr 2003). Bottom et al. (2005) hypothesize that American shad may have altered the structure of food webs in the Columbia River, with potentially deleterious effects on salmonids."

Also importantly, the severe deficiencies in our understanding of the relative amounts of natural and hatchery salmonid production in the Central Valley during recent decades—and which have continued to the present (2012)—were explicitly noted a decade ago by the Joint Hatchery Review Committee (JHRC) for the California Department of Fish and Game and the National Marine Fisheries Service (JHRC 2001). Those deficiencies were, and are, largely due to the inadequate marking of hatchery-produced fish. The inadequacy of the marking and recovery-sampling of hatchery fish and the consequences thereof on population assessments and management of Central Valley salmonids were explained by the JHRC (2001, p.18-19):

". . . The relatively low and variable proportion of chinook salmon that are currently marked at Central Valley hatcheries results in a lack of reliable data on which to base management decisions. In addition, both DFG and NMFS expressed concern regarding the inadequacy of Central Valley fresh water CWT recovery programs. Small sample sizes and non-random sampling may bias CWT expansions and subsequent estimates of the contribution rates of hatchery fish to naturally spawning populations and to freshwater recreational fisheries. A DFG/DWR workshop on escapement estimation methodology (UC Davis, June 22, 2000) highlighted the fact that the accuracy of most Central Valley escapement estimates are unknown and may not be sufficient to meet federal and state management needs, CalFed or CVPIA requirements. Within the DFG, there is presently no forum for the review, discussion or oversight of salmon escapement estimates."

> “The lack of adequate marking and sampling of Central Valley hatchery fish has several consequences.”
>
> “1) An approved HGMP must evaluate, minimize and account for the propagation program’s genetic and ecological effects on natural populations, including disease transfer, competition, predation and genetic introgression caused by straying of hatchery fish. Without effective monitoring and evaluation of returning hatchery populations, the effects of hatchery rearing and release strategies cannot be fully evaluated. . . .”
>
> “2) There is currently no estimate of an exploitation rate for any Central Valley salmonid population. The lack of an exploitation rate estimate for Central Valley fall chinook substantially impairs NMFS’ ability to assess fishery impacts on listed stocks that may share similar ocean and river distributions and vulnerability to harvest. None of the biological opinions that authorize the incidental take of listed salmon in ocean fisheries off California have been able to specify the amount of incidental take that occurs in ocean fisheries. This is a serious problem.”
>
> “3) The impact of straying hatchery fish on natural populations is a key federal ESA concern. Without adequate marking and monitoring of hatchery populations, the estimation of straying rates between watersheds and the genetic exchange between hatchery and naturally producing stocks will remain a matter subject to speculation.”
>
> “4) Substantial effort and resources are being expended on improving the spawning and migration habitat for Central Valley salmonids. The CVPIA mandates doubling of natural populations and assessment of the progress toward meeting the goal. Evaluating the success of restoration actions and the impact of changes in water operations is difficult or impossible without adequate monitoring and evaluation of the populations the actions are intended to benefit.”

FURTHER DISCUSSION ON DETERMINING PAST LEVELS OF NATURAL SALMONID PRODUCTION

There are a number of problems associated with accurately estimating natural levels of salmon (and steelhead) production and those problems are especially acute for earlier periods when the requisite data were incomplete or absent. Theoretically, the past levels of natural salmon production in the San Joaquin River basin could be quantified from estimates of total annual spawning-run sizes if the relative contributions of natural and hatchery-derived spawners are known or can be estimated. Specifically, two types of data are required:

(1) accurate identification of spawners as either naturally produced (i.e., in rivers) or hatchery produced, and
(2) spawner straying rates (for both natural and hatchery fish) into and out of the San Joaquin basin tributaries.

These two required types of data have only recently become available in amounts and of quality that allow them to be applied for estimating current natural production, but there still is considerable statistical uncertainty about the estimates they provide. Newman and Hankin (2004) developed statistical procedures for assessing past (i.e., 1967-1991) and present natural production, and they provided an analytical framework for hypothesis testing and for clarifying the reasons for sustainability of those estimated production levels. Yet again, those authors emphasized the critical importance of having a solid foundation of population-level data (Newman and Hankin 2004: p.2-3):

> "**Concerns regarding available data.** While we believe that state-space models are the proper statistical tool for comparing natural production levels in different periods, we have concerns over the quality of estimates of natural production in both the 1967-1991 period and in years since then. In particular estimates of the proportion of total production attributable to hatchery fish depend upon problematic assumptions and estimates of the imprecision and bias of the estimates are lacking. For state-space models, or even modified t-test or t-based confidence intervals to be successfully implemented, measures of the bias and imprecision of natural production estimates are needed. For the point estimates of natural production during the historical period of 1967-1991, statistical measures of accuracy and precision need to be calculated. With future analyses in mind, we emphasize the need for immediate implementation of statistically sound tagging, marking, and sampling schemes with associated procedures for separately estimating hatchery and natural production on a stream by stream basis. This involves at a minimum the tagging of several well-chosen hatchery releases meant to serve as surrogates for the various Central Valley natural stocks that cannot themselves be tagged in adequate numbers."

Furthermore, to truly assess the relative levels of natural and hatchery production in a specific river, the spawning success rates of natural and hatchery-produced spawners in the river must be known and also the relative survival rates of their progeny—i.e., survival from the time of hatching/emergence until at least the time of emigration from the natal river or their entry to the ocean, whichever point is taken to measure total production of the cohort.

In addition, if production is measured at the adult stage, then estimated harvest numbers of adults (in the ocean and in-river fisheries) are required so they can be added to the escapement numbers to obtain total adult production levels. The yearly ocean harvest data for salmon (from both commercial and recreational fishing) are given in the annual Ocean Salmon Fisheries Reviews of the Pacific Fishery Management Council (Portland, Oregon, www.pcouncil.org) for specific coastal regions. However, detailed data on how that ocean catch is apportioned among the individual stocks originating from specific rivers appear to be lacking for much of the historical record, thus limiting our ability to accurately estimate production levels for the individual rivers.

Relative Levels of Hatchery versus Natural Production

A variety of markers can be applied to hatchery fish during rearing or prior to release that make them identifiable as such (e.g., Williams 2006). Simple fin clips (usually of the adipose fin) or chemically and thermally induced banding in the vertebrae or otoliths identify the fish as having originated from hatcheries. Alternatively, or in addition to the above markers, data-encoded coded-wire-tags (CWTs) or passive integrated transponder (PIT) tags can be inserted into individual hatchery fish and provide more detailed data about the origin of those fish. Recently, the use of micro-structural and micro-chemical characteristics (e.g., natural strontium, calcium, and sulfur isotopes) in otoliths has become important in identifying the natal origins of salmonids—viz., whether they are hatchery or naturally produced fish, and from which natal streams (e.g., Zhang et al. 1995, Ingram and Weber 1999, Volk et al. 2000, Barnett-Johnson et al. 2008). However, the use of such micro-structural and micro-chemical "markers" requires substantial effort and expense compared to the use of physical tags.

The major problem until very recently was that only a small fraction of hatchery fish in the Central Valley had been marked or tagged and so the great majority of hatchery fish were indistinguishable from, and could be mistaken for, naturally produced fish. Furthermore, until a few years ago the tagging or marking of hatchery fish (i.e., with CWTs and adipose fin clips) by Central Valley hatcheries had been conducted at variable rates. A constant-fractional-marking (CFM) program was finally initiated in 2006 by the major Central Valley hatcheries that produce anadromous salmonids (CDFG 2008). A target marking rate of 25% of all hatchery-produced fish was adopted by five hatcheries so that consistent and reliable estimates of hatchery production subsequently could be made. However, two minor hatcheries in the San Joaquin basin and eastside Delta have continued to mark fish at rates other than 25%--viz., 100% marking at the Merced River Hatchery and either 25% or 100% in various years at the Mokelumne River Hatchery ("Constant Fractional Marking" summary, January 25, 2012, on FISHBIO website: www.fishbio.com). Such deviation from the target 25% rate consequently introduces uncertainty (i.e., statistical error) in the Central Valley-wide estimates of hatchery production. Specifically, because the overall rate of hatchery marking is not entirely 25% of all hatchery fish, it is not possible to assume that the proportion of unmarked hatchery fish is consistently 75%--i.e., we cannot assume that for every marked hatchery individual there are always another three unmarked hatchery-produced individuals that are mixing with the naturally produced fish. Therefore, it is not yet possible to accurately determine how many of the returning adult spawners in the Central Valley rivers were hatchery produced or naturally produced in recent years—particularly for the San Joaquin River basin (influenced by Merced River Hatchery) and the Delta-eastside (influenced by Mokelumne River Hatchery).

Implications of Past and Present Hatchery Influences

The highly mixed (natural and hatchery) composition of Central Valley salmon and steelhead stocks in past decades presents a logical dilemma and potentially insurmountable obstacle to achieving the desired Doubling Goal. If the reference baseline level of putative natural production (i.e., for 1967-1991) actually was heavily subsidized by continual hatchery augmentation, then achieving that level as a target for current-to-future natural production would be far more difficult than expected and may not even be possible. That is because the doubling target level would be an artifact of heavy hatchery production that had inflated the real, natural production levels during that period. Hence, the fundamental question is: "If the reference baseline period did not actually produce the supposed levels of natural production, how can current-future salmonid management efforts be expected to do so?" Or stated another way, "Is the Doubling Goal as it is currently defined more a chimerical construct based on an erroneous perception of past natural production rather than a reality-based management goal?"

A recent study of fall-run Chinook salmon in the Mokelumne River watershed provides a specific example in which the continuing production of hatchery fish has subsidized the apparent natural in-river population (Johnson et al. 2012). In that study, the analysis of sulfur isotopic composition of otoliths demonstrated that the great majority of adult fall-run spawners in the river originally were produced by a hatchery—i.e., 95.9% of all the spawners (confidence interval, 90.7%-99.3%) were hatchery fish. The Mokelumne River situation represents a "source-sink" meta-population in which the hatchery (or several hatcheries) is the source of most recruits and the in-river population is a sink that could not otherwise exist as a viable population.

On a broader scale, the entire Central Valley system similarly represents a network of one or several meta-populations of fall-run Chinook salmon and steelhead that long have been, and continue to be, heavily supported by hatchery production, thus giving the appearance of “healthier” or larger natural (“wild”) populations than actually exist(ed).

Hence, the concept of a baseline or reference Doubling Goal—i.e., based on putative natural production during 1967-1991—is in need of a careful, realistic reevaluation. Particularly, the Doubling Goal may be a questionable target for those portions of the Central Valley system that historically have been heavily influenced by hatchery production—e.g., at least the upper mainstem Sacramento River, Battle Creek, and the Feather, American, Mokelumne and Merced rivers, and probably additional nearby rivers that have been inadvertently influenced by straying or experimental releases of hatchery fish. However, the Doubling Goal may be realistic for populations that have had little hatchery augmentation, such as the spring-run Chinook salmon in Deer, Mill and Butte creeks and possibly other runs.

Straying Rate Estimates

There have been a few attempts to estimate levels of straying by returning spawners among Central Valley rivers. For example, Dettman and Kelley (1987) provided straying estimates for the Feather River and American rivers. Recently, Dr. Carl Mesick (USFWS) presented inter-tributary straying rates based on recaptures of coded-wire-tagged (CWT) hatchery salmon (Mesick 2009, 2010) and his analysis indicated various levels of straying by returning spawners to localities other than their natal streams. In the absence of accurate, year-to-year straying estimates for each river-specific population in the Central Valley, a possible alternative approach might be to broadly apply Mesick’s empirically derived straying rates—e.g., by averaging the straying rates to the Stanislaus and Tuolumne rivers-- to the escapement estimates for the entire San Joaquin River basin and other Central Valley rivers in recent years and during earlier periods (e.g., for 1967-1991). Such extrapolation, albeit highly tenuous, may provide relative estimates of past and current levels of hatchery and natural production in each of the major rivers. Although far from ideal, the application of estimated straying rates especially to the Tuolumne River and other San Joaquin Basin and Delta-eastside tributaries would offer a more realistic picture of how much natural production and unintentional augmentation by hatchery-stray spawners from other rivers of the Central Valley region has occurred over the most recent decade (2000-2011) and at least a crude estimate for the earlier periods.

However, the straying rates of hatchery fish from specific hatcheries or release sites to other non-origin rivers and hatcheries are not constant over time and the straying rates depend on where the fish were planted (Dettman and Kelley 1987). For example, Dettman and Kelley calculated that 92% of the Feather River Hatchery fish that were released into the Feather River subsequently returned to the Feather River for spawning, compared to only 46% of Feather River Hatchery fish planted in the Delta-Estuary that ultimately returned to the Feather River for spawning.

Similarly, Dettman and Kelley (1987) cited a previous study that concluded that the homing rates of spawners for the American River decreased when the young had been released in the Sacramento River instead of into their natal lower American River. Dettman and Kelley furthermore estimated that the frequency of straying spawners originating from the American River (i.e., from Nimbus Hatchery) increased from less than 10% of the spawning escapement before 1971 to 30% of the spawning escapement after 1970 due to the increased plantings of young fish further downstream in the mainstem Sacramento River and in San Francisco Bay.

Table 1, based on information from Dettman and Kelley (1987), illustrates the extent to which release locations of hatchery fish from the Feather River Hatchery affects their homing tendency to their natal river (i.e., Feather River). Specifically, Feather River Hatchery fish that were released in the Feather River as smolts or juveniles returned to the Feather River for spawning at a far higher rate (91.62%) than strayed to other rivers. In contrast, the Feather River Hatchery fish that were released at other locations had substantially lower homing rates to the Feather River—viz., 82.31% of the Feather River Hatchery fish that were released in the Sacramento River homed to the Feather River, while only 46.44% of Feather River Hatchery fish released in the Delta and Estuary later homed to the Feather River and 37.61% strayed to the Sacramento River.

Table 1. Percent returns of Feather River Hatchery (fall-run) Chinook salmon, released as juveniles at different locations (columns) and recovered as spawners in the Feather River and in other Central Valley rivers (rows) (adapted from Dettman and Kelley 1987, Table III-8).

	Release Locations of Juveniles		
Recovery Locations	Feather River	Sacramento River	Delta & Estuary
Homed to Feather River	91.62%	82.31%	46.44%
Strayed to:			
Sacramento River, upstream of Red Bluff	0.02%	0.85%	2.22%
Sacramento River, downstream of Red Bluff and above Feather River confluence	8.25%	6.94%	35.39%
American River	0.11%	8.65%	14.73%
Mokelumne River	0.00%	1.25%	1.22%
	100%	100%	100%

Therefore, a major conclusion to draw is that the straying rates of fish from particular hatcheries have changed over the decades because the planting practices have changed—i.e., a shift to planting large numbers of hatchery juveniles and smolts in the Sacramento-San Joaquin Delta and San Francisco Bay rather than planting predominantly in the rivers where the hatcheries are situated. The magnitude of "off-site" releases—i.e., releases away from the natal hatcheries and rivers—has been substantial. To illustrate, the CDFG-NMFS Joint Hatchery Review Committee (JHRC 2001: p.13) noted:

> "Significant numbers of Central Valley hatchery-reared salmon are transported by truck to the San Francisco Bay and released. For example, in 1999 Feather River Hatchery released 78% (5.88 of 7.52 million) of its fall chinook smolts downstream of the Delta; Nimbus Hatchery released 100% of its 3.8 million fall-run there; and Mokelumne River Hatchery released 57%

(1.72 of 3.04 million) there. In the same year, Feather River Hatchery released 100% (2.12 million) of its spring chinook smolts in San Pablo Bay."

Additional information on off-site releases of hatchery-produced juveniles (Chinook salmon and steelhead) was provided by Williams (2006). Table 2 illustrates the substantial extent of off-site releases of fish from certain hatcheries and also the low proportions of released fish that were tagged or marked and, hence, were identifiable as hatchery fish.

Table 2. Production levels and release locations for Central Valley salmon and steelhead hatcheries (adapted from Williams 2006). "ad-clip" = adipose-fin clipped; CWT = coded-wire-tags.

Source Hatchery	Species or Run	Hatchery Production Goal (numbers of fish)	Tag or Marks	Release Location
Coleman Battle Creek	Fall Chinook	12 million smolts	~8% CWT for brood-years 1995-2002	Battle Creek
Coleman Battle Creek	Steelhead	600,000 smolts	100% ad-clip some CWT	75% at Balls Ferry (mainstem Sacramento River) 25% Battle Creek
Feather River	Spring Chinook	5 million smolts	100% CWT	50% Feather River 50% San Pablo Bay
Feather River	Fall Chinook	6 million smolts 2 million post-smolts	10% CWT 10% CWT	San Pablo Bay San Pablo Bay
Nimbus American River	Fall Chinook	4 million smolts		San Pablo Bay
Mokelumne River	Fall Chinook	1 million smolts 2.5 million post-smolts	Few CWT	Lower Mokelumne River or San Pablo Bay

It is now well known that off-site releases result in higher levels of straying (JHRC 2001). Thus, the impact on natural spawners by straying hatchery fish has increased and our ability to enumerate the natural spawners has become more difficult.

Additionally, studies on coded-wire-tagged hatchery and naturally reared Chinook salmon in the Mokelumne River revealed variable rates of recaptures of tagged fish—i.e., from the ocean fishery and spawner returns to the Mokelumne River and strays to other rivers (Smith and Workman 2004). The differences in return rates to the Mokelumne River (and Mokelumne River Hatchery) and straying rates to other rivers depended on a variety of factors such as stock origin (e.g., Mokelumne River, Feather River and Nimbus-American River hatcheries), rearing environment (hatchery versus natural in-river), body size and developmental stage at release, and release location. Based on analyses of mark-release-recapture data for hatchery fish (spanning years 1991-2000) and for naturally reared Mokelumne River fish (years 1993-2000), it was found that significantly higher proportions of hatchery fish (all three hatcheries combined) strayed to other rivers for spawning (range, 14.8%-71.3%, depending on release group) than did naturally-reared Mokelumne River fish (7.3%). Releases of tagged fish at Bay-

Delta release locations led to significantly higher straying rates than occurred when the tagged fish were released into the Mokelumne River (Smith and Workman 2004).

The results from the Mokelumne River studies clearly show that the incidence of straying from the natal river during the spawning migration is affected by a variety of interacting factors, making even present-day attempts to estimate straying rates quite challenging. Hence, attempts to estimate straying rates for past periods are far more difficult because so little is known about the year-to-year variation in conditions that may have affected the levels of straying by both hatchery and natural fish.

Alternative Measures of Natural Production: Indices at Different Life-History Stages (or Ages)

There is the fundamental question of how natural production of a population is best measured—whether by spawning escapement numbers or by indices of other life-stages. The use of spawning escapements appears to be the easiest and evidently the only practical approach for estimating past levels of natural production. Those escapement numbers can be combined with known or estimated harvest numbers to obtain adult production estimates.

However, for estimating current levels of natural population production, it is possible to use other life-stages aside from adult spawners—e.g., numbers or densities of rearing juveniles or numbers of outmigrating juveniles and smolts--although such attempts would require substantial field efforts. Current monitoring activities in some Central Valley rivers provide assessments of juvenile abundance—e.g., rotary screwtrapping, regular seining activities. Such regular monitoring of juvenile salmonids was rarely conducted during previous decades in the Central Valley; thus, early-life-stage abundance information is largely not available for estimating natural production during the 1967-1991-baseline.

Implications for Management Perspective, Goals and Strategy

The preceding discussion has pointed to the tenuous nature of the numerical baseline for Central Valley salmonid populations (pertaining to the 1967-1991 period) and, consequently, to the questionable validity of that baseline for defining current-future salmonid restoration goals. A fundamental issue—and perhaps the key one—is that the overall habitat conditions in Central Valley streams during 1967-1991 likely were not capable of producing the putative numbers of natural salmon (and steelhead) represented by the average baseline numbers that defined the Doubling Goals. Previous assessments of Central Valley salmonid resources (e.g., Reynolds et al. 1993, McEwan and Jackson 1996) indicate that environmental conditions in the major Central Valley tributaries were substantially worse during the 1967-1991 period than in the past two decades (~1991-2012) due to the recent implementation of actions such as increased instream flows and physical habitat restoration including the removal of various small dams.

Hence, some emergent questions are:

(1) What can or should be done to clarify the apparent obscurity about, and rationale for, the basis of the current restoration "Doubling Goal" for naturally produced anadromous salmonids in the Central Valley?
(2) Should there be different restoration target-levels for natural salmonids, and what should they be?

(3) Given that different parts of the Central Valley have different histories and, consequently, different current environmental and socio-economic factors—such as the present use of the mainstem Sacramento River to convey large volumes of water from Shasta Reservoir and Oroville Reservoir specifically destined for the south Delta export pumps, which has no parallel in the San Joaquin River basin--how should the restoration target for salmonid populations be tailored to accommodate those regional differences?
(4) Is it realistic to expect that the restoration target levels, whatever they may be, can be achieved within a given time-frame? If so, what are those time-frames?
(5) Should population (production) target-levels for naturally produced salmonids be periodically adjusted upward in tandem with general improvements of salmonids habitats in the Central Valley? Conversely, at some point in time, should the target-levels be adjusted downward in conformance with generally deteriorating environmental conditions due to extended droughts and eventual regional climate warming?

It is not suggested here that answers to those questions are straightforward or fully achievable, but the questions nonetheless deserve attention. Some relevant aspects of re-evaluating the salmonid restoration targets are offered in the following section. In addition, Williams (2006) provided an informative summary of various options and recommendations concerning the role of hatcheries in Central Valley salmonid management. Those options also deserve consideration in regard to setting salmonid restoration targets.

Potential Alternative Actions for Increasing Natural and Total Salmonid Production

- Adjust the restoration goal (target numbers) for natural populations (production) downward to realistically match current and expected future habitat conditions in each of the salmon-supporting tributaries.
- Manage hatchery production for harvest separately, while ensuring that natural stocks are protected. For example, it has been proposed that large-scale production hatcheries be relocated from the Central Valley to coastal localities in order to eliminate or at least minimize straying. Such measures to insulate the natural stocks from the continual influx of hatchery fish would lend greater clarity to measuring (1) the actual population sizes of natural stocks and (2) the effectiveness of ongoing restoration efforts as gauged by recent population trends of the natural stocks.
- If certain hatcheries are maintained in the Central Valley with the intention of rebuilding or preserving natural populations, then in-river releases of hatchery-produced juveniles and smolts should be conducted in amounts and along schedules that do not compromise the growth and survival of natural fish. Occasional large-volume releases could be conducted (e.g., once every 3-5 years) to simulate the occasional large cohorts that naturally occur in response to exceptionally favorable ocean (or other) conditions.
- Instead of a single, static numerical population target for each Central Valley tributary—i.e., the Doubling Goal number—a workable alternative may be to determine a **multi-pronged set** of numerical targets that is more dynamic and reflective of the existent or expected habitat conditions. For example, the numerical goal-set for a specified river may be a range of values that the population average should fall within during a 10-year or 15-year time-frame. In addition, there should be a range of maximum values that the population should closely approach or exceed a specified number of times (years) within that time-frame, and a minimum population level that the population should always exceed during that time-frame.

The actual target numbers would be determined through realistic assessments of in-river habitat conditions and potential productivity by agency biologist in consultation with non-agency biologists, including nationally recognized salmon experts (such as those at the National Laboratories).

REFERENCES

Anadromous Fish Restoration Program – United States Fish and Wildlife Service (AFRP-USFWS). 2001. Final Restoration Plan for the Anadromous Fish Restoration Program. Report of the Anadromous Fish Restoration Program Core Group, Central Valley Improvement Act. Stockton, CA.

Araki, H., B.A. Berejikian, M.J. Ford and M.S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 1:342-355.

Araki, H., B. Cooper and M.S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science 318:100-103.

Araki, H., B. Cooper and M.S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biology Letters (online). DOI: 10.1098/rsbl.2009.0315

Barnett-Johnson, R., T.E. Pearson, F.C. Ramos, C.B. Grimes and B. MacFarlane. 2008. Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. Limnology and Oceanography 53(4):1633-1642.

Beamish, R.J., R.M. Sweeting, C.M. Neville, K.L. Lange, T.D. Beacham and D. Preikshot. 2011. Wild Chinook salmon survive better than hatchery salmon in a period of poor production. Environmental Biology of Fishes (online: 06 April 2011). DOI 10.1007/s10641-011-9783-5

Berejikian, B.A. and M.J. Ford. 2004. Review of Relative Fitness of Hatchery and Natural Salmon. NOAA Technical Memorandum NMFS-NWFSC-61. December 2004. Seattle, Washington.

California Department of Fish and Game (CDFG). 2008. Status of the Fisheries Report—An Update through 2006. Report to the Fish and Game Commission as directed by the Marine Life Management Act of 1998. California Department of Fish and Game, Marine Region. June 2008.

Dettman, D.H. and D.W. Kelley. 1987. The Roles of Feather and Nimbus Salmon and Steelhead Hatcheries and Natural Reproduction in Supporting Fall Run Chinook Salmon Populations in the Sacramento River Basin. Report for the California Department of Water Resources. D.W. Kelley & Associates. July 1987.

Independent Review Panel of the CVPIA Fisheries Program (IR-CVPIA). 2008. Listen to the River: An Independent Review of the CVPIA Fisheries Program. Report for the U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service.

Independent Scientific Advisory Board (ISAB). 2003. Review of Salmon and Steelhead Supplementation. June 4, 2003. Independent Scientific Advisory Board for the Northwest Power Planning Council, the National Marine Fisheries Service, ad the Columbia River Basin Indian Tribes. Portland, Oregon.

Independent Scientific Group (ISG). 1996. Return to the River: Restoration of Salmonid Fishes in the Columbia River Ecosystem. Development of an Alternative Conceptual Foundation and Review and Synthesis of Science underlying the Fish and Wildlife Program of the Northwest Power Planning Council. September 10, 1996. The Independent Scientific Group. Available online: www.nwppc.org

Ingram, B.L. and P.K. Weber. 1999. Salmon origin in California's Sacramento-San Joaquin river system as determined by otolith strontium isotopic composition. Geology 27(9):851-854.

Johnson, R.C., P.K. Weber, J.D. Wikert, M.L. Workman, R.B. MacFarlane, M.J. Grove and A.K. Schmitt. 2012. Managed metapopulations: do salmon hatchery "sources" lead to in-river "sinks" in conservation. PLoS One Vol. 7 (Issue 2).

Joint Hatchery Review Committee (JHRC). 2001. Final Report on Anadromous Salmonid Fish Hatcheries in California. December 3, 2001. California Department of Fish and Game and National Marine Fisheries Service, Southwest Region.

Kostow, K.E. 2004. Differences in juvenile phenotypes and survival between hatchery stocks and a natural population provide evidence for modified selection due to captive breeding. Canadian Journal of Fisheries and Aquatic Sciences 61:577-589.

Kostow, K.E., A.R. Marshall and S.R. Phelps. 2003. Naturally spawning hatchery steelhead contribute to smolt production but experience low reproductive success. Transactions of the American Fisheries Society

Levin, P.S., R.W. Zabel and J.G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society of London B268:1153-1158.

McEwan, D. and T.A. Jackson. 1996. Steelhead Restoration and Management Plan for California. February 1996. California Department of Fish and Game. Sacramento, CA.

McLean, J.E., P. Bentzen and T.P. Quinn. 2004. Differential reproductive success of sympatric, naturally spawning hatchery and wild steelhead, *Oncorhynchus mykiss*. Environmental Biology of Fishes 69:359-369.

Mesick, C. 2009. The High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases. Report by the U.S. Fish and Wildlife Service, Sacramento, California. September 4, 2009.

Mesick, C. 2010. The High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Merced River due to Insufficient Instream Flow Releases. Report by Carl Mesick Consultants to the California Sportfishing Protection Alliance. 7981 Crystal Boulevard, El Dorado, California 95623.

National Research Council (NRC). 1996. Upstream. Salmon and Society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids. National Academy Press, Washington, D.C.

Newman, K.B. and D.G. Hankin. 2004. Statistical Procedures for Detecting the CVPIA Natural Chinook Salmon Production Doubling Goal and Determining Sustainability of Production Increases. Report to the U.S. Fish and Wildlife Service under contract with CH2M Hill. June 21, 2004.

Reynolds, F.L., T.J. Mills, R. Benthin and A. Low. 1993. Restoring Central Valley Streams: A Plan for Action. November 1993. California Department of Fish and Game. Sacramento, CA.

Schroeder, S.L., C.M. Knudsen, T.P. Pearsons, T.W. Kassler, S.F. Young, C.A. Busack and D.E. Fast. 2008. Breeding success of wild and first generation hatchery female spring Chinook salmon spawning in an artificial stream. Transactions of the American Fisheries Society 137:1475-1489.

Schroeder, S.L., C.M. Knudsen, T.N. Pearsons, T.W. Kassler, S.F. Young, E.P. Beall and D.E. Fast. 2010. Behavior and breeding success of wild and first-generation hatchery male spring Chinook salmon spawning in an artificial stream. Transactions of the American Fisheries Society 139:989-1003.

Smith, J.R. and M.L. Workman. 2004. Escapement, Ocean Harvest and Straying of Hatchery and Naturally Reared Chinook Salmon in the Mokelumne River, California. Draft Report by the East Bay Municipal Utility District, 1 Winemasters Way, Suite K, Lodi, CA 95240. January 2004.

United States Fish and Wildlife Service (USFWS}. 1995. Working Paper: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Volume 2. May 6, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, California.

United States Fish and Wildlife Service (USFWS}. 2005. Recommended Streamflow Schedules to Meet the AFRP Doubling Goal in the San Joaquin River Basin. Document appended to USFWS Comments to the State Water Resources Control Board Review of San Joaquin River Flow and South Delta Salinity Standard. December 2010.

Volk, E.C., A. Blakley, S.L. Schroder and S.M Kuehner. 2000. Otolith chemistry reflects migratory characteristics of Pacific salmonids: using otolith core chemistry to distinguish maternal associations with sea and freshwaters. Fisheries Research 46:251-266.

Williams, John G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4(3). (http://escholarship.org/uc/item/21v9x1t7)

Zhang, Z. R.J. Beamish and B.E. Riddell. 1995. Differences in otolith microstructure between hatchery-reared and wild chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 52:344-352.