California Hatchery Review Report

California Hatchery Scientific Review Group

June 2012

California Hatchery Review Report

Prepared by the
California Hatchery Scientific Review Group

June 2012

Document Citation:

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

Report Contents

List of Figures

List of Tables

Appendices

California Hatchery Review Report

1. Purpose and Scope of the Review

In 2000, the U.S. Congress established and funded a hatchery review process because it recognized that, while hatcheries have a necessary role to play in meeting harvest and conservation goals for Pacific salmonids, the hatchery systems were in need of comprehensive reform. Most hatcheries were producing fish for harvest primarily to mitigate for past habitat loss (rather than for conservation of at-risk populations) and were not taking into account the effects of their programs on naturally spawning populations. With numerous species listed as threatened or endangered under the Endangered Species Act, Congress identified salmon conservation as a high priority. Genetic resources in the region were at risk and many hatchery programs were contributing to those risks. Congress intended that the reviews be scientifically founded and evaluated; that independent scientists would interact with agency and tribal scientists to provide direction and operational guidelines; and that hatchery systems as a whole would be evaluated for compliance with science-based recommendations.

Hatchery program reviews were completed in Puget Sound and coastal Washington (2004) and then in 2005, Congress directed NOAA Fisheries to replicate the process in the Columbia River Basin. The scope of that review broadened and evaluation tools were refined. Implementation successes led Congress to further expand the geographic scope in 2010 and funds were appropriated to conduct a scientific review of hatchery programs in California, hereafter referred to as the California Hatchery Scientific Review Project. An appropriation for this purpose was provided to the US Fish and Wildlife Service and was administered through the Pacific States Marine Fisheries Commission. Due to limitations in time and other resources, the review was subsequently limited to hatchery programs in the Klamath/Trinity and Central Valley basins, with the programs at the two agency-operated hatcheries in coastal basins (Warm Springs Hatchery and Mad River Hatchery) to be reviewed at a later time.

The goal of this hatchery program review initiative is to ensure that hatchery programs are managed and operated to meet one or both of the primary purposes for hatcheries:

- Helping recover and conserve naturally spawning salmon and steelhead populations, and
- Supporting sustainable fisheries with little or no deleterious consequence to natural populations.

As for the previous hatchery program reviews, appointments of qualified fishery scientists and biologists were made to a California Hatchery Scientific Review Group (California HSRG). The California HSRG was assisted in their deliberations by consultants affiliated with DJ Warren and Associates (hereafter the Consultants). The primary role of the Consultants was to assemble and organize existing data concerning operation and performance of the majority of California's salmon and steelhead hatcheries and to identify current scientific literature that seemed most pertinent to operation and management of these hatcheries. The role of the California HSRG was to weigh available scientific information so as to produce consensus recommendations for changes in hatchery practices which should provide guidance to policy makers who will be responsible for implementing changes in how California hatcheries are operated.

1.1 Organization and Implementation of the Hatchery Review

The California HSRG and the Consultants together engaged in five distinct activities: (1) scientific review and policy development (the responsibility of the California HSRG), (2) technical support and facilitation (the responsibility of the consultants), (3) preliminary report development (shared by the California HSRG and the consultants), (4) policy coordination, and (5) final statewide report approval (the responsibility of the California HSRG). The scientific review, including development of Statewide and program-specific recommendations, was based in part on information compiled by the technical contractors who gathered and analyzed information relevant to the evaluation of hatchery programs in the Klamath / Trinity and Central Valley regions. Facility site visits and group discussions occurred over the 16 month review period. The facilitation team was responsible for project management, budgets, contracting, collection or existing data, meeting organization and coordination of draft work products. Policy Committee support provided a communications link between the California HSRG and the federal, state and tribal fishery agencies at the policy level.

1.1.1 California Hatchery Scientific Review Group

The California HSRG was composed of 11 members, six of whom were affiliated with agencies in California and five of whom were previously affiliated with resource agencies or who are university faculty. Affiliated members did not represent their respective agencies, but were instead expected to bring their individual scientific expertise to the table and act independently. The intent of this structure and approach was to ensure that the California HSRG maintained independence and impartiality, while at the same time assuring that it contained thorough knowledge of salmonid populations and hatchery programs in the Klamath / Trinity and Central Valley regions.

Members of the California HSRG were selected from a pool of candidates nominated by the American Fisheries Society and confirmed by the Policy Committee. Two additional members (one affiliated and one non-affiliated) were subsequently recommended to the Policy Committee and confirmed based on expertise with hatcheries in general and California programs in particular. The California HSRG operated without a chairperson or other officers.

Table 1-1 lists the California HSRG members and their associated organizations; brief professional biographies of the members are presented in Appendix II.

Table 1-1. Members of the California Hatchery Scientific Review Group

Name	Organization
Agency Affiliated Members	
Dr. John Carlos Garza	NOAA Fisheries
Scott Hamelberg	US Fish and Wildlife Service
Michael Lacy	California Department of Fish and Game
Michael Mohr	NOAA Fisheries
Kevin Niemela	US Fish and Wildlife Service
Kimberly True	US Fish and Wildlife Service
Unaffiliated Members	
Dr. David Hankin	Humboldt State University
Dennis Lee	Independent Consultant

Name	Organization
Dr. Bernie May	UC Davis
George Nandor	Pacific States Marine Fisheries Commission
Dr. Reg Reisenbichler	Independent Consultant

1.1.2 Technical Support, Facilitation and Policy Components

Technical support and facilitation of the California hatchery reviews was conducted by D.J. Warren and Associates, Inc. in association with Malone Environmental Consulting, Meridian Environmental, Inc. and ICF.

The Policy Committee tracked the progress of the review and convened periodic meetings to review progress and status of products, as well as draft recommendations for changes to hatchery programs. Policy Committee members identified agency and tribal resource specialists that provided program-specific information used in the review. Members of the Committee are identified in Table 1-2. Dr. Bernie May, a member of the California HSRG, acted as a liaison and provided direct communication to the Policy Committee as did Dr. Doug DeHart, a member of the facilitation team.

Table 1-2. Members of the Policy Committee

Name	Organization
Robert Clarke	US Fish and Wildlife Service
Randy Fisher	Pacific States Marine Fisheries Commission
Dave Hillemeier	Yurok Tribe
Mike Orcutt	Hoopa Valley Tribe
George Kautsky	Hoopa Valley Tribe
Kevin Shaffer	California Department of Fish and Game
Diane Windham	NOAA Fisheries

1.1.3 Work Sessions and Regional Review Process

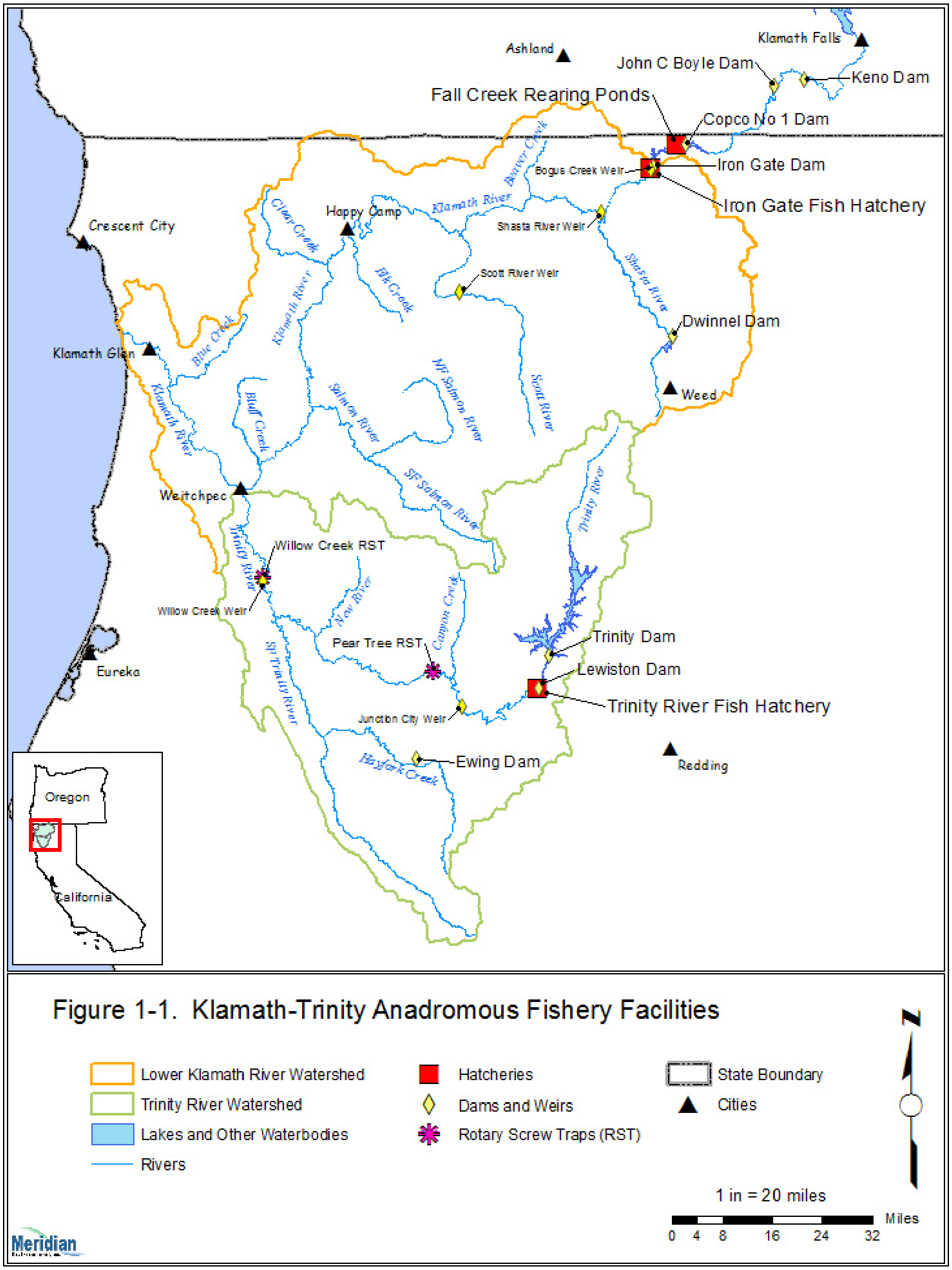
The review evaluated all salmon and steelhead hatchery programs in the Klamath / Trinity and Central Valley regions. For logistical purposes, the two regions were split into three geographic areas: (1) Klamath / Trinity, (2) Central Valley South, and (3) Central Valley North. Figures 1-1 through 1-3 show the prominent features and hatchery facilities in each of the regional review areas. Programs reviewed within each region are as follows:

- **Klamath-Trinity Region** - February-March 2011
  - Iron Gate Coho Program
  - Iron Gate Fall Chinook Program
  - Iron Gate Steelhead Program
  - Trinity Coho Program

- Trinity Fall Chinook Program
- Trinity Spring Chinook Program
- Trinity Steelhead Program

- **Central Valley South Region** – April –May 2011
  - Nimbus Fall Chinook Program
  - Nimbus Steelhead Program
  - Mokelumne Fall Chinook Program
  - Mokelumne Steelhead Program
  - Merced Fall Chinook Program
- **Central Valley North Region** – June-July 2011
  - Feather Fall Chinook Program
  - Feather Spring Chinook Program
  - Feather Steelhead Program
  - Coleman Fall Chinook Program
  - Coleman Late-Fall Chinook Program
  - Coleman Steelhead Program
  - Livingston Stone Winter Chinook Program

The review was conducted over a 16-month period from November 2010 to March 2012. Initial California HSRG meetings (1) developed definitions and an understanding of operational and programmatic data needed for the review and (2) defined and finalized the approach for presenting operational and programmatic information for evaluations of the hatchery programs. An overview of the project tasks, work sessions and schedule is provided as Table 1-3.



C:\04 GISData\ProjectData\CalHSRG\MapProjects\BasinMaps\StatewideMap\KTStateWideReport.mxd

Published Date : 12/20/2011

Figure 1-1. Klamath / Trinity Region

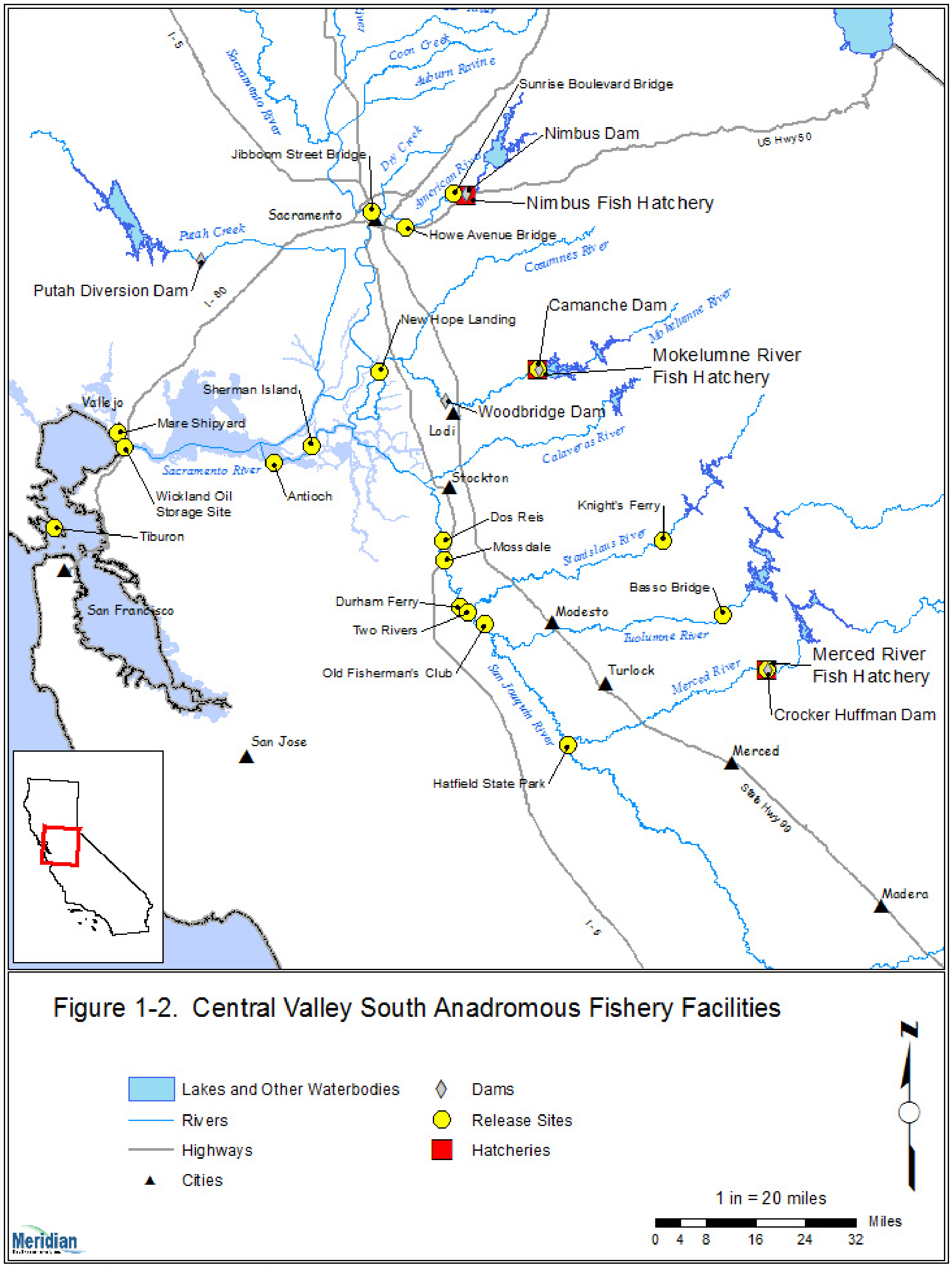


Figure 1-2. Central Valley South Region

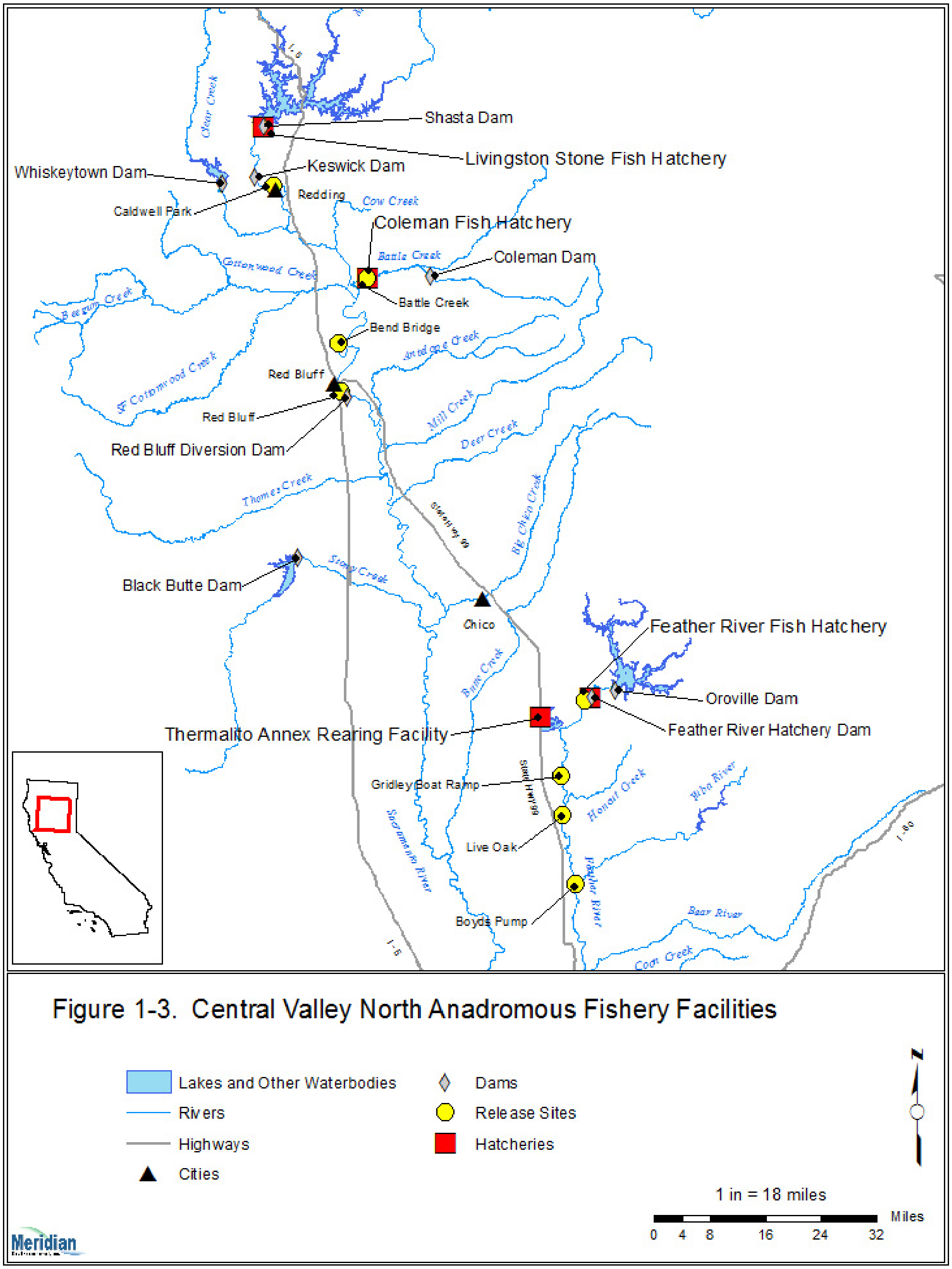


Figure 1-3. **Central Valley North Region**

Table 1-3. California Hatchery Review Regional Process

Task Description	Work Session Date	Specific Objectives
Work Session, Sacramento, CA	November 2010	Define review and participants (CA HSRG and Contractors)
Conference call	December 2010	Define review, schedule and components (CA HSRG and Contractors)
Planning Session / Sacramento, CA	January 4, 5 2011	Define review, schedule and components (CA HSRG and Contractors)
Klamath/ Trinity / data and information collection	February, 2011	Conduct hatchery and biological / programmatic data and information workshops and develop draft reports (Contractors)
Klamath/ Trinity tour and workshop / Redding, CA	March, 2011	Regional review of Iron Gate and Trinity hatchery programs (Contractors and CA HSRG)
Central Valley, South / data and information collection	April, 2011	Conduct hatchery and biological / programmatic data and information workshops and develop draft reports (Contractors)
Central Valley, South / tour and workshop, Sacramento, CA	May, 2011	Regional review of Nimbus, Mokelumne and Merced hatchery programs. Refined framework for review (Contractors and CA HSRG)
Central Valley, South / data and information collection	June, 2011	Conduct hatchery and biological / programmatic data and information workshops and develop draft reports (Contractors)
Central Valley, North / tour and workshop, Redding, CA	July, 2011	Regional review of Feather, Livingston Stone and Coleman hatchery programs. Refined framework for review (Contractors and CA HSRG)
Work session on review products, Sacramento, CA	September, 2011	Develop premise for standards and guidelines, refinement of statewide issues and observations, development of recommended standards and guidelines for operating hatchery programs (Contractors and CA HSRG)
Work session on review products and recommendations, Sacramento, CA	November 2011	Application of recommended standards and guidelines, develop recommendations for specific hatchery programs of final (Contractors and CA HSRG)
Work on draft final report for California HSRG	November, December 2011	Prepare draft of final report for California HSRG Review (Contractors and CA HSRG)
Work session on final report, Sacramento, CA	January, 2012	Finalize draft report and incorporate comments (CA HSRG and Contractors)
Telephone work sessions on final report	February, 2012	Four conference calls to complete report review (CA HSRG and Contractors)
Final report complete	March, 2012	Contractors and CA HSRG
Policy Committee comments on Final Report	April, 2012	Contractors consolidate and provide as Appendix VII
Report submitted to PSMFC	June, 2012	Project complete

Data and information collection and the review process in each region included the following steps:

(1) The contractors requested, collected and consolidated available information on hatchery programs in a region. This included data and information about direct hatchery program operations and biological and programmatic issues for each specific region (see Appendix III).

(2) Work sessions were then conducted to solicit information about specific hatchery program operations. These sessions, conducted at each hatchery (and for each program) in a region, generally involved hatchery operations staff and other key regional hatchery staff. The method for the sessions was an interview format using a standardized set of approximately 90 questions (see Appendix A-1 of each program report presented in Appendix VIII).

(3) Work sessions were then conducted with regional and other biologists to identify biological/programmatic issues. These work sessions included consolidation of data and information on:

- Population structure of Chinook, coho and steelhead;
- Life history characteristics of Chinook, coho and steelhead by population;
- Ocean and in-river catch and harvest rates on Chinook, coho and steelhead;
- Spawner abundance estimates for Chinook, coho and steelhead; and
- Composition of spawners (hatchery and wild) by population or population component.

(4) Contractors compiled both operational and biological information in the draft Hatchery Program Reports (Appendix VIII). Draft reports were then sent back to hatchery staff and biologists to confirm data accuracy. The reports were provided to the California HSRG in advance of each regional review.

(5) Regional work sessions attended by both contractors and the California HSRG were then conducted. These sessions generally involved a one- to two-day tour of the watershed and hatcheries followed by a two- to three-day work session to review programs and develop the framework for program recommendations

Additional work sessions and conference calls were conducted in August, September, and November 2011 and January and February 2012. These four to five day sessions generally focused on a premise for development of standards and guidelines and development of recommended standards and guidelines for operating hatchery programs (Chapter 4).

1.2 Analytical Approach

This review of the California hatchery programs is based on criteria that derive from three fundamental principles:

(1) Well-defined Goals

Goals for salmon and steelhead resource management should be quantified, where possible, and expressed in terms of values to the community (e.g., conservation, restoration, adult production, harvest and harvest opportunity, research or education). Hatchery juvenile production may be a means to contribute to harvest, conservation goals, or other values, but it is not an endpoint. When population goals are clearly defined in terms of these community values, hatcheries can be managed as tools to help meet those goals. Explicitly defined goals, performance standards, and success criteria should be established for all hatchery programs.

To be successful, hatcheries should be used as part of a comprehensive strategy where habitat, hatchery management and harvest are coordinated to best meet resource management goals that are defined for each population in the watershed or larger affected area. Hatcheries are by their very nature a compromise—a trade-off among benefits and risks to the target population, other populations, and the natural and human environment affected by the hatchery program.

(2) Scientific Defensibility

The operation and management, as well as the purpose of each hatchery program, must be scientifically defensible. Once a set of well-defined goals has been identified, the scientific rationale for a hatchery program must be formulated in terms of benefits and risks, explaining how the program expects to contribute to the goals. The benefits of a well-designed and properly operated hatchery program significantly outweigh the risks. The operational strategy of the hatchery program, as a part of an integrated or segregated strategy, must be explicitly stated. The chosen strategies for operation and management must be consistent with current scientific knowledge. Where there is uncertainty, hypotheses and assumptions should be articulated. This structured approach needs to be applied to current program operations, when formulating modifications to existing programs, and when developing new hatchery programs.

This approach ensures a scientific foundation for hatchery programs, a means for addressing uncertainty, and a method for demonstrating accountability. Documentation for each program should include a description of analytical methods and should be accompanied with citations from the scientific literature.

In Chapter 4, the state-wide recommendations of the California HSRG for operating California hatchery programs are presented in the form of Standards and Guidelines that are consistent with current science. These sets of standards are then applied to each of the 19 programs that were part of this review (Appendix VIII), along with recommended implementation guidelines specific to each program.

(3) Informed Decision-Making and Adaptive Management

Decisions about resource goals and defensible scientific rationales should be informed and modified by continuous evaluation of success at meeting hatchery program goals, changing circumstances, and new scientific information. Systems affecting and affected by hatchery programs are dynamic and complex; therefore, uncertainty is unavoidable and surprises should be anticipated. Managing hatchery programs is an ongoing and dynamic process that requires flexibility in programs, facilities, management, and expectations.

Managers must monitor the results of their programs and identify when environmental conditions or scientific knowledge has changed. Climate change and human population growth are examples of factors that must be taken into consideration in the future. New data will change our understanding of the ecological and genetic impacts of hatchery programs. Recognizing these changes and new information should lead directly to changes in hatchery operations.

This adaptive management approach will require a substantial increase in scientific oversight of hatchery operations, particularly in the areas of genetic, population, and ecological monitoring. Hatchery programs and associated monitoring should be structured to encourage directed research, innovation and experimentation so that hatchery programs may be effectively modified to better contribute to new goals and incorporate new concepts in fish culture practices.

1.3 Report Organization

The findings and recommendations of the California Hatchery Review Group for the 19 salmon and steelhead hatchery programs currently operating in the Klamath-Trinity Basin and the Central Valley are compiled in this report, as are a suite of proposed statewide hatchery standards. The following summary is provided to guide reviewers through the components of this report.

- Chapter 1 introduces the hatchery review project, specifically the purpose of the review and the analytical approach taken.
- Chapter 2 provides an overview of the unique California context within which the California Hatchery Scientific Review Project was conducted. Included in this section are overviews of habitat loss and hatchery development, integrated and segregated program distinctions, harvest management issues, marking and tagging strategies and anadromous fish population structure.
- Chapter 3 describes 14 major issues that the California HSRG judged of greatest importance for management of California's salmon and steelhead hatcheries.
- Chapter 4 presents the California HSRG standards and guidelines for hatchery operations. These are organized into five key topic areas: broodstock management; program size and release strategies; incubation, rearing and fish health management; monitoring and evaluation; and direct effects of hatchery operation on local habitat and aquatic or terrestrial organisms.
- Chapter 5 is a summary of the 19 program reviews, identifying key aspects of the current program and the major program-specific recommendations of the California HSRG.
- Chapter 6 is a suggested framework for implementing hatchery reforms and outlines a number of key research topics identified by the California HSRG as a result of this review.
- Chapter 7 lists citations referenced in the body of this report.
- Appendix I is a glossary defining technical terms and acronyms used throughout this report.
- Appendix II briefly summarizes the credentials of California HSRG members.
- Appendix III describes the data collection methods and sources interviewed for preparation of the 19 program reports.
- Appendix IV provides a list of required and recommended data collection and reporting.
- Appendix V presents information on two key fish health topics, BKD management and Iodophor disinfection.
- Appendix VI provides electronic links to the extensive resource library compiled as part of this review.
- Appendix VII presents comments from the Policy Committee based on their review of a draft of this report.
- Appendix VIII presents full reports, prepared by the Contractor team, about each of the 19 programs reviewed by the California HSRG. These reflect up-to-date program information obtained from published reports and interviews with program and regional managers and biologists. Each report contains program-specific standards and guidelines that were selected by the California HSRG from the complete list of standards and guidelines presented in Chapter 4. Appended to each program report is a set of tables with key hatchery data.

2. Context of the California Hatchery Scientific Review

This section provides an overview of the unique California context within which the California Hatchery Scientific Review Project was conducted. Although California's Central Valley is near the southern limits of the distribution of Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*), historic runs of Chinook salmon in the Sacramento-San Joaquin system were once among the largest in North America. California is the largest state in the lower 48, with the largest population, and with enormous competing demands for water, from the agriculture industry and from the human population. California's anadromous salmonids must compete with these other water users in a highly modified landscape.

The hatcheries that were the focus of the California HSRG's attentions are found in two large river systems that are quite different in many respects. The Klamath-Trinity system, near the California/Oregon border, has terminal hatcheries (Iron Gate and Trinity River) located immediately below dams that limit further upstream migration of anadromous fish. Although this river system has very clearly been affected by construction of dams, the watershed is sparsely populated, much of the landscape is dominated by National Forest land, and the Hoopa and Yurok tribes have large reservations along the Trinity and lower Klamath rivers, respectively. The Hoopa and Yurok tribes have a recognized legal right to 50 percent of the harvestable surplus of Klamath-Trinity fall Chinook salmon (Parravano vs. Babbitt 1995) and substantial tribal terminal fisheries have been in place since the mid-1990s. As a consequence, ocean fisheries for Klamath-Trinity-origin fall Chinook salmon have been reduced so as to allow appropriate numbers of fish to escape to freshwater. Well-coordinated multi-agency sampling programs have operated since about 1978 and there is excellent information on the dynamics of fall Chinook salmon in this system. Both spring and fall run Chinook are propagated at Klamath-Trinity hatcheries and neither run is listed under the Endangered Species Act (ESA). Threatened coho salmon are present in this system and are the focus of conservation efforts at both Iron Gate and Trinity River hatcheries. Information on abundance and distribution of coho is poor compared to that for fall Chinook salmon. Renowned steelhead runs enter the Klamath-Trinity system, including substantial returns of a distinctive "half-pounder" life history type. Half-pounders are immature steelhead that return to freshwater after just a few months at sea, at a size of about 12-18 inches. They feed in the winter while in freshwater, return to the ocean and then subsequently return to freshwater as adults to spawn. Both Iron Gate and Trinity River hatcheries propagate steelhead. Steelhead are not listed under the ESA in the Klamath-Trinity system. Information on abundance of steelhead populations is relatively limited, especially in the Klamath River.

Spring, fall, late-fall, and winter runs of Chinook salmon are recognized in the Sacramento/San Joaquin River system. Spring and winter run have been listed under the ESA; although the fall run is a stock of concern, it has not been listed. Fall Chinook are propagated at five hatcheries (Coleman, Feather River, Nimbus, Mokelumne and Merced); spring Chinook are propagated at Feather River Hatchery; late-fall Chinook are propagated at Coleman; and winter run Chinook are propagated at the Livingston Stone conservation hatchery. Naturally-produced and hatchery-produced fall Chinook salmon from the Central Valley are the primary contributors to ocean fisheries off central California. Because there are no established Native American fishing rights in the Central Valley and freshwater recreational harvest of Chinook is modest, ocean fishery harvest rates are much higher off central California where Sacramento fall Chinook dominate, than off northern California, where Klamath-Trinity Chinook are present in large numbers. Although ocean fishery harvest information is excellent for Central Valley salmon fisheries, historic data on freshwater returns, particularly information on freshwater age-specific harvests and escapements to natural spawning areas, is poor when compared to the Klamath-Trinity system. No coho salmon are propagated in Central Valley hatcheries, but steelhead are raised at Coleman, Feather River, Nimbus and Mokelumne hatcheries. Steelhead are listed as threatened in the Central Valley. Information on abundance and harvest from steelhead populations is quite limited and of questionable accuracy.

In the sections that follow, we present brief overviews of the following topics:

- How habitat loss and dam construction have altered abundance and distribution of steelhead and salmon in the Klamath-Trinity and Sacramento-San Joaquin river systems, and how hatcheries have been developed in response to these habitat alterations;
- The concept of segregated and integrated hatchery programs, as defined by HSRG (2004) and considered by the California HSRG;
- The role that hatcheries have played in supplementing fishery harvests and how harvest regulations differ between the two river systems;
- Current and proposed marking and tagging strategies and background relevant to the marking and tagging programs that are recommended by the California HSRG;
- A review of the current state of knowledge concerning population structure of anadromous salmonids in the Klamath/Trinity and Sacramento/San Joaquin river systems.

Together, these sections are intended to provide the reader with the background context that is needed to appreciate the major issues that the California HSRG has recognized as of greatest importance for future management of steelhead and salmon hatcheries in these two large river systems**.**

2.1 Habitat Loss and Hatchery Development in the Sacramento-San Joaquin and Klamath-Trinity River Basins

2.1.1 Historical Salmon and Steelhead Abundance

The Central Valley of California consists of the Sacramento River Basin in the north and San Joaquin River Basin in the south and historically has been one of the most productive systems for Chinook salmon on the west coast of the United States. Chinook salmon were once widely distributed and highly abundant in virtually all the major Central Valley tributaries, with some salmon swimming 400 miles upstream to adult holding and spawning areas (Moyle 2002, Yoshiyama et al. 2001). The historical high abundance of salmon in the Central Valley is documented by fishery records dating back to the 1850s. The Central Valley is unique in that it is the only system supporting four temporal runs of Chinook salmon. Before extensive habitat modification of the 19th and 20th centuries, maximum historical abundance (harvest plus escapement) of all four runs were estimated by Fisher (1994) at 2 million (100,000 late-fall, 200,000 winter, 700,000 spring and 900,000 fall). Steelhead (*Oncorhynchus mykiss*) were also broadly distributed throughout the system, with an historical run size that may have approached 1 to 2 million adults annually (McEwan 2001).

The Klamath River watershed once produced large runs of Chinook salmon, steelhead and coho salmon, and also supported significant runs of other anadromous fish, that contributed to substantial commercial, recreational, subsistence, and Tribal harvests. The historical range of salmon abundance for the Klamath-Trinity River has been estimated at 650,000–1 million fish (*see* Hamilton et al. 2005).

2.1.2 Abundance Decline of Salmon and Steelhead Associated with Reduction of Habitat Quantity and Quality

Abundance of all Chinook salmon runs and steelhead in the Central Valley and Chinook salmon, coho salmon and steelhead in the Klamath-Trinity Basin has declined substantially. For example, Central Valley spring-run and Sacramento River winter-run Chinook salmon are now listed as threatened and endangered, respectively, under the ESA, and fall Chinook abundance fell to about 50,000 adults system-wide in 2009. By the early 1960s, Central Valley steelhead declined to about 40,000 adults (McEwan 2001) and are now listed as threatened under the ESA.

Many factors including overfishing, pollution, and introduction of invasive species have contributed to the decline of salmon and steelhead in California; however, habitat loss, degradation, and modification associated with the construction of dams and water diversion on all major rivers seems to be the single greatest cause of population abundance decline in the Central Valley (Moyle 2002, Yoshiyama et al. 2000). Historical records document that in several major Central Valley streams and rivers, large salmon runs were severely reduced or extirpated in the 1870s and 1880s by hydraulic gold mining and blockage by dams (Clark 1929, Yoshiyama et al. 1998). Construction of permanent dams and corresponding loss of salmon habitat peaked during the 1890s to 1920s and continued into the 1970s (Yoshiyama et al. 1998). The amount of Chinook salmon spawning and holding habitat lost in the Central Valley probably exceeds 72%, and may be as high as 95%, as most of the prime spawning and adult holding habitat is in upstream reaches now inaccessible for salmon and steelhead (Yoshiyama et al. 2001, Reynolds et al. 1993, Moyle 2002). The direct loss of steelhead habitat is likely greater than for salmon because steelhead were able to access headwater habitat areas due to their greater athleticism and higher flows during their migration. Downstream consequences of dam construction include water temperature changes, flow modification/disruption /diversion, and diminished spawning gravel recruitment, which in combination have affected productivity of natural populations in their remaining accessible habitat. In fact, effects of water management and water diversion have rendered some tributaries largely incapable of supporting natural production and/or no longer favoring an anadromous life history for steelhead. There also appears to be inadequate nursery habitat in the American, Feather and Mokelumne rivers to support natural steelhead populations. Periodic natural events (drought and poor ocean conditions) have also severely affected the remaining natural populations. For example, the droughts in the mid/late 1970s and late 1980s to early 1990s, had major effects on natural populations (most notably winter-run Chinook) and poor prevailing ocean conditions resulted in the most recent (~2007-2010) fall Chinook salmon abundance collapse (Lindley et al. 2009).

Habitat loss due to dam construction is also substantial in the Klamath-Trinity system. In the Klamath River, Iron Gate Dam now limits access to about 190 miles of habitat. In the Trinity River Basin, 50% of the spawning habitat was lost following the construction of Lewiston Dam (Moffett and Smith 1950). In addition to habitat blockages, major factors affecting the habitat in the Klamath-Trinity system include hydropower development and the associated water management (NMFS 1996). Resource managers should consider how removal of the Klamath River dams may alter the need and purpose for the future program.

2.1.3 Hatchery Development and Roles

Fish hatcheries in the Central Valley and in the Klamath-Trinity Basin were constructed to mitigate for the habitat loss associated with a number of the major dams. In recognition of the importance of preserving significant runs of Chinook and coho salmon and steelhead, seven hatcheries were constructed (five in the Central Valley[1] and in two in the Klamath/Trinity system) between the early 1940s and 1970. For example, the U.S. Fish and Wildlife Service's (USFWS) Coleman National Fish Hatchery was constructed to partially mitigate for the permanent loss of almost 200 miles of habitat following construction of Shasta and Keswick dams. We note that additional downstream consequences of dam construction and water management (i.e., water temperature changes, flow modification/disruption, diminished spawning gravel recruitment) resulted in further serious impacts to natural production, effects that were not considered in assigning the mitigation responsibilities for the hatcheries in the Central Valley or in the Klamath-Trinity systems.

Presently, hatchery-origin Chinook salmon make-up a substantial percentage of Central Valley salmon runs (Yoshiyama et al. 2000). Hatcheries will continue to provide opportunity for egg fertilization and incubation and early life history protection, and hatcheries and hatchery programs appear to be capable of maintaining salmon/steelhead runs even in areas where habitats have been significantly modified or degraded. Even this scenario, however, requires a functional migration corridor for both juvenile and adult fish. Spawning escapement to some major streams is now dominated by hatchery-origin fish. Because salmon and steelhead tend to home to their natal stream, it is not unexpected that thousands of returning adults may be found a short distance below hatchery sites, especially when the hatchery is at the terminus of anadromous fish migration. As abundance of natural-origin fish continues to decline, hatchery production has become increasingly important to support important ocean commercial and recreational, and in-river fisheries for fall- and spring-run Chinook salmon, and the in-river catch of steelhead. The largest combined hatchery program in the Central Valley is for fall-run Chinook salmon and the California ocean and in-river fisheries depend heavily on this stock.

2.1.4 Challenges to Face

While harvest opportunities are an important societal benefit, hatchery operations and programs also have effects on natural salmon and steelhead productivity. The California HSRG identified areas where hatchery facilities and programs can and should be modified to control undesirable impacts. However, it is important to emphasize that the hatcheries under review were constructed as a result of substantial habitat loss, and natural populations have been displaced to areas that are often subject to additional habitat modifications. Hatchery reform alone will not reverse the effects from accumulated degradation of salmonid habitats nor is it reasonable to assume that it can restore historic levels of naturally produced Chinook salmon and steelhead in the Central Valley or the Klamath-Trinity system.

Although most anadromous fish hatchery programs in California are operated to mitigate for lost habitat and decreased production capacity caused by dam construction, these hatcheries must have a larger role than simply producing and releasing defined numbers of juvenile fishes, and mitigators have a greater responsibility to help maintain, and in some cases rebuild, healthy naturally producing populations of anadromous fish. To accomplish this, the California HSRG believes that hatcheries in California should be operated not as isolated entities, but as components within the broader context of habitat restoration and protection, water management and harvest (see section below), that affect both natural and hatchery fish populations. The California HSRG recommends not only to limit the hatchery impacts, but also to restore habitat quantity and quality to increase opportunity for natural production.

[1] An additional facility, Livingstone Stone National Fish Hatchery, was constructed 1997 at the base of Shasta Dam to assist in the recovery of endangered winter Chinook salmon. The Livingston Stone NFH is part of the Coleman NFH Complex.

Therefore, in conjunction with this Hatchery Scientific Review and expected subsequent implementation of its recommendations, major efforts to restore and/or protect habitat in California's Central Valley and Klamath/Trinity river systems (including migration corridors) must occur and/or continue. A sincere commitment to preserve and protect salmon and steelhead in California will require difficult decisions that will likely require societal compromises. Lackey (2000) pessimistically noted that …"it is likely that society is chasing the illusion that wild salmon runs can be restored to the Pacific Northwest without massive changes in the number and lifestyle of its human occupants, changes that society shows little willingness to seriously consider, much less implement." California is the most populous state in the nation, growing from less than 100,000 people in 1850, to over 37 million today[2] . By 2025, the state's population is expected to increase to between 44 million and 48 million[3] , and reach approximately 60 million by 2050[4]. Continued population growth, coupled with climate change, will impart tremendous pressures on the state's natural resources, especially water development and water management.

Protecting and increasing the quality and quantity of habitat (including stream flows) and the biotic community in holding, spawning, and rearing areas and throughout migration corridors must be a priority if natural reproduction of salmon and steelhead populations is desired and the abundance of natural-origin fish expected to increase. The likelihood of collapse of salmon or steelhead runs and of further listings under ESA will be reduced if the abundance of the natural populations increases. Impacts of hatcheries are also reduced when the health and size of natural populations is improved. Prominent among the requirements for such increases will be maintaining high quality water flows to support all life history stages and behaviors inherent in each of the runs, thus allowing full opportunity for evolutionary adaptation. As stated by Neff et al. (2011), maintaining healthy habitats and ecological processes is the only effective approach to ensure the persistence of wild populations, and the rehabilitation and maintenance of healthy habitat and ecological function should be the first choice to preserve existing populations in their native habitat and avoid the potential loss of local adaptations.

2.2 California HSRG Position Concerning Integrated and Segregated Hatchery Programs

According to HSRG (2009), hatchery programs should be managed as either genetically integrated with, or segregated from, the natural populations they most directly influence:

> "A fundamental purpose of an i*ntegrated* hatchery program is to increase abundance, while minimizing the genetic divergence of a hatchery broodstock from a naturally spawning population. An integrated program is intended to maintain the genetic characteristics of a local, natural population among hatchery-origin fish by minimizing the genetic effects of domestication. This is expected to reduce the genetic risks that hatchery-origin fish may pose to the naturally spawning population.
>
> "The intent of a *segregated* hatchery program is to maintain a genetically distinct hatchery population. The only way to reduce risk (genetic and ecological) to natural populations from segregated programs is to minimize the contribution of hatchery fish to natural spawning."

[2] http://geography.about.com/od/obtainpopulationdata/a/californiapopulation.htm.

[3] www.ca2025.org

[4] http://www.dof.ca.gov/research/demographic/reports/projections/p-1/

The California HSRG believes that for a program to be truly segregated, returning hatchery-origin adults must not breed in naturally-spawning populations, and thus must be completely isolated reproductively from these populations. In a truly segregated program, neither domestication selection nor phenotypic divergence of a hatchery population from a natural population would pose any risk to natural populations through interbreeding, although ecological and disease risks from the hatchery program might still exist. We emphasize that for a program to be truly segregated, the proportion of hatchery-origin spawners on a natural spawning ground, pHOS, must be equal to zero. To meet this criterion, hatchery fish must, at a minimum, be released at a location and in such a way as to foster reliable homing, although this tactic will not result in 100% fidelity to the release site (a low stray rate is expected and is "natural"). Thus, when hatchery fish return to spawn, (a) it must be to locations that are free of naturally-spawning fish or (b) they must be behaviorally and/or physiologically isolated reproductively from naturally-spawning fish. It is theoretically possible that returning hatchery-origin adults could be entirely removed from natural spawning grounds through the use of mechanical methods (e.g., segregation weirs). In practice this mechanism is not always an option and, when an option, is never completely efficient. We note that numerous Columbia River hatchery programs have been designated as segregated, but have not achieved the criterion of pHOS equal to zero. In addition, when hatchery-origin fish from highly segregated programs breed in natural populations, the potential reduction in fitness of the natural population is greater than that from hatchery-origin fish from an integrated program. Therefore, the California HSRG asserts that a truly segregated anadromous fish hatchery program is not possible in California, and we are therefore generally unsupportive of the concept.

For integrated hatchery programs, some returning hatchery-origin fish are expected to breed in naturally-spawning populations and natural-origin fish must be incorporated into the hatchery broodstock. When hatchery-origin fish spawn in natural areas, domestication and other effects will generally reduce the mean level of fitness of the naturally-spawning population; recruits per spawner will be less than if the naturally-spawning population included no hatchery-origin fish. The magnitude of this effect can be highly variable, depending upon the differences in fitness and phenotype between the hatchery- and natural-origin fish. Regular incorporation of natural-origin fish into hatchery broodstock should significantly reduce the intensity of domestication and other effects that can cause reduced fitness in natural areas.

The first Hatchery Scientific Review Group (HSRG 2004) followed Ford (2002) and adopted general guidelines for pHOS and pNOB (the proportion of natural-origin fish used as broodstock in a hatchery program) for integrated hatchery programs that are intended to guarantee that the "Proportionate Natural Influence" (PNI = pNOB/(pNOB+pHOS)) of the entire (hatchery + natural) integrated population exceeds some specified value when the natural population is judged to be of substantial importance. However, these guidelines implicitly assume that the geographic boundaries of the natural portion of an integrated population either can be or have been clearly identified. Previous efforts of Technical Recovery Teams (Williams et al. 2006; Lindley et al. 2004) have identified populations and population boundaries for listed ESUs of salmon and steelhead in California (coho salmon in the Klamath-Trinity system; spring-run and winter-run Chinook salmon and steelhead in the Central Valley), but similar populations and population boundaries have not yet been established for fall-run Chinook in the Central Valley or for fall-run and spring-run Chinook or steelhead in the Klamath-Trinity system.

The California HSRG believes that in successful integrated hatchery programs, the natural environment is the primary factor that determines adaptation and fitness of the integrated (hatchery- and naturally-spawned) population. This will help to minimize differences in fitness between hatchery- and natural-origin fish and reduce the potential detrimental effects of hatchery-origin fish spawning in natural areas. To accomplish this, PNI should exceed 0.5 in most cases.

The California HSRG considered two difficult questions related to hatchery fish spawning in natural areas: (1) What should be the geographic extent of the population with which a hatchery is integrated, and (2) Should we adopt explicit guidelines for pHOS, pNOB, and PNI, as was done by the Columbia River HSRG?

The California HSRG believes that the geographic boundaries of the population with which a hatchery is considered integrated should adhere to the following guidelines.

- Where independent populations and associated boundaries have been identified for listed species, these same populations and boundaries should be used to define the geographic boundaries of the population with which a hatchery should be integrated.

- For non-listed species for which neither independent populations nor population boundaries have thus far been established, boundaries for related species could be used, on an interim basis, while work is done to better define population boundaries for these non-listed species. Thus, for example, defined populations and boundaries for coho salmon in the Klamath-Trinity system (Williams et al. 2006) could be used, provisionally, for fall and spring Chinook salmon, to the extent that they are applicable.

The California HSRG makes the following explicit recommendations for pHOS, pNOB and PNI:

- An "overall" pHOS should be calculated over the entire spawning population with which a hatchery is determined to be integrated.

- It would be imprudent to adopt a single numerical guideline for pHOS in all natural spawning areas integrated with hatcheries, because optimal pHOS will depend upon multiple factors. Among these factors are the amount of spawning by natural-origin fish in areas integrated with the hatchery, the value of pNOB, the importance of the integrated population to the larger stock, the fitness differences between hatchery- and natural-origin fish, and societal values, such as angling opportunity. pHOS can also vary considerably from year to year, as it depends on the year-class strength of the contributing natural- and hatchery-origin cohorts, and controlling it to specific values would require intensive management, even in years when pHOS thresholds would not be exceeded. Therefore, the California HSRG recommends that program-specific management plans be developed for the natural spawning areas integrated with hatcheries that reflect these different factors, and with corresponding population-specific targets and thresholds for pHOS, pNOB, and PNI. When insufficient information or tools are available to designate such targets, average levels of pNOB and pHOS should be manipulated so that PNI at least exceeds 0.5 while further research can determine the importance of shifting PNI toward higher values.

- The California HSRG further recommends that pHOS be monitored in natural spawning areas not considered integrated with hatchery programs and that target and threshold pHOS values be established for each such spawning population, taking into account the same factors used for designating pHOS guidelines for integrated spawning areas. We recommend pHOS less than 0.05 as a provisional rule for populations not integrated with the program. When pHOS thresholds are consistently exceeded, consideration should be given to reducing program size or to reducing the straying of hatchery fish into spawning populations not integrated with the program.

- For conservation-oriented programs that are involved in reintroduction or supplementation efforts, acceptable pHOS may be much higher than 5 percent and could actually approach 100 percent in some generations.

2.3 Hatcheries and Harvest

A primary goal of the California Hatchery Scientific Review Project was to develop recommendations that, when implemented, would result in a more holistic management approach for salmonids, including hatcheries along with other factors that affect natural populations of salmon and steelhead. To accomplish this, the California HSRG believes that hatcheries in California should be operated not as isolated entities, with goals only of achieving specified release targets, but rather, within the broader context that includes habitat quantity and quality and harvest management, which collectively affect the abundance and sustainability of natural salmonid populations. Only by considering management of hatcheries, habitat, and harvest together can we maximize the efficiencies and benefits of hatchery production programs while, at the same time, providing the level of protections necessary for the conservation of natural salmonid populations.

2.3.1 Hatchery Goals

Currently, goals for most anadromous fish hatchery facilities in California are described as 'mitigation', and measured only in terms of numbers of juvenile fish to be produced and released annually. Annual production from salmon and steelhead hatcheries in California approaches 50 million juveniles, with fall-run Chinook being the predominant stock in terms of overall production. In most years, over 32 million fall-run Chinook salmon are produced at five hatcheries in California's Central Valley and nearly 9 million are produced at two hatcheries in the Klamath-Trinity Basin. Hatchery production, particularly of Sacramento River Fall Chinook (SRFC), contributes to major recreational and commercial fisheries in ocean and inland areas.

While supporting fisheries is a primary goal of hatcheries and an important goal for state and federal resource management agencies, efforts to augment harvest must also be balanced against the impacts of fisheries on natural salmon and steelhead populations. Substantial research has shown that fish produced in hatcheries can have detrimental genetic and ecological effects on natural salmonid populations (Kostow 2009; Araki et al. 2008). Indeed, Standard and Guidelines put forth in this document are intended to limit the potential for these types of effects. Fishery harvests that are sustained at high levels by targeting abundant hatchery-origin fish may over-exploit naturally reproducing salmonids and may also induce selection on maturation schedule and other traits. Effects of exploitation on naturally producing salmon were not directly addressed by the California HSRG and are not addressed in the Standards and Guidelines of this document; however, fishery exploitation rates must be in alignment with the productivity of naturally reproducing salmon stocks for the recommendations in this report to be successful at conserving natural salmonid populations.

2.3.2 Harvest Management Setting

The ocean salmon fisheries off the coast of Washington, Oregon, and California are managed under authority of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act or MSA). The Pacific Fishery Management Council (PFMC) manages these fisheries under the terms of the Pacific Coast Salmon Plan (FMP), which specifies stock management objectives, exploitation rate control rules, status determination criteria, user-group allocation agreements, etc., consistent with the provisions of the MSA. Annual fishery management measures are developed by the PFMC under the terms of the FMP, and recommended to the Secretary of the U.S. Department of Commerce for implementation.

The California Fish and Game Commission is responsible for managing California's river recreational fisheries, and the Yurok and Hoopa tribes are responsible for managing their tribal fisheries on the Klamath River, and do so consistent with the terms of the FMP and the PFMC annual fishery management measures. For ESA-listed stocks, the National Marine Fisheries Service (NMFS) specifies take limits (typically in the form of exploitation rate limits) through its Biological Opinions and consultation standards which are adhered to by the PFMC and the other management entities.

The FMP requires that annual fishery management measures be crafted to achieve, in expectation, the management objectives for all stocks each year. When coupled with the ESA consultation standards for listed stocks, this results in a given year's fisheries effectively being constrained by those stocks whose abundance in that year dictates the allowable level of exploitation. This is commonly referred to as "weak-stock management". One property of weak-stock management is that the harvest of some stocks may be less in a given year than would otherwise be allowed under that stock's management objective in that year. Moreover, although the ocean distributions of California's Chinook stocks overlap considerably, there are differences in the relative distributions of these stocks, both temporally and spatially, as indicated through analysis of coded-wire tag recoveries. Therefore, in any given year, the PFMC crafts management measures using a combination of time and area closures (and infrequently quotas) of California fisheries that attempt to maximize the opportunity to harvest the more abundant stocks, while also meeting the management objectives and consultation standards of the weakest stocks. In general, Sacramento River fall Chinook Salmon (SRFC) is the dominant stock available to ocean fisheries off California and Oregon.

2.3.3 Sacramento River Fall Chinook Management Objective

The SRFC management objective contrasts with the management objectives for other California Chinook salmon stocks. In particular, the PFMC manages fall Chinook salmon from the Klamath River system to achieve an overall brood harvest rate of 68 percent, subject to a minimum natural area spawning escapement target of 40,700 adults. These reference points are based on a stock-recruitment analysis of recruits produced by fish spawning in natural areas (which are a mixture of natural and hatchery-origin adults). The Klamath River management regime is thus based directly on the observed productivity of fish spawning in natural areas. In contrast, SRFC historically has been managed to achieve a total aggregate spawning escapement (returns of adults to hatcheries and natural spawning areas) of 122,000-180,000 adults. This value is viewed by the PFMC as approximately representing the level of spawning escapement at maximum sustainable yield (MSY), but this management strategy is not based directly on the capacity and productivity of SRFC spawning in natural areas. From 1988 through 1997, SRFC was not a constraining stock for fishery management and there were few ESA-listed stocks to constrain harvests: overall brood harvest rates averaged 79 percent and were as high as 87 percent. The California HSRG believes that these overall brood harvest rates likely exceeded MSY harvest rates for SRFC natural area production. From 1998 through 2007, SRFC were not a constraining stock, but other stocks were: overall brood harvest rates averaged 58 percent and, with the exception of 2004 (75 percent), were below 70 percent. It is unclear whether or not these more recent harvest rates exceeded the MSY harvest rate for SRFC natural area production. Salmon fisheries that impact SRFC were largely closed during 2008 and 2009, and highly constrained during 2010, due to low aggregate abundance of SRFC in those years. As of 2012, SRFC will be managed for an aggregate spawning escapement of

122,000 adults, but with an overall brood harvest rate capped at 70 percent. The overall brood harvest rate previously has not been capped for this stock.

2.3.4 Concerns and Recommendations

The California HSRG is concerned that an overall brood harvest rate of 70 percent may be too high considering the productivity of naturally spawning fish under current habitat conditions (see habitat discussion, Section 2.1). While this harvest rate is similar to that estimated as optimal for natural area spawning fall Chinook salmon in the Klamath Basin, the Sacramento Basin habitat (particularly the conditions for downstream migration) for fall Chinook is more highly degraded and SRFC natural spawning areas are probably less productive. The California HSRG also believes that an aggregate escapement target for this stock that includes returns to hatcheries lacks biological support. The target could theoretically be met if all fish returned to hatcheries and none returned to natural spawning areas, or if all fish in natural spawning areas were of hatchery origin. Both of these outcomes would clearly be at odds with a desire to foster sustainable natural production of fall Chinook salmon in the Sacramento River system. Therefore, we recommend that the SRFC management objective be reviewed by the appropriate state and federal fishery management entities in reference to these concerns, and revised to explicitly account for the status and productivity of SRFC spawning in natural areas.

Even if harvest management of Sacramento River fall Chinook salmon were revised to be more consistent with the current productivity of this stock as we recommend above, and even if California hatcheries were operated in the future as integrated programs with PNI greater than 0.5, as we also recommend above, the California HSRG remains concerned about possible long-term declines in the productivity of Chinook in natural spawning areas. To assist identification of potential causes of productivity decline (i.e., continued degradation of habitat conditions or impacts from hatchery-origin adults spawning in natural areas), we recommend (in Section 6.2) that high priority be given to long-term studies of productivity (e.g., smolts produced per spawner) that would be carried out in a stream or streams where habitat conditions for spawning and rearing are excellent, but where a substantial fraction of the spawners are of hatchery origin (e.g., pHOS greater than 20%). Only through such studies will it be possible to determine if the new concepts of integrated hatchery programs can truly lead to long-term sustainable coexistence of salmon and steelhead hatcheries and the naturally spawning populations with which they are associated.

2.4 Current and Proposed Marking and Tagging Strategies

Throughout this report, marking and tagging programs are described and recommended as means to distinguish between hatchery- and natural-origin fish, a purpose stressed by HSRG (2004), but also for many other purposes related to successful operation and evaluation of hatchery programs. For example, we recommend marking by adipose fin-clipping and tagging by insertion of coded wire-tags (CWT) for many Chinook salmon programs for identification of hatchery- and natural-origin fish, but also for identification of stock-of-origin to maintain the distinctness of runs reared in a single hatchery, and to exclude stray hatchery-origin fish from program broodstock where that is a problem. Maxillary fin clipping is currently used with coho salmon in the Klamath/Trinity basin to distinguish them from natural-origin fish, from northern hatchery-origin stocks that are all adipose fin-clipped, and to distinguish Iron Gate Hatchery fish (left maxillary fin clip) from Trinity River Hatchery fish (right maxillary fin clip). The California HSRG recommends an adipose fin clip plus an additional distinguishing external mark or CWT for the Nimbus steelhead program so that these fish (of out-of-basin ancestry) can be excluded from steelhead broodstock at other Central Valley hatcheries, until a native broodstock is established at Nimbus Hatchery. We also recommend an additional distinguishing external mark or tag (e.g., a ventral fin clip) for "yearling" releases of Chinook salmon (Iron Gate Hatchery, Trinity River Hatchery, and Mokelumne River Hatchery) to allow for the exclusion of adults released as yearlings from the broodstock to reduce the degree of domestication in these programs. We anticipate that future technological developments (e.g., RFID tags suitable for implantation in juvenile salmonids, or real-time identification using genetic tags) may permit these important objectives to be achieved in a more efficient or cost-effective manner.

2.4.1 Coded Wire-Tagging and Constant Fractional Marking

Current tagging programs for most Chinook salmon hatcheries in California consist of "constant fractional marking" (CFM) programs in which a fixed proportion (25 percent) of all hatchery fish are externally marked by an adipose fin clip and internally tagged with a CWT. CWTs provide a batch tag whereby fish released from a particular hatchery can subsequently be identified as belonging to a particular release group (brood year and release location) and hatchery of origin. Remaining fish are released unmarked and untagged. CFM marking programs were introduced at Trinity River Hatchery system beginning with the 2000 brood year; at all Central Valley hatcheries beginning with the 2006 brood year; and at Iron Gate Hatchery beginning with the 2008 brood year. Adoption of CFM marking/tagging programs was specifically designed to allow unbiased estimation of the proportion of hatchery fish in freshwater catches, natural spawning escapements (pHOS), and among hatchery returns, while at the same time delivering the typical estimates of fishery and life history parameters that are required by salmon fishery managers. Historically, a very low percentage of hatchery Chinook salmon were marked and tagged, particularly in the Central Valley, tagging programs were not coordinated across hatcheries, and as a consequence, it was very difficult to determine the contribution of hatcheries to escapement or to determine the proportion of hatchery fish on spawning grounds.

The CWT technology was very quickly adopted by many agencies following its introduction in the early 1970s and a collaborative coast-wide (California, Oregon, Washington, British Columbia and Alaska) tag recovery system and database management system (RMIS, managed by the Pacific States Marine Fisheries Commission [PSMFC]) was also developed rapidly (see Hankin et al. 2005 for a detailed review). Initially, the adipose fin clip was "sequestered" as a fin mark that could be used only if it were directly associated with an internal CWT, so that ocean and freshwater samplers could visually identify fish that were tagged. Quantitative fisheries scientists soon realized that cohort reconstruction methods could be used to estimate important ocean and freshwater fishery parameters (e.g., age-specific exploitation rates), overall survival of individual CWT release groups, and important life history parameters (e.g., age-specific maturation probabilities). With the emergence of harvest rate-based theories of harvest management, target and estimated ocean fishery exploitation rates assumed a dominant role in stock assessment and the development of annual fishery management measures by the PFMC. Prior to the advent of mark-selective ocean and/or freshwater fisheries, the exploitation history of a hatchery indicator stock was assumed to be the same as that of its unmarked natural stock counterpart. Thus, the estimated exploitation rates associated with tagged hatchery indicator stocks provided information on the likely fishery impacts on natural populations. If exploitation rates were judged too high for natural populations of concern, fishery managers revised fishery regulations so as to reduce exploitation rates to levels appropriate for natural populations.

2.4.2 Mark-Selective Fisheries

Mark-selective fisheries for marked hatchery steelhead were introduced throughout the Northwest beginning about 1965, and recreational fishery regulations were often changed to allow harvest of adipose-fin clipped steelhead, a species where all hatchery fish are typically marked. Thereafter, fisheries on natural steelhead populations were usually of a catch-and-release nature, or bag limits for unmarked steelhead were considerably less than for marked steelhead, theoretically generating relatively low fishery mortality rates on unmarked steelhead of natural origin. Mark-selective ocean fisheries for coho salmon were first adopted in Oregon coastal fisheries in 1998; mark-selective ocean coho fisheries were subsequently introduced in Washington and British Columbia, but not in California waters. Mark-selective ocean fisheries for Chinook salmon were first adopted in 2010 in Washington waters remain of fairly limited extent, and similarly have not been introduced in California waters.

Mark-selective fisheries for coho and Chinook salmon also rely on angler identification of hatchery-origin fish via absence of an adipose fin. Millions of hatchery coho and Chinook salmon released from hatcheries are currently "mass marked" (100 percent marked with adipose fin-clip) in Oregon, Washington and British Columbia. In mass marking programs, however, many fish are released with an adipose fin-clip but without an associated CWT. Thus, a consequence of the introduction of mass marking without a commensurate 100 percent tagging rate was a de facto "de-sequestration" of the adipose fin-clip as a mark reserved for fish with CWTs. Also, because fish with an adipose fin-clip could be retained in mark-selective fisheries, but unmarked fish could not, exploitation history of an adipose fin-clipped hatchery stock could no longer be assumed to be the same as that of their unmarked natural-origin counterpart. Whether or not unmarked fish subjected to mark-selective fisheries actually experience reduced exploitation rates compared to marked fish is a complex subject that involves consideration of the proportion of available fish that are marked and various assumptions concerning non-catch mortality rates, independence of fishery encounters and other variables (see, e.g., Lawson and Sampson 1996).

Mark-selective ocean or freshwater salmon fisheries have not been introduced in California waters and whether or not such fisheries should be introduced remains a complex and controversial subject (see, e.g., lists of presentations given at a 2009 CAL-NEVA sponsored symposium - available at http://marking.fishsciences.net/afs_forum.php). Within the California HSRG there was substantial divergence of opinion regarding the wisdom of mark-selective fisheries in California. Because CDFG has not indicated an intention or desire to introduce mark-selective fisheries for salmon, and because there is no consensus among California HSRG members concerning the desirability of such fisheries, we recommend marking and tagging programs for Chinook salmon that will be highly effective in achieving the large number of objectives (specified under Standards for Monitoring and Evaluation, Chapter 4.4 of this report) that are needed for effective management of our salmon hatchery programs and associated fisheries, while not unintentionally facilitating mark-selective fisheries.

2.4.3 Parentage-Based Tagging

We recommend use of parentage-based tagging (PBT) of steelhead in California, in addition to marking with adipose fin-clips. PBT relies on genotyping with molecular markers of the hatchery broodstock for tag issuance and genotyping fish from the next generation with the same molecular markers, followed by large scale parentage analysis to identify the parent pairs in the previous generation (Hankin et al. 2005; Anderson and Garza 2006; Garza and Anderson 2007). Use of the PBT approach is already underway in the Central Valley. Unlike CWTs, these genetic tags can be recovered non-lethally, which is an important consideration for this iteroparous species, many distinct population segments of which are ESA-listed. Genetic tags identify stock of origin and this information will provide estimates of straying and broodstock incorporation rates between hatcheries within the Central Valley and Klamath/Trinity basins. The PBT programs will also provide broodstock age distribution information and allow estimation of genetic effective size and trends in inbreeding by age of parents, as well as many other parameters. Moreover, several of the molecular markers currently used for PBT in California have been shown to be strongly associated with resident/anadromous life history strategy (Limborg et al. 2012; Miller et al. 2012) and may therefore have some predictive power for assessing whether particular fish chosen as broodstock are likely to produce anadromous progeny. However, more research and evaluation of this topic is needed (see Section 6.2).

2.5 Population Structure of Anadromous Salmonids in the Klamath-Trinity and Sacramento-San Joaquin Systems

Another application of genetic data with relevance to hatchery management is the elucidation of population structure of salmon and steelhead. Such population structure information helps to inform hatchery management in several ways, including identifying the extent of differentiation between local populations and the related issue of gene flow between them, and providing a better understanding of the effects of hatchery programs on naturally spawning populations. Evaluations of genetic population structure have been undertaken for all of the stocks of relevance to the California HSRG.

For steelhead, several studies of population structure have been undertaken in the Central Valley. Nielsen et al. (2005) and Garza et al. (2008) both found significant structure of *O. mykiss* populations in the Central Valley, although it was largely not geographically consistent. Both of these studies found that populations of fish above dams were generally more closely related to each other than to populations of fish below dams in the same basin. Garza and Pearse (2008) used data from steelhead populations in coastal California to infer that this pattern is due to primarily native ancestry in the fish populations above dams, with below dam populations affected by the presence of and introgression by fish with non-native ancestry. At least some part of this pattern was due to the long-standing use of broodstock derived from out-of-basin sources in the Nimbus Hatchery steelhead program, although it was unclear the extent to which this stock affected populations beyond the central portion of the Central Valley Basin. Evaluations of steelhead/*O. mykiss* population structure in the Klamath/Trinity Basin found somewhat different patterns, with genetic differentiation strongly dependent upon geographic distance, and the presence of subbasin specific genetic groups (Pearse et al. 2007; M. Peterson et al. unpublished data). These patterns indicated that most of the tributary populations of steelhead in the Klamath/Trinity Basin, aside from those in the Shasta and Scott rivers, are largely unaffected by gene flow from hatchery programs.

Population structure of coho salmon in the Klamath/Trinity Basin has also been evaluated (Garza et al. unpublished data), although with insufficient sampling in the Trinity River subbasin. This evaluation has shown that coho salmon in the Klamath River and the Trinity River are substantially differentiated, in spite of the fact that spawning of fish from the Trinity River Hatchery has been documented in the Iron Gate Hatchery program. Genetic examination of eight years of Iron Gate Hatchery coho salmon broodstock found that a policy of not spawning two-year-old fish had induced differentiation between the three brood cycles spawned at the hatchery and that this structure was greater than that between naturally spawning populations in different upper Klamath tributaries. Substantial gene flow of hatchery-origin fish into the Shasta River population was also evident.

Detailed studies of Chinook salmon population structure are available for both the Central Valley and the Klamath/Trinity Basin. In the Central Valley, the four long-recognized temporal runs – winter, spring, late-fall and fall – are arranged into four primary genetic groups, but those groups are not coincident with run identity (Banks et al. 2000; Garza and Pearce 2008). Winter-run are highly differentiated from all other salmon, at least partly due to documented bottlenecks in abundance, and form one group. Naturally spawning spring-run Chinook salmon form two differentiated groups, those from Butte Creek and those from Mill and Deer creeks. The smaller populations in other streams, such as Clear Creek, are comprised of migrants from both of these groups, as well as from the Feather River Hatchery program (Smith and Garza unpublished data). Feather River Hatchery spring-run Chinook salmon have been introgressed by fish from the fall-run program (Garza and Pearse 2008) and cluster more closely with the fourth genetic group- fall-/late fall-run Chinook salmon. Fall-run and late fall-run salmon at Coleman National Fish Hatchery and in natural areas are extremely similar genetically and cannot be reliably distinguished with genetic stock identification methods. Within the fall-run, there is little or no significant population structure present in the Central Valley (Williamson and May 2005; Garza et al. 2008). This has been attributed to the off-site release of fall-run Chinook salmon in the Central Valley and the consequent elevation of straying rates. One of the goals of the California HSRG is to reestablish conditions for local adaptation to reemerge. As a first step toward reestablishing adaptive genetic differentiation among Central Valley fall Chinook salmon populations, all releases should be made on-site (at or in the near vicinity of the hatchery of origin).

In the Klamath/Trinity Basin, both spring-run and fall-run Chinook salmon are present. The Trinity River Hatchery produces spring-run salmon, and spring-run salmon are found primarily in the Trinity River subbasin, although a small population of spring-run salmon is also present in the Salmon River tributary of the Klamath River subbasin. Genetic analysis has shown that these two populations of spring run are not each other's closest relatives (i.e., are not monophyletic) and that spring-run and fall-run Chinook salmon at the Trinity River Hatchery are only marginally differentiated (Kinziger et al. 2008; Kinziger et al. *in prep*). In contrast, substantial structure exists within the Klamath/Trinity Basin fall-run. Genetic evaluation of both the Iron Gate and Trinity River hatchery stocks, as well as most of the large naturally spawning populations in the basin, found substantial differentiation between Klamath and Trinity stocks, as well as a gradient of gene flow from the hatchery stocks into downstream natural populations, with the amount of hatchery ancestry commensurate with distance from the hatchery.

The contrast between the geographically consistent population structure of fall-run Chinook salmon in the Klamath/Trinity Basin, some of which is likely associated with local adaptation, the substantial structure found in other large basins (e.g., Columbia and Fraser rivers) and the near complete lack of genetic structure of fall-run salmon in the Central Valley highlights the effects of off-site release programs on population structure and associated local adaptation.

3. Issues of Greatest Importance for Management of California's Salmon and Steelhead Hatcheries

In this section, 14 major issues were identified as having paramount importance by the California HSRG during its review of salmon and steelhead hatcheries in the Klamath-Trinity and Sacramento-San Joaquin systems. Because it is difficult to fully appreciate the significance of these specific issues without context, Chapter 2 provides critical background material that we highly recommend be read before proceeding to the 14 major issues discussed in this chapter.

It has not escaped the California HSRG's attention that many reviews of individual hatcheries or groups of hatcheries have been done in the past, including a relatively recent inter-agency review of Central Valley salmon and steelhead hatcheries (CDFG/NMFS 2001). The recommendations that have been presented in these reviews have often been only partially implemented. It is our hope that the relevant agencies and stakeholder groups will use this document as leverage to initiate needed changes in the operation of California hatcheries and that their attention will be focused especially on the major issues that we identify below. We suggest this document is the only the first step in essentially an adaptive management approach to continued evolution in the operation of California's anadromous salmonid hatcheries.

3.1 Serious Loss and Degradation of Habitat Limits Natural Production of Salmon and Steelhead in California

A substantial amount of historic habitat for anadromous salmonids has been lost in the Klamath/Trinity and Sacramento/San Joaquin river systems due to the construction of large impassable dams. Associated downstream water management and other land-use practices have resulted in additional habitat modifications further impacting productivity of anadromous species. The California HSRG has identified areas where hatchery facilities and programs can and should control undesirable hatchery impacts. The California HSRG notes, however, that hatcheries and hatchery reform alone will not recoup historic adult holding, spawning, and nursery habitats or likely influence water or land-use management. Protecting the remaining available habitats and restoring former habitats must be a priority if viable natural populations of salmon and steelhead are desired and the abundance of natural-origin fish is expected to increase. Therefore, in conjunction with this Hatchery Scientific Review and expected subsequent implementation of changes in hatchery practices, major efforts to protect and restore habitat quality and quantity in California's Central Valley and in the Klamath/Trinity river system (including migration corridors) must continue or expand.

3.2 Hatchery Program Goals have been Consistently Expressed in Terms of Juvenile Production Rather than Adult Production

Because survival from release to adult varies substantially across hatcheries and programs, as well as across years, juvenile production is not an adequate or sufficient measure of program goals. Instead, the California HSRG recommends that program goals should be expressed in terms of expected (average) adult production which has direct relevance for fishery harvests and spawning escapements. For Chinook salmon, adult production should be measured by age 3 pre-fishery ocean recruits. For coho salmon (currently not subjected to ocean harvest in California) and steelhead (also not subjected to significant ocean harvest), adult production goals should be expressed as adult freshwater returns.

3.3 Program Purposes Have Not Been Clearly Defined

Most hatchery programs in California do not have clearly defined purposes other than juvenile production targets and, sometimes, undefined contribution to harvest. Providing fish for harvest, population supplementation or prevention of extinction are potential purposes. Lack of clearly defined program purposes hinder success in meeting program goals and has likely led to negative impacts on natural spawning populations. We recommend that hatchery program purposes be clearly defined and used to guide management decisions. Also, an emerging conservation focus for many of the State's steelhead, Chinook and coho programs needs to be recognized, and appropriate operational procedures adopted.

3.4 Hatchery Monitoring and Evaluation Programs and Hatchery Coordination Teams Are Needed

Monitoring and evaluation (M&E) programs perform a critical role in assessing whether hatcheries are achieving their goals of providing societal benefits (e.g., harvest opportunity) and assisting in the conservation of depressed populations. M&E programs also are critical to assess the level of impact hatchery programs may have on natural populations. Effective monitoring and evaluation provides accurate, timely, and objective information collected within a sound scientific framework. Despite the importance of hatchery M&E programs, they have generally received insufficient emphasis at California's anadromous fish hatcheries. The California HSRG recommends that every anadromous fish hatchery program in California have a dedicated M&E program and that Hatchery Coordination Teams be formed to bring together the knowledge and expertise of hatchery managers, biologists and fish culturists, M&E biologists, fish health specialists, regional fish biologists, fishery managers, and other representatives from management or funding agencies. Implementation of these M&E programs and associated review processes will inform hatchery decisions and document compliance with best management practices. Furthermore, we urge periodic interaction among the Hatchery Coordination Teams from different facilities to share scientific approaches and practices.

3.5 Program Size (as Measured by Juvenile Production) has been Set Independent of any Consideration of Potential Impacts of Hatchery Fish on Affected Natural Populations

There are a large number of possible negative impacts that release of millions of hatchery fish may have on natural populations, including direct competition or predation among hatchery- and natural-origin juveniles, transmission or promotion of disease from hatchery to natural populations, competition between hatchery- and naturally-produced adults for spawning habitat, and reduction in fitness due to interbreeding of hatchery and naturally-produced adults on spawning grounds. We recommend that studies be carried out to assess these interactions and their effects on naturally spawning populations of salmon and steelhead. Where substantial negative effects occur, hatchery programs should be modified to ameliorate those effects. In cases where hatchery operational strategies cannot be modified to satisfactorily reduce negative impacts on natural salmonid populations, program size should be reduced. Among situations where program size is reduced or programs eliminated, in no case should such change result in relinquishment of mitigation responsibility.

3.6 Off-site Releases Promote Unacceptable Levels of Straying Among Populations

All releases of Chinook salmon and steelhead in the Klamath-Trinity system have been made on-site at the hatcheries where fish were spawned and reared, with a few exceptions in the mid-1980s. As a consequence, the majority of adult hatchery fish return to spawn either at the hatchery or in natural areas in the immediate vicinity of the hatchery. In the Central Valley, however, because of the degraded conditions of downstream migration corridors, most Chinook salmon hatchery production has been routinely released off-site, significantly downstream of the hatchery or in the estuary. Although this off-site release practice has improved survival rates and resulted in increased ocean harvest of hatchery fish, it has also led to widespread straying of hatchery fish throughout the Sacramento-San Joaquin system. For example, in fall 2010, about 70 percent of fall Chinook salmon spawning in the Yuba River were of hatchery origin, mostly from the Feather River Hatchery. Genetic evidence suggests that the long-term use of off-site release locations has substantially contributed to the lack of genetic differentiation among Central Valley fall Chinook salmon (Williamson and May 2005), whereas, in the smaller Klamath-Trinity system, where on-site release has been the predominant policy, substantial genetic differentiation continues to exist among fall Chinook salmon populations. One of the goals of the California HSRG is to reestablish conditions for local adaptation to reemerge. As a first step toward reestablishing adaptive genetic differentiation among Central Valley fall Chinook salmon populations, all releases should be made on-site (at or in the near vicinity of the hatchery of origin). Until all off-site releases of Chinook salmon are eliminated in the entire Central Valley, coded wire tag analysis should be used at Feather, Nimbus, Mokelumne, and Merced hatcheries to identify stray hatchery-origin fish among those fish selected for broodstock. Strays from other hatchery programs should not be used as broodstock, or if eggs are collected from or fertilized by such fish, they should be culled soon after spawning. We note that this interim action will not, however, address straying of out-of-subbasin hatchery-origin fish into natural spawning areas, and is therefore an insufficient solution to the problem of off-site releases.

3.7 Marking/Tagging Programs are Needed for Real-time Identification of all Hatchery Chinook Salmon

Current marking programs for Chinook salmon in the Klamath-Trinity system and, for the most part, in the Central Valley system, consist of a constant fractional marking program in which 25 percent of fish produced are released with adipose fin-clip and coded-wire tag (CWT). This marking program is adequate to allow reasonably accurate statistical estimation of the proportion of hatchery fish on natural spawning grounds and in hatchery returns, and does a good job of supporting needs of fishery managers, but it does not allow real-time identification of <u>all</u> hatchery fish as being of hatchery origin. For the immediate future, we recommend generally that all Chinook salmon (100 percent) should be tagged with CWT and that 25 percent should be adipose fin-clipped to allow real-time identification of hatchery-origin fish (using electronic CWT detection devices). This is essential for the following purposes: to enable improved monitoring of hatchery and natural interactions throughout the entire life cycle; to enable culling of undesirable hatchery matings between out-of-subbasin and local stocks or between spring and fall Chinook stocks from the same basin (through CWT reading), to enable improved management of hatchery broodstock (incorporation of known numbers of natural fish), and to monitor and potentially control spawner composition in natural spawning areas. While 100 percent adipose fin-clipping would also allow real-time identification of all hatchery-origin fish, it is a crude mark which doesn't provide the hatchery of origin or run-type.

3.8 Standards for Fish Culture, Fish Health Management and Associated Reporting are Inadequate and Need to be Improved

Fish culture techniques and fish health management are intrinsically intertwined; each discipline requires attention to detail, prompt remediation of adverse conditions and a coordinated effort to promote optimum fish health and survival. Clearly defined goals, roles and standards for fish culture and fish health management, promulgated in official policy, foster optimum health of hatchery fish while preventing the importation, dissemination, and amplification of pathogens and diseases known to adversely affect both hatchery and natural fish populations. The California HSRG observed large variation in hatchery operations relevant to fish health, including fish culture techniques, the level of fish health support requested or provided, and the data collected during each production cycle (adult collection to juvenile release) that affect fish health and survival, and provide inadequate protection for both hatchery and natural fish populations from disease impacts. The California HSRG also noted that the current fish culture protocols (Leitritz and Lewis 1976) are now outdated and that infrastructure needs and inadequate fish pathology staff compromise efficient and cost-effective operation of some hatchery facilities.

The California HSRG recommends adopting the standards of the Integrated Hatchery Operations Team (IHOT, IHOT 1995) for California anadromous fish hatchery programs. These policies and procedures were developed in the Columbia Basin anadromous salmonid hatcheries and include comprehensive standards for fish culture techniques, fish health management and reduction of negative ecological interactions with natural populations. In addition to the IHOT standards, the California HSRG recommends that a comprehensive fish health policy, fish health management plans for ESA species, and an updated fish culture operational manual be developed for state-operated anadromous fish hatchery programs.

3.9 Populations and Population Boundaries have not been Established for Non-listed Species and are Needed for Effective Development of Integrated Hatchery Programs

Previous HSRG efforts in Puget Sound and the Columbia River (HSRG 2004, 2009) primarily reviewed hatchery programs that affected species of anadromous fish whose associated Evolutionarily Significant Unit (ESU) or Distinct Population Segment (DPS) had been previously listed as Endangered or Threatened under the Endangered Species Act. Because of this, ESU/DPS population boundaries were established by Technical Recovery Teams and population importance was established in associated Recovery Plans. In contrast, the majority of the populations with which California hatcheries are associated, including all fall Chinook programs, belong to ESUs/DPSs that have not been listed under the ESA, and as such, the component populations have not been explicitly delineated. Therefore, in many cases, it is not a straightforward matter to identify the geographic boundaries of the population with which a hatchery is intended to be integrated. For example, what is the lower population boundary of fall Chinook salmon spawning in the mainstem Trinity River with which the Trinity River Hatchery program is integrated? Challenges such as these are further complicated by genetic homogenization of Central Valley fall Chinook salmon (Williamson and May 2005).

The California HSRG recommends that the geographic boundaries for naturally spawning populations to be integrated with hatchery programs should adhere to the following guidelines for ESA-listed species.

- Where independent populations and associated population boundaries have been identified for listed species, these same populations and boundaries should be used to define the geographic boundaries of the population with which a hatchery should be integrated.

The California HSRG recommends that provisional identities and boundaries for non-ESA listed species should be established in one of the following ways:

- Where judged appropriate, boundaries for related species could be used, on an interim basis, while work is done to better define and motivate population boundaries for these non-listed species. Thus, for example, defined populations and boundaries for coho salmon in the Klamath-Trinity system (Williams et al. 2006) could be used, provisionally, for fall Chinook salmon.

- In the Central Valley, populations and population boundaries as defined in the Anadromous Fish Restoration Program (AFRP) under the Central Valley Project Improvement Act may be used to define populations and their boundaries.

The California HSRG also makes two important observations. First, designation of population boundaries can have an important influence on the proportion of hatchery-origin spawners (pHOS) in natural areas and on the associated proportion of natural-origin broodstock (pNOB) that would be required to achieve a particular proportionate natural influence (PNI) value for an integrated hatchery program. Second, population boundaries are important so that managers can assess the prevalence of stray hatchery fish (pHOS) in natural populations that are not integrated with hatchery programs.

3.10 Harvest Management of Sacramento River Fall Chinook Should Account for the Productivity of Naturally-Spawning Adults

The Pacific Fishery Management Council (PFMC) and California Fish and Game Commission manage the ocean and river fisheries that impact Sacramento River fall Chinook salmon. As of 2012, the total overall brood harvest rate for this stock is capped at 70 percent with a minimum aggregate spawning escapement (returns to hatcheries and natural areas) target of 122,000 adults. In contrast, the total overall brood harvest rate for Klamath-Trinity fall Chinook salmon is capped at 68 percent with a minimum natural area spawning escapement target of 40,700 adults. The allowable harvest rate for Klamath-Trinity fall Chinook salmon is based on a stock-recruitment analysis of natural area spawning fall Chinook salmon and is therefore consistent with the productivity of naturally spawning fish in this system. The California HSRG is concerned that an overall brood harvest rate of 70 percent for Sacramento River fall Chinook salmon may be too high for naturally-spawning fish given the degraded conditions for downstream migration that are experienced throughout this basin. We also believe that an aggregate escapement target for this stock that includes returns to hatcheries lacks biological support. The target could theoretically be met if all fish returned to hatcheries and none returned to natural spawning areas, or if all fish in natural spawning areas were of hatchery origin. Both of these outcomes would clearly be at odds with a desire to foster sustainable natural production of fall Chinook salmon in the Sacramento River system. We therefore recommend that the current approach used to manage the harvest rate on Sacramento River fall Chinook salmon be reviewed by the fishery management entities, and revised to explicitly account for the status and productivity of Sacramento River fall Chinook spawning in natural areas.

3.11 Several Steelhead Programs Have Seriously Underperformed

Several steelhead programs reviewed by the California HSRG were observed to be underperforming or potentially detrimental to native steelhead populations. The winter steelhead program at Nimbus Fish Hatchery uses broodstock derived from fish imported from the Eel and Mad rivers and there is evidence that these fish have introgressed native steelhead populations in the Central Valley. We recommend that this broodstock be replaced with an appropriate native broodstock. Several steelhead programs experience very low adult return rates and appear to use resident fish as broodstock. At Iron Gate and Mokelumne River hatcheries, adult return rates are so low in comparison to historical returns, that the California HSRG recommends managers review the existing programs and develop alternative broodstock collection and rearing strategies so as to meet program goals and objectives. Finally, runs of both natural- and hatchery-origin steelhead in the Central Valley are at record lows when compared to historical numbers both before and after construction of numerous water projects. The California HSRG believes that the recommendations for steelhead hatchery programs in this report should be assigned a high priority for implementation, and that continuing improvements in monitoring freshwater returns, including creel surveys, also have high priority.

3.12 Adults Returning from "Yearling" Releases of Hatchery Chinook Salmon Should be Excluded from Broodstock

Chinook salmon are reared and released as subyearlings during their first spring or fall at Iron Gate Hatchery, Trinity River Hatchery, and Mokelumne River Hatchery. "Fingerlings" are released in early June at about 90-100 fish/pound, and "yearlings" are released in early October at about 10 fish/pound. Yearlings typically have greater survival rates to adult than fingerlings. Also, release of smolts in fall, after naturally-produced juvenile salmon have left the river for the ocean, probably reduces competition with natural Chinook during the juvenile phase. The longer duration of rearing in the hatchery, however, almost certainly increases the potential for domestication of yearlings as compared to fingerlings and likely causes greater detrimental effects to natural populations when these fish spawn in natural areas. To reduce the degree of domestication in these programs, we recommend that all yearlings receive an additional distinguishing external mark or tag (e.g., a ventral fin clip), and be completely excluded from hatchery broodstock upon return. Adequate numbers of fingerlings should be released each year to meet numerical goals for broodstock. When adult returns from fingerling releases are inadequate to satisfy hatchery egg take needs, then yearling returns may be used to reduce the deficit.

3.13 True "1:1 Matings" and Associated Incubation Protocols Need to be Adopted by California Steelhead and Salmon Hatcheries

Most of the production (non-conservation) programs reviewed by the California HSRG used mating practices whereby eggs from multiple females (e.g., 5) and sperm from multiple males (e.g., 5) were placed, sequentially, in the same tub. Eggs from such matings are then distributed across a number of incubators based on the total volume of eggs fertilized in any given set of females. Such procedures do not constitute "1: 1 matings" as we define them, and, in many cases, the contributing males may have widely different levels of egg fertilization success (see Campton 2004), due to differences in sperm motility and fertilization success among males. This unequal male contribution reduces the genetic effective size of a population.

For programs that spawn more than 250 females, the California HSRG instead recommends that they routinely adopt true 1:1 mating protocols in which eggs from only one female are fertilized by sperm from only one male in a separate pan. Coleman National Fish Hatchery currently employs a very efficient 1:1 spawning protocol for all Chinook salmon (more than 4,000 males and 4,000 females are spawned in most years). For smaller programs, we further recommend eggs from each female be split into two or more lots and that each lot be fertilized by sperm from a different male in a separate pan, and also that eggs from no more than two females be incubated in a single incubator tray, ideally with a divider to separate the two families, so that eggs from undesired matings (e.g., in-subbasin and out-of-subbasin stocks) can be readily culled. These same incubation protocols should also be considered for adoption in large-scale hatchery programs, especially when large numbers of out-of-subbasin broodstock have been unintentionally incorporated into the broodstock historically. Efficient systems to track eggs from the spawning area to the incubation area likely will also need to be developed.

3.14 Effective Methods are Needed to Ensure Maintenance of Distinct Runs of Chinook Salmon Reared at the Same Facility

Three facilities in California produce multiple runs of Chinook salmon: Coleman National Fish Hatchery (late fall- and fall-run), Feather River (spring- and fall-run), and Trinity River (spring- and fall-run) hatcheries. Different methods are used at the three facilities for separating the broodstock for the two Chinook programs and they have different effectiveness. The late fall- and fall-run separation at Coleman Hatchery is achieved through periodic trap operation, differential mark rate application and subsequent identification and phenotypic discrimination. Fish collected between the fall and late-fall spawning seasons are euthanized and excluded from the broodstock. Coded wire-tag analysis has shown this to be highly effective at maintaining separation of these two stocks. At Feather River Hatchery, spring-run broodstock are identified using a phenotypically-based method (Hallprint dart-type tag) and appears to be effective at limiting gene flow from the fall- to spring-run. In contrast, fall-run identification at Feather River Hatchery is not effective and the California HSRG recommends coded-wire tag analysis during the first few weeks of fall-run broodstock collection to identify and remove spring-run fish. (We note that this will not, however, allow identification of natural-origin spring-run fish in the broodstock.) At Trinity River Hatchery, some degree of separation between spring- and fall-run is achieved through a two week trap closure, but separation does not appear to be sufficient to isolate spring from fall runs. We recommend that the fish trap remain open during the period between spring- and fall-run broodstock collection but that fish collected during this period be euthanized. We further recommend coded-wire tag analysis of broodstock in the last two weeks of the spring-run and the first two weeks of the fall-run spawning seasons to establish run-type of spawners. Eggs identified from matings of spring- and fall-run fish should be culled. We further recommend that facilities be constructed to allow early-returning spring-run fish to be held at the Trinity River Hatchery for up to several months prior to spawning.

4. California Statewide Issues and Recommended Statewide Standards and Guidelines for Operating Hatchery Programs

For each of the 19 anadromous hatchery programs evaluated during this review, contractors initially compiled both operational and biological information as draft program reports. These draft reports were provided to the California HSRG in advance of each regional review. Regional work sessions attended by both contractors and the California HSRG were then conducted (see Table 1-3). These sessions generally involved a one-day tour of the watershed and hatcheries and discussions with hatchery personnel and regional biologists. These information gathering reviews were followed by a two- or three-day work session of the California HSRG. Additional multi-day work sessions and conference calls were conducted by the California HSRG as well. During these reviews and work sessions, the California HSRG deliberated at length on the challenges facing all 19 of the programs.

Based on our review, the California HSRG identified a suite of issues that were applicable to hatchery programs statewide. These common issues were organized under five key hatchery topics (1) broodstock management; (2) program size and release strategies; (3) incubation, rearing and fish health management; (4) monitoring and evaluation; and (5) direct effects of hatchery operation on local habitat and aquatic or terrestrial organisms. The California HSRG then developed standards and guidelines for each topic along with the scientific rationale for the standards and guidelines. Each of the 19 hatchery programs was then reviewed for compliance with the standards; non-compliance was noted along with relevant guidelines. In many cases, comments were supplied as well. These program-specific compliance/non-compliance determinations, by topic, are recorded in the 19 individual Program Reports (Appendix VIII). Major program specific recommendations are highlighted in Chapter 5. Below we present the complete set of standards and guidelines that we recommend for use at all anadromous salmonid hatcheries in California.

4.1 Broodstock Management

Maturing adult fish are available for use as broodstock in hatchery operations when they return to the hatchery or are trapped at an auxiliary facility. The way in which fish are chosen for use as broodstock and their subsequent handling are critically important issues for performance of hatchery programs. The California HSRG identified several areas of broodstock management where standards and guidelines are necessary: the source and life history attributes of fish used; the collection and subsequent holding of fish until spawning and, with steelhead, until release; the selection of fish for spawning from among all fish trapped; the selection of mating partners for spawning; and the effects of broodstock collection on the naturally-spawning populations of the same species.

In California, almost all of the salmon and steelhead hatchery programs have been using broodstock that originated from the natural population in the immediate vicinity of the hatchery for at least several decades. The one exception is the Nimbus steelhead program, which uses broodstock derived from out-of-basin sources, including California's Eel and Mad rivers. Many other hatchery programs historically imported some broodstock or eggs, but it is now widely accepted that such out-of-basin broodstock typically performs poorly, and such introductions generally fail to produce consistent adult returns. In addition, fish from out-of-subbasin, not locally adapted to be basin of interest, are expected to have greater negative consequences on naturally spawning populations of fish native to the basin where the hatchery is located. For these reasons, the California HSRG recommends that broodstock be taken from fish native to the hatchery location or thereabouts and with life history attributes appropriate to program goals. When native fish of multiple life history types, such as temporal runs of salmon or resident and anadromous *O. mykiss*, occur within the basin where the hatchery is located, particular care must be taken in collection of broodstock for use in the hatchery.

Incorporating natural-origin fish into hatchery broodstock is complicated by the fact that natural-origin fish do not enter most primary hatchery trapping facilities in sufficient numbers to meet either current program goals or those recommended by the California HSRG. Existing broodstock collection facilities for most of the hatchery programs are located at the hatchery site, which is typically the terminus of the migratory pathway. These facilities are often extremely limited in their ability to capture a representative sample of the naturally-spawned population with which the hatchery stock is associated. Additional broodstock trapping facilities and protocols are needed to collect adequate numbers of natural-origin fish displaying the full range of phenotypic variation in the stock to meet program goals. The California HSRG notes that one goal of all of the steelhead programs is to produce anadromous fish and that this is best accomplished by using anadromous adults as broodstock.

In addition, many fish collected for broodstock are not spawned immediately or at all. Steelhead may be held at the hatchery following spawning for reconditioning and eventual release. Adequate facilities are necessary to hold fish in the hatchery until spawning and/or release in the numbers that they are typically encountered and without substantial hatchery-related mortality (e.g., disease and predation). Since steelhead are iteroparous and can perform more than one anadromous migration, some fish used as broodstock should be reconditioned prior to release; adequate facilities for such reconditioning are required.

Protocols must be in place for selecting fish for broodstock because more fish are generally brought into the hatchery than are needed to meet program goals. These protocols must specify how different size and age groups are used in spawning, how different life-history types are identified and selected, and how natural- and hatchery-origin fish will be incorporated into the program's broodstock. Several salient issues identified by the California HSRG are that smaller adults are generally believed to have lower reproductive success than larger fish in natural spawning, and 2-year-old fish (i.e., jacks for salmon), which are most frequently males, may have much lower reproductive success in naturally-spawning populations. As such, they should be incorporated into broodstock at rates that are lower than their abundance and, ideally, commensurate with their reproductive contribution in the naturally spawning population, to avoid possible hatchery selection on age distribution. For the coho salmon programs in California, it is of particular importance to incorporate 2-year-old fish (i.e., jacks and jills) into broodstock. Most fish in these stocks mature as 3-year-olds and all fish mature as either 2- or 3-year-olds so that excluding jacks will reduce effective population size and induce divergence among the three brood cycles.

The California HSRG also recognized that total isolation of the hatchery stock from the naturally-spawning populations in the same basin is impossible. Since the negative consequences of hatchery fish breeding in natural populations are generally greater the more divergent the fish are, some level of integration between hatchery and natural populations is desirable. Incorporating natural-origin fish into the hatchery broodstock decreases divergence between hatchery and natural populations (Reisenbichler and McIntyre 1986, Lichatowich and McIntyre 1987, Cuenco et al. 1993). Natural-origin fish should be incorporated into broodstock in the highest proportion possible (Harada et al. 1998), and a minimum proportion of 10 percent natural-origin fish as broodstock (pNOB) is a widely employed general guideline to reduce divergence of the hatchery- and natural-origin components of integrated populations. However, use of natural-origin fish as broodstock must be achieved without decreasing the viability of the natural population due to the demographic effects of removing mature fish.

Once fish have been selected for broodstock, mating partners must be chosen. As a general rule, care must be taken not to induce selection by using phenotypic characters to select fish to mate (Neff et al. 2011). The California HSRG recommends that once fish have been identified as belonging to the stock being produced (i.e., the intended temporal run or life history type), mating partners should not be chosen on the basis of any phenotypic traits, such as size or color (except where size is used to identify jacks or anadromous steelhead). However, in natural populations, larger salmonids generally garner higher reproductive success. As noted above, Chinook salmon jacks (age-2) should be incorporated into broodstock at a rate that is lower than their abundance and, ideally, commensurate with their reproductive contribution in the naturally spawning population. Similarly, larger females typically have greater fecundity (i.e., more eggs). Moreover, size is strongly correlated with age, although the size distributions of different age fish from the same cohort generally overlap and the size distributions of different age fish can vary considerably between cohorts. Because age at reproductive maturity has a considerable heritable component (Hankin et al. 1993), choosing mating partners without regard to size may induce unintentional selection for early age at maturity in Chinook (Hankin et al. 2009). An alternative, and relatively simple, mating strategy has been suggested for Chinook salmon to mitigate this concern, whereby no female is mated with a smaller male (except when the male is a jack). The California HSRG is intrigued by this concept but did not fully endorse it, instead preferring to recommend experimentally evaluating the protocol in a selected stock (late-fall Chinook salmon at Coleman NFH). Such a protocol would have to include a provision for incorporation of some jacks so as to avoid inducing selection on age distribution of the stock.

In addition, mating protocols must not substantially contribute to inbreeding in the stock. Inbreeding occurs when related individuals mate and produce offspring, with many of their gene copies then identical by descent. Inbreeding leads to the expression of deleterious recessive traits, reduces genetic diversity and has been shown to decrease fitness in salmonids dramatically. To address inbreeding concerns, the California HSRG considered the widely adopted breakpoints for effective population size (N_e>50 to avoid inbreeding depression, N_e>500 to maintain additive genetic variation, N_e>5,000 to allow for mutation and to maintain genetic variation at quasi-neutral loci; Frankel and Soule 1981, Lande 1995) to evaluate the adequacy of the numbers of spawners used or to help develop guidelines for when to consider factorial mating designs. In such natural populations, fish can choose mates with the appropriate level of relatedness and avoid severe inbreeding. Even so, some inbreeding in natural populations (e.g., that between non-sibling relatives) is not only unavoidable, but may serve a beneficial role. In hatcheries, natural mate choice does not operate, and higher rates of inbreeding can occur as a result. In large hatchery programs integrated with large natural populations, the proportion of inbred matings that occurs during hatchery spawning is relatively minor and controlling it is impractical. However, in smaller programs, or those integrated with a small natural population, it can be a substantial problem. For such programs, protocols must be in place to avoid inbreeding and reduce loss of genetic diversity due to inbreeding and genetic drift. Such techniques include multifactorial mating (i.e., splitting egg lots) and molecular genetic specification of mating partners, so-called genetic broodstock management. For salmon and steelhead propagation programs of all sizes, it is also important to ensure that male gametes are not mixed prior to or at the time of fertilization, as sperm competition can reduce the effective number of broodstock by skewing contribution of different males.

The potentially iteroparous nature of steelhead raises a unique set of issues regarding the disposition of fish trapped as part of broodstock collection efforts, since these fish may potentially return to spawn in subsequent years whether they are used as broodstock or not. There are two main issues to consider in an adult steelhead disposition plan: 1) reducing reproductive contributions of hatchery-origin fish in natural populations, and 2) avoiding selection against iteroparity in the hatchery stock and, therefore, the integrated population. The ESA-listed status of some of the hatchery stocks is also an important consideration in such a plan.

With all of this in mind, the California HSRG provides recommendations for the disposition of trapped steelhead for the six hatchery programs we reviewed. Note that the current Nimbus broodstock and a potential native Nimbus broodstock, to be used in the future per our other recommendations below, are treated separately in the plan and have different disposition recommendations.

The California HSRG steelhead disposition plan recommends that all natural-origin steelhead, male and female, spawned and unspawned, are released. Hatcheries should undertake extended reconditioning of spawned fish prior to release. Extended reconditioning means that fish are held until after the spawning season. A summary of the plan, with associated rationale, follows.

For the Klamath/Trinity programs, unspawned hatchery-origin fish should be released when it is determined that they will not spawn in natural areas that year, which requires extended reconditioning for males and stripping eggs followed by extended reconditioning for females. Preventing spawning of hatchery-origin fish in that year will reduce pHOS, whereas releasing them to potentially return in subsequent years will not result in selection against iteroparity. Spawned fish should be removed. This will prevent their subsequent reproduction in natural areas either that year (males) or in following years (both males and females). Since these fish are reproducing and broodstock will include a mix of fish that would have returned to spawn and those that would not, it should result in little selection against iteroparity. Fish that are iteroparous may have greater lifetime reproductive success than non-iteroparous fish, which would favor iteroparity, but any under-representation of these fish will be largely compensated for by only allowing iteroparous fish to spawn in the non-broodstock component of the trapped fish.

For the Central Valley programs, we recommend removal of all fish, spawned or unspawned, from the current Nimbus program. It is important to limit reproduction of this non-native stock in natural areas as much as possible and we are not concerned about selection against iteroparity in this stock. For the rest of the programs, including a future Nimbus program with a native broodstock, the recommendation for unspawned fish is the same as for the Klamath/Trinity programs: release steelhead after ensuring that they do not spawn in that season.

For spawned fish, however, there is the option to either remove or recondition them. The option to recondition steelhead is important because Coleman and Feather River stocks are ESA-listed and it may be problematic to remove them. If steelhead are released, extended reconditioning is necessary to prevent them from engaging in spawning activities again that year in either natural areas or the hatchery. The Mokelumne River stock is not ESA-listed, but a recent genetic analysis (Garza and Pearse unpublished data) shows that it is genetically derived from the Feather River Hatchery stock or otherwise very similar to it, and it should therefore be treated similarly to the ESA-listed stocks. Any future Nimbus stock should be of native origin and be treated similarly.

The California HSRG also recognizes that small hatchery programs and/or those that are integrated with small or ESA-listed populations must adopt best management practices that are essentially those of designated conservation programs; the California HSRG therefore employs the term conservation-oriented programs to refer to all such hatchery programs.

The specific standards that broodstock management must achieve are listed below.

Broodstock Source

- **Standard 1.1**: **Broodstock is appropriate to the basin and the program goals and should encourage local adaptation.**

    Guideline 1.1.1. Broodstock should be chosen from locally adapted stocks native to the basin and with life history characteristics appropriate for the program goals.

    Guideline 1.1.2. Broodstock should be representative of the natural population with which the hatchery program is integrated. Spatial distribution of the integrated population should not be based on straying associated with off-site releases.

Broodstock Collection

- **Standard 1.2**: **Trapping is done in such a way as to minimize physical harm to both broodstock and non-broodstock fish.**

- **Standard 1.3**: **Collection methods are appropriate for the program goals.**

    Guideline 1.3.1. Trapping locations should include mechanisms for collecting sufficient numbers and diversity of both hatchery- and natural-origin fish to meet program goals. If inadequate numbers of natural-origin fish are available with current collection methods, then additional collection methods are required.

- **Standard 1.4: Trapping is designed to collect sufficient fish as potential broodstock to be representative of the entire run timing and life history distribution of the population or population component with which it is integrated.**

    Guideline 1.4.1. Fish traps should be operated for at least the entire temporal period of the run and should not exclude fish with any particular life history characteristics. An exception to this guideline is allowable when non-representative broodstock collection is necessary to achieve program goals, such as separating broodstock of differing eco-types.

- **Standard 1.5**: **Hatcheries have effective facilities for the extended holding of unripe fish and males that will be used for multiple spawning.**

Guideline 1.5.1. Holding facilities in hatcheries should provide adequate space, water flows and temperature requirements to hold the expected number of unripe adult fish for extended periods of time with minimal hatchery-caused mortality (refer to Senn et al. 1984 for specific water quality, flow and temperature parameters).

Guideline 1.5.2. Holding facilities in hatcheries should permit appropriate antibiotic and/or chemical treatments when deemed necessary to control adult mortality or prevent vertical transmission of diseases to progeny.

Broodstock Composition

- **Standard 1.6**: **Broodstock is primarily comprised of fish native to the hatchery location, with incorporation of fish from other locations not exceeding the rate of straying of natural-origin fish.**

Guideline 1.6.1. Broodstock should originate in the subbasin in which the hatchery is located, except when estimates of natural straying from proximate locations are known, in which case, incorporation of returning adults from those locations should not exceed this natural stray rate.

Guideline 1.6.2. Until all off-site releases of Chinook salmon are eliminated in the entire Central Valley, coded wire tag analysis should be used at Feather River, Nimbus, Mokelumne and Merced hatcheries to identify stray hatchery-origin fish among those fish selected for broodstock. Strays from other hatchery programs should not be used as broodstock, or if eggs are collected from or fertilized by suck fish, they should be culled soon after spawning.

- **Standard 1.7: The levels of natural-origin broodstock are appropriate for program goals.**

Guideline 1.7.1. For conservation-oriented programs, the proportion of natural-origin broodstock proportions should be approaching 100 percent.

Guideline 1.7.2. For integrated programs, pNOB should be at least 10 percent to avoid run divergence. Higher pNOB may be applied to avoid/minimize domestication but should not be large enough to pose a demographic hazard to the natural population(s).

Guideline 1.7.3. For segregated programs where some natural-origin fish from original sources may be incorporated to maintain the genetic health of the hatchery stock, the number of natural-origin fish incorporated should not increase adverse effects on natural populations.

- **Standard 1.8: Fish from different runs are not crossed**.

Guideline 1.8.1. Hatcheries should employ effective methods to identify fish from different runs and avoid crossing them. Eggs produced by unintentionally crossing types should be culled.

- **Standard 1.9**: **Steelhead broodstock collection focuses on the anadromous life history. Integrated steelhead programs incorporate non-anadromous fish in a proportion not greater**

than their natural (pre-disturbance) abundance in the local population and commensurate with their reproductive contribution in the naturally spawning population when known. For segregated programs, only anadromous broodstock are used.

Guideline 1.9.1. Programs should incorporate an effective mechanism to identify non-anadromous (resident) individuals so as to control their rate of incorporation.

Guideline 1.9.2. Non-anadromous fish should only be incorporated in conjunction with a management plan that specifies maintenance or manipulation of life history diversity.

Guideline 1.9.3. Steelhead programs should retain a 16-inch cutoff to identify non-anadromous fish unless population-specific data are available.

- **Standard 1.10: For Chinook and coho salmon, fish from all age classes and sizes are incorporated into broodstock at rates that are commensurate with their relative reproductive success in natural areas, when known.**

Guideline 1.10.1. For Chinook salmon, the number of jacks to be incorporated into broodstock should not exceed the lesser of: 1) 50 percent of the total number of jacks encountered at the hatchery, and 2) 5 percent of the total males used for spawning.

Guideline 1.10.2. For Chinook and coho salmon, when the number of males available as broodstock is less than or equal to 50, or when less than or equal to 50 broodstock are used to accomplish specific program objectives, the acceptable number of two-year-olds is unlimited.

Guideline 1.10.3. For coho salmon, the number of jacks to be incorporated into broodstock should not exceed the lesser of: 1) 50 percent of the total number of jacks encountered at the hatchery, and 2) 10 percent of the total males used for spawning.

Guideline 1.10.4. For all programs, broodstock should be selected so as to not induce changes in the maturation schedule of the natural population with which the hatchery population is integrated.

Mating Protocols

- **Standard 1.11**: **The program uses genetically conscious mating protocols to control or reduce inbreeding and genetic drift (random loss of alleles), to retain existing genetic variability and avoid domestication, while promoting local adaptation for integrated stocks.**

Guideline 1.11.1. For broodstock numbers greater than or equal to 250 females, matings should be 1 male x 1 female, with each 1:1 spawn in a single spawning pan. Limit the reuse of males to unavoidable situations (e.g., where loss of eggs might result if males are not reused and loss of eggs threatens program goals).

Guideline 1.11.2. For broodstock number between 50 and 250 females, female's eggs should be split into 2 egg lots and each lot should be fertilized with a different male in a separate pan. Limit the reuse of males to two egg lots (or the equivalent of one female), except for unavoidable situations (e.g., where loss of eggs might result if males are not reused and loss of eggs threatens program goals).

Guideline 1.11.3. For broodstock numbers less than 50 females, egg lots should be split into greater than 2 with each lot fertilized by a different male in a separate pan. Limit the reuse of males to no more than 4 egg lots, but ideally males will not be reused.

Guideline 1.11.4. For steelhead, if both non-anadromous and anadromous parents are spawned as broodstock, a non-anadromous fish should never be mated with another non-anadromous fish.

Guideline 1.11.5. For integrated programs including conservation programs:

- Maximize incorporation of natural-origin fish into broodstock to the extent that the number of natural-origin broodstock used in the hatchery program does not substantially reduce the population viability of the donor stock.

- Hatchery-origin fish should be preferentially mated with natural-origin fish. Hatchery origin x hatchery origin matings should be considered least desirable.

- In conservation-oriented programs, relatedness between mated pairs may be more important than hatchery vs. natural origin.

- **Standard 1.12**: **Inbreeding is avoided.**

Guideline 1.12.1. For conservation-oriented programs, populations that have experienced known bottlenecks, populations that exhibit evidence of inbreeding depression, and programs where broodstock numbers are regularly less than or equal to 50 individuals, zero matings should be between fish related at the half-sibling level or higher.

Guideline 1.12.2. For conservation-oriented programs, genetic broodstock management techniques (e.g., genetically-based spawner candidate lists, individual spawner marking and holding) should be used to reduce mating of related individuals.

Guideline 1.12.3. For conservation-oriented programs that cannot institute genetic broodstock management but where inbreeding is of concern, or as a transition protocol prior to eventual genetic broodstock management, mate hatchery-origin x natural-origin fish as frequently as possible to reduce inbreeding potential. When possible and appropriate, mate individuals from different cohorts.

Guideline 1.12.4. Census size of small natural populations should be increased in order to reduce the probability of inbreeding.

Guideline 1.12.5. Assume that inbreeding is an issue, especially for small populations or small numbers of broodstock, to avoid unintentional diversity loss (Hedrick and Kalinowski 2000).

- **Standard 1.13**: **The proportion of natural-origin fish used as broodstock does not negatively affect the long-term viability of the donor population. For conservation-oriented programs, extinction risk of the ESU may take precedence.**

  Guideline 1.13.1. For integrated programs, the number of natural-origin broodstock should not substantially decrease the viability of the donor stock.

  Guideline 1.13.2. For conservation-oriented programs, maximize incorporation of natural-origin fish into broodstock. Generally, the number of natural-origin broodstock should not decrease viability of the donor stock. However, some conservation-oriented programs may need to take the entire run into the hatchery to protect existing diversity of very small, very threatened, high value (e.g., unique diversity element) stocks.

  Guideline 1.13.3. For segregated programs, only hatchery-origin fish should be used and indigenous natural-origin fish should not be used as broodstock.

Steelhead Spawner Disposition

- **Standard 1.14**: **For steelhead hatchery programs, the post-spawning disposition of mature fish that are collected as potential broodstock are appropriate to program goals**.

  Guideline 1.14.1. Natural-origin fish from integrated programs will be reconditioned and released if spawned.

  Guideline 1.14.2. Hatchery-origin fish will be disposed of in a manner consistent with identified program goals and using methods that result in no or minimal effects to natural-origin fish.

4.2 Program Size and Release Strategies

Most salmon and steelhead programs in California's Central Valley and Klamath/Trinity River Basin were established as "mitigation" programs to replace anadromous fish production lost due to construction of dams that block upstream migration. Production goals for these and other programs (e.g., harvest augmentation and conservation) typically have been expressed in terms of numbers of juveniles released without specifying whether or how this hatchery production contributes to adult recruits, harvest, conservation, or other purposes. Such juvenile production goals alone are not acceptable. Although releasing juveniles is the means of producing adult fish that contribute to harvest, conservation, and other values, juveniles released is not a suitable endpoint in itself. Instead, hatchery goals must be expressed as adult production goals. In California, these are best expressed as age-3 pre-fishery ocean recruitment (Chinook salmon) or adult freshwater returns (coho salmon, steelhead). Additional, qualitative goals for integrated or conservation-oriented programs should include perpetuation of attributes such as size and age composition and run timing for the integrated or target natural populations.

Program size and release strategy can have important conservation effects on ecological (competition, direct or indirect predation, behavior or disease) or genetic interactions between hatchery-and natural-origin fish. Ecological interactions can be positive or negative; however, the standards and guidelines focus on the latter because negative effects are more prevalent and compromise conservation efforts. Potential examples of positive ecological effects of hatchery-origin fish are nutrient enrichment in low-productivity streams, and decreased predation rates on natural-origin fish when predators are swamped or satiated with hatchery-origin fish. Carcasses of hatchery-origin adults can increase nutrient levels in the stream (whether from fish that die in the stream or from fish that return to the hatchery, are killed, and are then distributed to the stream). Such nutrient enhancement has been shown to benefit natural-origin salmonids in low-productivity streams in the Pacific Northwest. The practice may warrant evaluation in California streams; however, productivity in many streams may already be high and care should be taken to avoid over-enrichment or exacerbation of disease problems (HSRG 2009, Appendix A). Another potential beneficial effect, depensatory predation, has long been prominent in theoretical considerations. However, the California HSRG is not aware that it has been documented for salmon or steelhead. Indeed, empirical data seem to show increased predation rates due to predator attraction rather than reduced predation rates (e.g., Nickelson 2003; Kostow 2009). Excessive aggregations of predators more likely call for reduced program size or altered time, date or location of release rather than expanded program size (Nickelson 2003; Chilcote et al. 2011). Any efforts to reduce predation rates by releasing more hatchery fish must be rigorously evaluated before implementation and are not recommended by the California HSRG at this time.

Survival of juvenile fish, economic efficiency for integrated hatchery programs, and production and viability for affected natural-origin populations all decline as numbers of fish approach or exceed carrying capacity of the river, estuary, or marine rearing areas. The California HSRG recommends that hatchery programs be sized so that overall populations of natural- and hatchery-origin fish remain within the carrying capacity of the available habitat. Although mitigation programs may simply replace natural-origin fish that were eliminated by dam construction and formerly fell within a system's carrying capacity, these programs might exceed present-day carrying capacities, which often are diminished by reduced flows, other habitat degradation or loss, or climate change. The California HSRG encourages all efforts to improve carrying capacity of these systems. Furthermore, the number or biomass of hatchery fish (smolts) required to produce a given number of adults seems to be several times greater than for comparable natural-origin fish. Although limitations in knowledge of carrying capacities are problematic, the issue should be revisited regularly as new knowledge is developed. During the interim, models and procedures are available for exploring the issue (e.g., Mobrand et al. 1997; Weber and Fausch 2005; Scheuerell et al. 2006; Beauchamp et al. 2007; Duffy 2009; HSRG 2009, Appendix C; Liermann et al. 2010).

Annual and decadal-scale variation in freshwater and ocean conditions often prevent programs from achieving their targets. Managers should not respond to a period of decreasing marine survival by releasing increased numbers of hatchery fish without considering the expected increase of hatchery-origin adults in natural spawning areas and whether freshwater carrying capacities may have concomitantly declined and deleterious ecological interactions intensified (Beamish and Bouillon 1993).

Program goals and objectives may create detrimental conditions for natural fish populations when the genetic effects of interbreeding between hatchery- and natural-origin fish are not recognized (Reisenbichler et al. 2003; Araki et al. 2008; HSRG 2009). Fishery and hatchery managers need to recognize and provide a balance between mitigation responsibilities and the number of hatchery-origin fish returning to spawn in natural areas. Program sizes and release strategies that result in inappropriately high levels of pHOS are undesirable.

Release strategy also can be problematic when hatchery fish are released at sizes and dates that differ markedly from those of natural-origin fish. Extended rearing and fall ("yearling") release of subyearling Chinook salmon is such a strategy, because almost all naturally spawned fall Chinook juveniles in

California emigrate in their first spring at much smaller sizes. Fall releases are expected to lead to increased domestication due to the more extended duration of rearing in the hatchery and because juvenile fish emigrating in the fall experience different developmental and environmental conditions than do those emigrating in the spring. Yearling releases have also been shown to change the size and age at maturity of adults (Hankin 1990, Hankin and Logan 2010). The practice has been favored because it greatly increases smolt-to-adult survival and eliminates most competitive and behavioral interactions with juvenile natural-origin Chinook salmon, as most of these natural-origin fish have emigrated months before yearlings are released. Managers who elect to release a portion of their juveniles in the fall should distinctively mark all of these fish so that they can be readily identified as adults. Such fall released fish should be removed to the extent possible and excluded from the hatchery broodstock. Unfortunately, the distinctive mark will not totally eliminate some of the yearling-released fish from spawning in natural areas.

Release strategy can also affect homing and straying. Throughout this report, straying of hatchery fish is defined as failure of hatchery-origin fish to return to the hatchery from which they originated or to the watershed in the immediate vicinity of the hatchery. When hatchery fish are released on-site (at or near the hatchery of origin), most fish will effectively home back to this local area. When fish are released off-site, often at distances far from hatcheries of origin, many of these fish enter spawning streams or hatcheries other than where they were reared (Hallock and Reisenbichler 1979; Quinn 1993; Chapman et al. 1997). In such cases, straying of hatchery-origin fish, with consequent interbreeding with natural-origin fish, may constrain genetic divergence among populations and compromise local adaptation. Hatchery-origin fish may also have reduced reproductive performance (compared to natural fish) when they interbreed with one another or with natural-origin fish on spawning grounds.

When hatchery-origin fish that have been released on-site return to the watershed in the vicinity of the hatchery but do not enter the hatchery of origin, they may generate high pHOS in the population with which they are integrated, even though straying rates are very low. Since excessive pHOS can conflict with program goals, it is therefore important that hatchery ladders and other attraction devices are operated so as to encourage the highest possible percentage of returning hatchery-origin adults to enter hatchery facilities. If pHOS in this area consistently exceeds management targets and/or thresholds, consideration should be given to reducing program size. Among situations where program size is reduced or a program is eliminated, in no case should such change result in relinquishment of mitigation responsibility. If changes in hatchery program operations do not achieve pHOS goals, additional harvest or manual removal of hatchery-origin fish may also be a means to control pHOS.

The specific standards that program size and release strategies must achieve are listed below.

Program Size

- **Standard 2.1: Program size is established by a number of factors including mitigation responsibilities, societal benefits, and effects on natural fish populations.**

  Guideline 2.1.1. Program purpose should be identified and expressed in terms of measurable values such as harvest, conservation, hatchery broodstock, education, or research.

- **Standard 2.2: Program size is measured as adult production.**

  Guideline 2.2.1. Production goals (program size) should be expressed in terms of number of adult recruits just prior to harvest (age-3 ocean recruits for Chinook salmon in California) or at freshwater entry (age-3 adults returning to freshwater for coho; anadromous adults returning to freshwater for steelhead).

- **Standard 2.3: Annual assessments are made to determine if adult production goals are being met.**

  Guideline 2.3.1. Consider variation in environmental conditions when evaluating the performance of a hatchery program, recognizing that poor environmental conditions in one or more years can temporarily preclude attainment of production goals in the best of hatchery programs and do not necessarily call for modification of the hatchery program size or release strategies.

  Guideline 2.3.2. A program that consistently fails to achieve its adult production goals by a substantial margin, especially if it fails to meet broodstock needs, should be judged a failure and remedial action should be taken. Naturally spawning populations should not be depleted to maintain such failed programs.

  Guideline 2.3.3. A program that consistently exceeds its adult production goals by a substantial margin should be reduced in size.

- **Standard 2.4: Program size is based on consideration of ecological and genetic effects on naturally spawning populations, in addition to harvest goals or other community values.**

  Guideline 2.4.1. If deleterious ecological or genetic effects result in substantial reduction of productivity for high-priority naturally spawning populations, and these effects cannot be alleviated by other changes, program size should be reduced. Under certain circumstances, conservation-oriented programs might increase program size to eliminate deleterious effects, for example to reduce inbreeding.

  Guideline 2.4.2. Managers should consider program changes, including reducing program size, to mitigate disease issues. Large numbers of naturally spawning fish may increase the incidence of *C. shasta* disease through the release of myxospores from carcasses, which in turn increases the probability of severe juvenile infection rates the following spring and summer.

- **Standard 2.5: Natural spawning populations not integrated with a hatchery program should have less than five percent total hatchery-origin spawners (i.e., pHOS less than five percent). Spawners from segregated hatchery programs should be absent from all natural spawning populations (i.e., pHOS from segregated programs should be zero).**

Release Strategy

- **Standard 2.6: Size, age, and date at release for hatchery-origin fish produce adult returns that mimic adult attributes (size at age and age composition) of the natural population from which the hatchery broodstock originated (integrated program) or achieve some other desired size or condition at adult return (segregated programs).**

  Guideline 2.6.1. Size and date at release should generally mimic size and period of emigration of naturally migrating smolts in the river system on which a hatchery is located. Deviations from this guideline require substantial justification that addresses both the ecological and genetic consequences of such a strategy, particularly when extended rearing is proposed. Consider retaining some flexibility in release date to take advantage of beneficial flow, turbidity, or temperature conditions without increasing deleterious ecological effects on natural populations.

Guideline 2.6.2. Size and date at release should ensure physiological readiness to migrate rapidly to the sea (to limit predation on or competition with natural-origin fish).

Guideline 2.6.3. When hatchery fish are released at sizes and dates that substantially differ from those of the natural-origin population with which they are integrated, they should all be distinctively marked so that they can be recognized as adults and excluded from hatchery broodstock and spawning in natural areas.

Guideline 2.6.4. For steelhead, size (mean and frequency distribution) and date at release should be managed to limit residualization or extended rearing near the release site prior to emigration.

- **Standard 2.7: Juveniles are released at or in the near vicinity of the hatchery.**

4.3 Incubation, Rearing and Fish Health Management

State-operated anadromous fish hatcheries in California are managed under the statutes and policies of the Fish and Game Code and the Fish and Game Commission. Consistent with these policies and procedures, anadromous fish hatcheries use a goals and constraints document for each facility that provides general directions for the production of fish. Typically, the goals and constraints provide broad guidance and include topics such as broodstock selection, mating and spawning protocols, and disposition of excess fish and eggs (CDFG/NMFS 2001). A "working" fish health policy is provided in the California Department of Fish and Game Operations Manual; however, specific standards and actions have not been prepared or adopted.

The Bonneville Power Administration developed regional policies and procedures for operation of anadromous fish hatcheries in the Columbia River Basin. This document, *Integrated Hatchery Operations Team 1995 Policies and Procedures for Columbia Basin Anadromous Salmonid Hatcheries* (IHOT 1995), includes comprehensive policy guidance and standards for regional coordination, performance, fish health, genetics, and ecological interactions for hatchery programs. The California HSRG reviewed the report and concurred that the fish health and culture standards established by the IHOT are generally applicable to anadromous fish hatcheries in California.

The California HSRG recommends adopting the IHOT standards with minor modifications that address the current and unique conditions of California's anadromous fish hatchery programs. The California HSRG recommends that the State of California develop a comprehensive Fish Health Policy and Biosecurity Plan for all anadromous fish hatchery programs. Additionally, a Fish Health Management Plan (FHMP) should be developed for ESA-listed species or where fish disease poses a risk to hatchery or natural fish populations. Suggested protocols to control BKD and for iodophor disinfection of eggs are presented in Appendix V.

There are two federally operated anadromous fish hatcheries in California, Coleman National Fish Hatchery and its satellite facility, Livingston Stone National Fish Hatchery. These facilities are operated under the USFWS Aquatic Animal Health Policy (USFWS 2004), as well as all applicable federal and state laws pertaining to hatchery operations. The USFWS Aquatic Animal Health Policy includes a chapter from the American Fisheries Society's "Fish Health Blue Book", entitled *Standard Procedures for Aquatic Animal Health Hatchery Inspections*. This widely accepted "Hatchery Inspection Manual" describes procedures and protocols for conducting fish health inspections at anadromous fish hatcheries.

Written fish rearing protocols provide a training tool for employees, and provide standardization between hatchery programs or facilities that ensure they are operated in a cost-effective and efficient manner. *Trout and Salmon Culture (Hatchery Methods) - Fish Bulletin 164* (Leitritz and Lewis 1976) provides information related to anadromous fish culture and is used by personnel at the State of California operated fish hatcheries. New techniques and procedures related to fish rearing have been developed since its publication and the California HSRG recommends updating the information in Fish Bulletin 164 with more current protocols or adopting an alternative updated manual.

The California HSRG believes that biologists and hatchery managers should use Best Management Practices that help ensure the conservation of both natural and hatchery produced fish through the responsible operation of hatcheries. The rationale, benefits, risks, and expected outcomes of any deviations from established best management practices for fish culture and fish health management should be clearly articulated in a Hatchery Genetic and Management Plan, Fish Health Management Plan, or a similar plan.

The standards and guidelines presented in this section are intended to outline processes for hatchery operations once broodstock have been collected and artificially spawned, and production numbers have been established. The California HSRG believes that maintaining and restoring anadromous fishery resources, including both hatchery- and natural-origin populations, requires the protection of existing and future fish stocks from the importation, dissemination, and amplification of pathogens and diseases. To help achieve this goal, the California HSRG believes that a formal Fish Health Policy that describes prescriptions for monitoring, therapeutic treatments, and a definite course of action when disease epizootics occur is needed to help managers and fish health specialists make decisions.

The specific standards that incubation, rearing and fish health management must achieve are listed below.

Fish Health Policy

- **Standard 3.1: Fishery resources are protected, including hatchery and natural fish populations, from the importation, dissemination, and amplification of fish pathogens and disease conditions by a statewide fish health policy. The fish health policy clearly defines roles and responsibilities, and what actions are required of fish health specialists, hatchery managers, and fish culture personnel to promote and maintain optimum health and survival of fishery resources under their care. The Fish Health Policy includes the California HSRG's Bacterial Kidney Disease (BKD) management strategy (see Appendix V)**

  Guideline 3.1.1. Develop and promulgate a formal, written fish health policy for operation of DFG anadromous fish hatcheries through the Fish and Game Commission policy review process. Such a policy may be formally identified in regulatory code, Fish and Game Commission policy, or in the Department of Fish and Game Operations Manual.

Hatchery Monitoring by Fish Health Specialists

- **Standard 3.2: Fish health inspections are conducted annually on all broodstocks to prevent the transmission, dissemination or amplification of fish pathogens in the hatchery facility and the natural environment, as follows:**

  a) Inspections are conducted by or under the supervision of an AFS certified fish health specialist or qualified equivalent. For state-operated anadromous fishery programs, specific standards and qualifications are to be defined during development of a fish health policy.

  b) Annual inspections follow AFS 'Fish Health Bluebook' guidelines for hatchery inspections.

  c) Broodstocks are examined annually for the presence of BKD and where the causative bacterium *Renibacterium salmoninarum* recurs, the California HSRG's control strategy will be implemented.

  Guideline 3.2.1. Number of individuals examined per stock may vary according to management objectives, but the minimum number should be at the 5 percent Assumed Pathogen Prevalence Levels (APPL), generally 60 fish.

  Guideline 3.2.2. Methodology and effort should meet or exceed AFS "Fish Health Blue Book" procedures.

  Guideline 3.2.3. Develop a fish health management plan to address BKD when present (see California HSRG BKD protocols – Appendix V).

- **Standard 3.3: Frequent routine fish health monitoring is performed to provide early detection of fish culture, nutrition, or environmental problems, and diagnosis of fish pathogens, as follows:**

  a) Monitoring is conducted by or under the supervision of an AFS certified fish health specialist or qualified equivalent.

  b) Monitoring is conducted on a monthly, or at least bi-monthly basis, for all anadromous species at each hatchery facility.

  c) A representative sample of healthy and moribund fish from each lot is examined. Results of fish necropsies and laboratory findings are reported on a standard fish health monitoring form.

  Guideline 3.3.1. The frequency of monitoring should depend on the disease history of the facility, the importance of the species being reared, and the variable environmental conditions that occur in a particular rearing cycle (e.g., elevated water temperatures in spring and summer months).

  Guideline 3.3.2. Review fish culture practices with manager including nutrition, water flow and chemistry, loading and density indices, handling methods, disinfection procedures, and preventative treatments.

  Guideline 3.3.3. The number of fish examined is at the discretion of the fish health specialist.

- **Standard 3.4: All antibiotic or other treatments are pre-approved by the appropriate fish health specialist for each facility. If antibiotic therapy is advised, fish health personnel will culture bacterial pathogens to verify drug sensitivity. Post-treatment examinations of treated units are conducted to evaluate and document efficacy of antibiotic or chemical treatments.**

  Guideline 3.4.1. Re-occurring mortality, or repeated use of antibiotics or chemicals to control mortality, generally indicates that underlying fish culture, nutritional or environmental problems are not being fully remediated and should be further investigated.

- **Standard 3.5: Examinations of fish are conducted prior to release or transfer to ensure fish are in optimum health condition, can tolerate the stress associated with handling and hauling during release, and can be expected to perform well in the natural environment after release.**

  Guideline 3.5.1. Review transportation protocols with appropriate hatchery staff to ensure fish are handled and hauled in a manner that minimizes stress and provides the best opportunity for survival.

- **Standard 3.6: Annual reporting standards and guidelines will be followed for fish health reports, including results of adult inspections, juvenile monitoring and treatments administered, and pre-liberation examinations for each hatchery program. A cumulative five year disease history will be maintained for each program and reported in annual or other appropriate facility reports.**

  Guideline 3.6.1. Include an annual fish disease assessment for each program in the hatchery annual report (see Standard 3.14).

- **Standard 3.7: Fish health status of stock is summarized prior to release or transfer to another facility.**

  Guideline 3.7.1. Written reports should include findings of monitoring and laboratory results. For fish transfers, feeding regime and current growth rate, and any other information necessary to assist fish culturists at the receiving station, should be provided.

Facility Requirements

- **Standard 3.8: Physical facilities and equipment are adequate, and operated in a manner that promotes quality fish production and optimum survival throughout the rearing period. If facilities are determined to be inadequate to meet all program needs, and improvements are not feasible, then the hatchery program(s) must be re-evaluated within the context of what the facility can support without compromising fish culture and/or fish health, or causing adverse interactions between hatchery and natural fish populations.**

  Guideline 3.8.1. Facilities and equipment should allow: effective capture and holding of adults, appropriate incubation and rearing units with adequate capacity to meet program size, equipment and/or methods for effective predator control, and release of fish without undue stress or harm (see Section 4.1.1, Broodstock Management for additional adult holding requirements).

Guideline 3.8.2. Hatchery managers, fish health specialists, biologists and fish culturists should identify facility/equipment deficiencies that constrain hatchery operations and/or prevent the facility from meeting program goals. Such facility deficiencies or constraints should be communicated to resource managers for remedy or redress.

Guideline 3.8.3. When physical facility and/or equipment needs exist, resource managers and appropriate funding source(s) should actively pursue facility maintenance, upgrades or equipment needs through a prioritized budget process. In the interim, modifications should be made to program goals to minimize adverse impacts to fish culture and/or fish health.

- **Standard 3.9: Distinct separation of spawning operations, egg incubation, and rearing facilities is maintained through appropriate sanitation procedures and biosecurity measures at critical control points to prevent potential pathogen introduction and disease transmission to hatchery or natural fish populations, as follows:**

a) Disinfect/water harden eggs in iodophor prior to entering “clean” incubation areas. In high risk situations, disinfect eggs again after shocking and picking, or movement to another area of the hatchery.

b) Foot baths containing appropriate disinfectant will be maintained at the incubation facility’s entrance and exit. Foot baths will be properly maintained (disinfectant concentration and volume) to ensure continual effectiveness.

c) Sanitize equipment and rain gear utilized in broodstock handling or spawning after leaving adult area.

d) Sanitize all rearing vessels after eggs or fish are removed and prior to introducing a new group.

e) Disinfect equipment, including vehicles used to transfer eggs or fish between facilities, prior to use with any other fish lot or at any other location. Disinfecting water should be disposed of in properly designated areas.

f) Sanitize equipment used to collect dead fish prior to use in another pond and/or fish lot.

g) Properly dispose of dead adult or juvenile fish, ensuring carcasses do not come in contact with water supplies or pose a risk to hatchery or natural populations.

Guideline 3.9.1. Use dedicated equipment and rain gear that is not moved between adult spawning, incubation and rearing areas of the hatchery; otherwise, thoroughly scrub and disinfect gear when moving between these areas.

Guideline 3.9.2. A critical control point is defined as the physical location where pathogen containment occurs from a "dirty" to a "clean" area (i.e., between functional areas such as spawning and incubation). In addition to egg disinfection, ensure that spawning buckets/trays are surface-disinfected before entering incubation area.

- **Standard 3.10: All hatchery water intake systems follow federal and state fish screening policies.**

  Guideline 3.10.1. Follow existing statutes, including NEPA, CEQA, ESA, CESA, and current court decisions.

Fish Health Management Plans

- **Standard 3.11: Fish Health Management Plans (FHMP) similar to or incorporated within an HGMP have been developed. The FHMP will:**

  a) Describe the disease problem in adequate detail, including assumptions and areas of uncertainty about contributing risk factors.

  b) Provide detailed remedial steps, or alternative approaches and expected outcomes.

  c) Define performance criteria to assess if remediation steps are successful and to quantify results when possible.

  d) Include scientific rationale, study design, and statistical analysis for proposed studies aimed at addressing disease problems or areas of uncertainty pertaining to disease risks.

  Guideline 3.11.1. Compliance with the FHMP should be reviewed annually, through the hatchery coordination team, and include any new data or information that may inform actions or decisions to address disease concerns.

Water Quality

- **Standard 3.12: Water chemistry and characteristics at any new hatchery site meet the water quality required by salmonids, as identified in Hatchery Performance Standards (IHOT 1995) or a comparable reference such as Fish Hatchery Management (Wedemeyer 2001).**

- **Standard 3.13: Existing facilities strive for suggested water chemistry and characteristics (IHOT 1995, Wedemeyer 2001) which may require water filtration and disinfection, additional heating or cooling, degassing and/or aeration, or other modifications to the quantity and quality of an existing water supply, as follows:**

  a) Pathogen-free water supplies will be explored for each facility, particularly for egg incubation and early rearing.

  b) Water supplies must provide acceptable temperature regimes for egg incubation, juvenile rearing and adult holding.

  c) Water supplies will have appropriate water chemistry profiles, including dissolved gases: near saturation for oxygen, and less than saturation for nitrogen.

  d) Water supplies for egg incubation must not contain excessive organic debris, unsettleable solids or other characteristics that negatively affect egg quality and survival.

  Guideline 3.13.1. When surface water is used, a biosecurity evaluation should be performed, and water supplies protected to the extent feasible, to avoid direct contamination of hatchery water supply by potential disease vectors (i.e. live fish, amphibians, birds, or mammals).

Guideline 3.13.2. Cooling and/or heating of water supplies may be necessary to meet water quality standards and program goals, for example, when egg incubation and early rearing water temperatures are too low in fall and winter months to consistently achieve desired fish size-at-release.

Guideline 3.13.3. Degassing columns or aeration devices may be necessary to meet water quality standards throughout the rearing cycle.

Guideline 3.13.4. If unable to remediate siltation problems for egg incubation, alternative incubation sites, water supplies, or incubation methods should be considered.

Best Management Practices

- **Standard 3.14: The rationale, benefits, risks, and expected outcomes of any deviations from established best management practices[5] for fish culture and fish health management are clearly articulated in the hatchery operational plan (including specific fish culture procedures), Hatchery and Genetic Management Plan (HGMP), Fish Health Management Plan, the hatchery coordination team process, and/or in annual written reports.**

Guideline 3.14.1. Develop required plans.

- **Standard 3.15: Information on hatchery operations is collected, reviewed, and reported in a timely, consistent and scientifically rigorous manner (see requirements and list of reporting parameters in Section 4.4, Monitoring and Evaluation (M&E)).**

Guideline 3.15.1. An annual report containing monitoring and evaluation information (see M&E standards), including pathogen prevalence, fish disease prevalence, and treatment efficacies, should be produced in a time such that the information can be used to inform hatchery actions during the following brood cycle.

- **Standard 3.16: Eggs are incubated using best management practices and in a manner that ensures the highest survival rate and genetic contribution to the hatchery population, as follows:**

a) Eggs are incubated at established temperatures, egg densities, and water flows for specific species. Appropriate egg incubation parameters are identified in Hatchery Performance Standards (IHOT 1995, Chapter 4) or Fish Hatchery Management (Wedemeyer 2001).

b) Incubation techniques should allow for discrimination of individual parents/families where required for program goals (e.g., for conservation-oriented programs and steelhead programs, or to exclude families for genetic (hybridization) or disease culling purposes).

c) Eggs in excess of program needs are discarded in a manner that is consistent with agency policies and does not pose disease risks to hatchery or natural populations.

---

[5] Best management practices are procedures for operating hatchery programs in a defensible scientific manner to: 1) utilize well established and accepted fish culture techniques and fish health methodologies to ensure hatchery populations have the greatest potential to achieve program goals and, 2) minimize adverse ecological interactions between hatchery and natural-origin fish.

Guideline 3.16.1. Culling should be done to minimize unintentional selection.

Guideline 3.16.2. Excess eggs are culled in a manner that does not eliminate representative families or any temporal segment of the run; and culled in portions that are representative of the entire run. Culling may be done to change the variance in family size.

Guideline 3.16.3. Non-representative culling may occur to achieve specific program goals, but must be justified based on genetic considerations of maintaining or rebuilding desired characteristics of the spawning stock.

Guideline 3.16.4. Eggs, fry, or juvenile fish in excess of production needs are disposed of in a manner that is consistent with agency policies on egg culling and fish disposal and will not be released, and should have no effects on natural populations.

Guideline 3.16.5. For conservation-oriented programs, individual reproductive output should be as close to equivalent as possible, while avoiding selection for egg size and age at maturity, and not unduly reducing overall production. These stipulations generally require that families are kept separate until staff can move eyed eggs for separate rearing for specific program types. Avoid loss of within-population diversity resulting from reduced effective population size in the hatchery stock.

- **Standard 3.17: Fish are reared using best management practices and in a manner that promotes optimum fish health to ensure a high survival rate to the time of release, and provides a level of survival after-release appropriate to achieve program goals, while minimizing adverse impacts to natural fish populations, as follows:**

a) Fish performance standards (i.e., species-specific metrics for size, weight, condition factor, and health status) will be established for all life stages (fry, fingerling, and yearling) at each facility.

b) Fish nutrition and growth rates are maintained through the proper storage and use of high quality feeds. Appropriate feeding rates will be closely monitored and adjusted as needed to accommodate fish growth/biomass in rearing units.

c) Juvenile fish will be reared at density and flow indices and temperature that promote optimum health. Appropriate density and flow requirements for anadromous fish are identified in Hatchery Performance Standards Policy (IHOT 1995, Chapter 4) or in a comparable reference such as Fish Hatchery Management (Wedemeyer 2001).

d) Appropriate growth strategies will be developed, with particular attention to photoperiod, temperature units and feeding rates to optimize parr-to-smolt transformation, to ensure juvenile fish reach target size-at-release and are physiologically ready to out-migrate and survive salt-water entry.

Guideline 3.17.1. Feeding practices should supply feed at a rate that is quickly consumed by juvenile fish, and does not permit excess feed to accumulate in rearing units. Excess or uneaten food has a high potential to increase organic loads in the rearing unit that can lead to fish pathogen amplification and disease outbreaks.

Guideline 3.17.2. Fish Health specialists should be promptly contacted when fish feeding behavior appears abnormal or when fish stop feeding.

Guideline 3.17.3. Stress-induced infections or diseases, related to crowding or high rearing densities, should be minimized to promote optimal growth, and to avoid excessive use of therapeutics (antibiotic medicated feed or chemical treatments).

Guideline 3.17.4. Rearing strategies will optimize the physical layout and use of rearing units at the facility to minimize handling of juvenile fish for inventory, transfer between rearing units, or tagging purposes. Preferably, fish are placed in units that allow adequate space and flows to permit extended periods of growth with no handling.

Guideline 3.17.5. Steelhead size at release should follow guidelines established in IHOT 1995 (Table 16, Chapter 4-Hatchery Performance Standards Policy), or guidelines established through program-specific experimental management strategies, but should not substantially alter the natural maturation schedule of the population from which broodstock originate.

4.4 Monitoring and Evaluation

Monitoring and evaluation must be recognized as an essential component of all anadromous fish hatchery programs in California. Monitoring and evaluation are necessary to determine the quality of fish stocks, to assess impacts of hatchery programs on natural populations, and to determine how well hatcheries achieve their specified goals and objectives. Effective monitoring and evaluation provides accurate, timely, and objective information collected within a sound scientific framework. Despite the importance of hatchery monitoring and evaluation, it has generally received insufficient emphasis at California's anadromous fish hatcheries.

In this section, we focus on eight central topics: (1) the need to prepare a Hatchery and Genetic Management Plan (i.e., a detailed operational plan) or similar document for each hatchery program; (2) the need to form, for each hatchery program, an active and independent Monitoring and Evaluation Program to assess hatchery performance and impacts; (3) the need to develop Hatchery Coordination Teams to bring together specialized expertise from a broad diversity of disciplines to enable more informed decisions and better coordinated hatchery management; (4) in-hatchery monitoring, data collection, and reporting associated with fish propagation and culture; (5) monitoring, data collection, and reporting associated with hatchery juvenile post-release emigration; (6) marking and tagging programs designed to achieve various species-specific standards to evaluate the performance and impacts of hatchery fish; (7) monitoring, data collection, and reporting associated with adult fishery contributions and escapement; and (8) evaluation standards that allow assessment of hatchery program performance with respect to operational goals (e.g., adult recruitment) and societal benefits.

Hatchery and Genetic Management Plans

Hatchery and Genetic Management Plans (HGMPs) are described in the final salmon and steelhead 4(d) rule (July 10, 2000; 65 FR 42422) and are used as a mechanism to address the take of listed species that may occur as a result of artificial propagation activities. The NMFS uses the information provided by HGMPs to evaluate the impacts on anadromous salmon and steelhead listed under the ESA and, in certain situations, the HGMPs will apply to the evaluation and issuance of ESA Section 10 take permits. Completed HGMPs may also be used for regional fish production and management planning by federal, state, and tribal resource managers. The primary goal of the HGMP is to devise biologically based artificial propagation management strategies that ensure the conservation and recovery of listed ESUs. The HSRG believes HGMPs should be prepared for all hatchery programs.

HGMPs include a description of hatchery facilities, operational protocols and the benefits derived from each hatchery propagation program, as well as assessments of the effects of the program on naturally produced fish. An addendum to the HGMP template may be used, when appropriate, to describe impacts of salmonid propagation programs on other aquatic and terrestrial organisms. The detailed descriptions and operational protocols provided in HGMPs also help to guide adaptive management decisions made at the hatchery level and provide accountability for deviations from established operational protocols.

- **Standard 4.1: Each hatchery program is thoroughly described in a detailed operational plan such as an HGMP or Biological Assessment. Operational plans are regularly updated to reflect updated data, changes to goals and objectives, infrastructure modifications, and changing operational strategies.**

  Guideline 4.1.1. Funding entities should provide the necessary resources to prepare and implement HGMPs for all California anadromous fish hatchery programs.

Hatchery Evaluation Programs

Every anadromous fish hatchery in the State of California should have a dedicated Monitoring and Evaluation (M&E) program. M&E programs perform a critical role in assessing whether hatcheries are achieving their goals and whether these goals are achieved with a minimum of negative impacts on natural populations of anadromous fish. Improving our knowledge of natural population responses to hatchery activities is essential and, when appropriate, may lead to recommended changes in hatchery operations that would reduce negative effects and possibly also increase benefits. M&E programs provide an important information feedback loop that promotes hatchery operation on the basis of scientific management principles and practices. M&E programs can also be used to develop and implement processes for hatcheries to respond to requests for experimental fishes, samples, and data.

- **Standard 4.2: For each hatchery, a Monitoring and Evaluation program dedicated to reviewing the hatchery's achievement of program goals and assessing impacts to naturally produced fishes must be established. Each M&E program will describe and implement a transparent, efficient, and timely process to respond to requests for experimental fishes, samples, and data.**

  Guideline 4.2.1. Hatchery Monitoring and Evaluation programs should be outside the direct hatchery line-of-command so they have a large degree of independence and autonomy from decisions made at the hatchery level. Program member expertise should include fish biology, population ecology, genetics, field sampling methods, experimental design and survey sampling strategies, database creation and management, and statistical analysis. Descriptions of specific monitoring and evaluation programs may be included as part of HGMPs.

Hatchery Coordination Teams

The effects of anadromous fish hatcheries are far reaching and overlap with several areas of science and resource management. The complexity and scope of issues affecting and affected by anadromous fish hatcheries is too broad to be effectively managed at the level of the hatchery alone. Complex decisions related to the management of fish hatcheries should draw upon information generated by a variety of specialized experts.

Hatchery Coordination Teams should be formed to bring together the knowledge and expertise of hatchery managers, biologists and fish culturists, M&E biologists, fish health specialists, regional fish biologists, fishery managers, and other representatives from management or funding agencies. Representatives from the hatchery's funding agency must be informed of critical operational, maintenance, and infrastructure needs. Hatchery Coordination Teams provide a forum to bring together a broad diversity of specialized technical expertise, providing more comprehensive, better informed, and more coordinated operation of hatcheries.

- **Standard 4.3. A Hatchery Coordination Team has been created for each hatchery.**

  > **Guideline 4.3.1**. Hatchery Coordination Teams should be comprised of hatchery managers, hatchery biologists/fish culturists, monitoring and evaluation biologists, fish health specialists, regional fish biologists, and fishery managers.

In-Hatchery Monitoring and Record Keeping

A comprehensive system of in-hatchery monitoring and record keeping is an integral part of effective and efficient hatchery management. In-hatchery monitoring and record keeping provides the means to evaluate hatchery facilities and operations and assess the performance of hatchery-produced fish.

- **Standard 4.4: The monitoring and record keeping responsibilities listed below are carried out on an annual basis in-hatchery for each anadromous salmonid program. Summaries of data collected, with comparisons to established targets, are included in annual hatchery program reports, and individual measurements (unless otherwise indicated) are stored in electronic data files. Sample sizes indicated are provisional pending further consideration (see Section 6.2). A complete list of required and recommended data collection and reporting is provided in Appendix IV.**

  a) Record date, number, size, age (if available), gender, and origin (natural or hatchery; hatchery- and basin-specific when available) of (a) all hatchery returns and (b) fish actually used in spawning. (Summaries in annual reports; individual measurements in electronic files.)

  b) Record age composition of hatchery returns, as determined by reading scales and/or tags, from a systematic sample of the hatchery returns (n>550, or all returns for programs with less than 550 returns).

  c) Record sex-specific age composition of the fish spawned, as determined by reading scales and/or tags, from a systematic sample of the fish spawned (n>550, or all spawned fish for programs with less than 550 spawned fish).

  d) Describe in detail the spawning protocols used for each program (by family group for conservation-oriented programs), including the number of times individual males were used.

  e) Describe in detail the culling protocols used for each program, including purpose.

  f) Calculate and record effective population size (in conservation-oriented programs).

g) Measure and record mean egg size, fecundity, and fish length for each individual in a systematic sample of spawned females (n>50), to establish and monitor the relation between fecundity, egg size, and length in the broodstock. (Include a table of all measurements in annual report.)

h) Record survival through the following life stages: green egg to eyed egg, eyed egg to hatch, hatch to ponding, ponding to marking/tagging, and marking/tagging to release.

i) Record mean, standard deviation, and frequency distribution based on n>100 measurements of fish length, by raceway, at periodic intervals (no less than monthly) prior to release and at time of release for all release types, to assess trends and variability in size throughout the rearing process. (Report means and standard deviations in annual reports; individual measurements and frequency distributions in electronic files.)

j) Maintain records of disease incidence and treatment, including monitoring of treatment efficacy.

k) Report CWT releases and recoveries to relevant databases (i.e., RMIS) on a timely annual basis.

Marking and Tagging Programs

The specific information needs to be addressed by marking and tagging programs differ by species, but broadly these programs must allow for (1) estimation of fishery impacts, (2) estimation of natural area and hatchery escapement, (3) estimation of the proportion of hatchery-origin adult fish in natural spawning areas and hatchery broodstock, (4) real-time identification of hatchery-origin juveniles and adults, and (5) identification of stock of origin for hatchery-origin fish.

Chinook salmon. The typical mass marking strategy for Chinook salmon currently used in the Pacific Northwest consists of 100 percent adipose fin-clip plus some generally unspecified level of tagging with CWTs. This strategy was designed primarily to support mark-selective fisheries on hatchery-origin fish, which, via this strategy, are all identifiable in real-time due to the absence of an adipose fin. Although this strategy does support mark-selective fisheries, it does not allow identification of most hatchery-origin fish to stock of origin (only those that receive a CWT can be so identified), and it imposes new sampling requirements for fisheries, hatcheries, and spawning escapement surveys. The mass marking strategy “desequestered” the adipose fin clip as a mark associated only with coded wire tagged fish. Therefore, all adipose fin-clipped fish must be scanned electronically to determine presence or absence of CWT before heads are taken by samplers for CWT extraction. Further, if double index tagged (DIT) groups of hatchery fish are used to attempt to assess fishery impacts on unmarked natural populations of Chinook salmon, then all fish encountered (adipose fin-clipped or not) during ocean and freshwater surveys must be electronically scanned for the presence of CWTs (see Hankin et al. 2005).

For Chinook salmon mitigation/harvest programs, the California HSRG recommends tagging 100 percent of hatchery-released fish with CWT plus marking 25 percent of hatchery-released fish by adipose fin-clip. The recommended strategy of inserting a CWT into 100 percent of hatchery-released fish means that all hatchery-origin fish can be identified as such in real-time at weirs, in samples, or at hatcheries using electronic detection devices, and that stock of origin can be determined (by CWT extraction) whenever necessary or desired. Using 100 percent CWT tagging therefore serves one of the important purposes of the 100 percent adipose fin-clip programs adopted elsewhere: all hatchery-origin fish can be unambiguously identified while in hand as being of hatchery origin. However, because all adipose fin-clipped fish possess a CWT with this marking and tagging strategy, there is no requirement to use electronic detection devices on adipose fin-clipped fish encountered in fishery or escapement surveys. Thus existing CWT recovery programs are unaffected by adoption of this new marking/tagging strategy. Whenever identification of stock of origin for particular hatchery-origin fish is needed (e.g., to eliminate crosses between different runs or populations at hatcheries, or to improve accuracy of estimation of stock-specific proportions of hatchery-origin fish present in natural spawning areas), CWTs can be recovered and read. Elimination of crosses between different runs or populations at hatcheries may necessitate infrastructure modifications in hatchery spawning buildings and additional staff and equipment for electronic detection and recovery of CWTs from all hatchery-origin fish used as broodstock.

The proposed marking and tagging strategy for Chinook salmon is not designed to promote mark-selective fisheries. As noted previously, the California HSRG makes no recommendation regarding the implementation of mark-selective fisheries, and was careful to avoid making recommendations that might unintentionally facilitate mark-selective fisheries in the absence of expressed agency intentions to implement such fisheries in California.

For Chinook salmon mitigation/harvest programs that produce both fingerling and yearling release types (Iron Gate Hatchery, Trinity River Hatchery, and Mokelumne River Hatchery), the California HSRG specifies that 100 percent of yearling releases receive an additional distinguishing external mark or tag (e.g., a ventral fin clip) to allow for real-time discrimination from fingerling releases at the adult stage. This will readily enable the exclusion of yearling-origin adult fish from the program broodstock to reduce the degree of domestication in these programs.

For Chinook salmon conservation-oriented programs (winter run Chinook salmon produced at Livingston Stone Hatchery), the California HSRG recommends 100 percent CWT plus 100 percent adipose fin-clip marking and tagging. While 100 percent CWT tagging will fulfill the same needs identified above for mitigation/harvest programs, the 100 percent adipose fin-clipping will amplify (by a factor of four) the number of CWT recoveries from these programs in fishery and escapement surveys, and thus increase the precision (by a factor of four) of the quantities being estimated therein. This is necessary given the relatively small number of fish released by conservation-oriented programs.

Coho salmon. For the coho salmon programs (Iron Gate Hatchery and Trinity River Hatchery), the California HSRG recommends that a hatchery-specific external mark (not an adipose fin clip) be applied to 100 percent of the program fish. This will enable real-time differentiation of Iron Gate and Trinity River hatchery-origin fish from each other, from natural-origin fish, and from northern hatchery-origin stocks which are 100 percent adipose fin-clipped to support mark-selective fisheries. Because a mark-selective ocean fishery for coho salmon is often conducted off the coast of Oregon for adipose fin-clipped fish, it is necessary that this external mark be something other than an adipose fin-clip in order to exclude them from being harvested in these fisheries. Presently maxillary fin clipping is used for these purposes (Iron Gate Hatchery – left maxillary fin clip, Trinity River Hatchery – right maxillary fin clip).

Steelhead. For steelhead programs, the California HSRG recommends parentage-based tagging plus 100 percent adipose fin-clip marking of program fish. This will enable mark-selective river fisheries, real-time identification of hatchery-origin fish in fishery and escapement surveys, identification of stock of origin, and evaluation of several genetics-related quantities (see Section 2.4.3).

Because the present Nimbus Hatchery steelhead stock is derived from out-of-basin sources, fish from this program should not be used as broodstock in any other Central Valley hatchery steelhead program. To enable real-time differentiation of Nimbus Hatchery fish from other Central Valley steelhead for broodstock exclusion purposes, we recommend that 100 percent of the Nimbus Hatchery program fish receive an additional distinguishing external mark (non-adipose fin clip) or CWT, until a native broodstock has been established for this program.

The specific standards that marking and tagging programs must achieve are listed below, by species. This is followed by guidelines for marking and tagging strategies as described above that rely on currently available technologies (primarily coded wire tagging and fin clipping) that are known to achieve these standards. We anticipate that future technological developments (e.g., RFID tags suitable for implantation in juvenile salmonids, or real-time identification using genetic tags) may permit these same standards to be achieved in a more efficient or cost-effective manner.

- **Standard 4.5: Chinook salmon marking and tagging programs allow for:**

  a) Estimation of ocean and freshwater fishery impacts, and natural area and hatchery escapement at the age-, stock- and release group-specific levels,

  b) Estimation of the proportion of hatchery-origin fish in natural spawning areas,

  c) Estimation of the proportion of natural-origin fish in hatchery broodstock,

  d) Real-time identification of hatchery-origin juveniles and adults (i.e., hatchery vs. non-hatchery origin),

  e) Identification of stock of origin for hatchery-origin fish,

  f) Real-time identification of yearling vs. fingerling release-type fish at the adult stage

  Guideline 4.5.1. For mitigation/harvest programs (fall-, late fall-, and spring-run), all releases should be 100 percent CWT and 25 percent adipose fin-clipped. Yearling releases should receive an additional distinguishing external mark or tag (e.g., a ventral fin clip) allowing real-time discrimination from fingerling releases at the adult stage. Deviation from this guideline must be rigorously justified, and in no circumstance can marking and tagging programs fail to meet Standard ((a) through (f) above).

  Guideline 4.5.2. For conservation-oriented programs (winter-run), all releases should be 100 percent CWT and 100 percent adipose fin-clipped.

- **Standard 4.6: Coho salmon marking and tagging programs allow for:**

  a) Estimation of natural area and hatchery escapement,

  b) Estimation of the proportion of hatchery-origin fish in natural spawning areas,

  c) Real-time identification of hatchery-origin juveniles and adults (i.e., hatchery vs. non-hatchery origin),

d) Identification of stock of origin for hatchery-origin fish,

e) Non-retention in mark-selective fisheries targeting adipose fin-clipped fish.

Guideline 4.6.1. All fish released should receive a hatchery-specific (Iron Gate Hatchery vs. Trinity River Hatchery) external mark (not an adipose fin-clip).

- **Standard 4.7: Steelhead marking and tagging programs allow for:**

a) Estimation of freshwater fishery impacts and natural area and hatchery escapements,

b) Estimation of the proportion of hatchery-origin fish in natural spawning areas,

c) Real-time visual identification of hatchery-origin juveniles and adults (i.e., hatchery vs. non-hatchery origin),

d) Real-time identification of Nimbus hatchery-origin adults from other hatchery-origin steelhead as long as broodstock derived from out-of-basin sources is used,

e) Identification of stock of origin for hatchery fish.

Guideline 4.7.1. All broodstock should be genotyped as part of a parentage-based tagging (PBT) program.

Guideline 4.7.2. All juvenile fish released should be adipose fin-clipped.

Guideline 4.7.3. All Nimbus Hatchery juvenile fish released should receive an additional distinguishing external mark (non-adipose fin clip) or CWT, until a native broodstock is established.

Post-Release Emigration Monitoring

Monitoring hatchery fish following their release in freshwater is necessary to evaluate effects on naturally produced juveniles and to provide insights about possible causes for failure to achieve program goals. Large-scale releases of hatchery-origin salmon and steelhead may (1) create competition for food and rearing space with naturally produced juvenile salmonids; (2) cause loss of natural-origin fish through predation by larger hatchery-origin fish or by attracting aggregations of piscivorous birds, fish, or mammals; or (3) cause premature emigration of natural-origin fish. Competition or predation can be especially important with steelhead, as some fish may rear in freshwater for extended periods following release and others may entirely fail to adopt an anadromous life history strategy (residualize). Monitoring should assess the likelihood of substantial deleterious effects by measuring degree of spatial and temporal overlap and size differences between hatchery- and natural-origin juveniles. High likelihood of spatial and temporal overlap should motivate additional work to verify a problem or assess its magnitude. Detecting and assessing the effect of predator aggregations requires directed studies considered beyond the scope of standard monitoring and evaluation programs.

- **Standard 4.8: The quantities listed below are monitored in the freshwater environment following release of juvenile Chinook and coho. Summaries of collected data and associated estimates, along with comparisons to established targets, are included in annual or periodic (every 5 to 10 years) reports produced by the monitoring agencies/entities.**

  a) Annual: Document length (mean, standard deviation, and frequency distribution) of hatchery fish at release as compared to naturally produced smolts.

  b) Periodic: Document the number of days (mean, standard deviation, and frequency distribution) from release of hatchery fish to passage at a location near entry to salt water (e.g., using PIT tags/detectors or acoustic tags/arrays) and the degree of overlap with natural-origin fish.

  c) Periodic: Estimate the percent hatchery-origin fish among outmigrating juveniles and, where feasible, estimate total juvenile production.

- **Standard 4.9: The quantities listed below are monitored in the freshwater environment following release of juvenile steelhead. Summaries of collected data and associated estimates, along with comparisons to established targets, are included in periodic (every 5 to 10 years) reports produced by the monitoring agencies/entities.**

  a) Assess residualization (permanent freshwater residence).

  b) Assess extended rearing (following release) prior to ocean entrance.

Adult Monitoring Programs

The specific information needs for and feasibility of monitoring programs differ substantially by species, but broadly these programs must allow for estimation of (1) fishery impacts, (2) hatchery returns, (3) within basin tributary spawning escapements, and (4) the proportion of hatchery-origin fish among natural area spawners.

Chinook salmon. Because Chinook salmon are subject to substantial recreational and commercial fisheries, monitoring programs for this species need to generate accurate and timely information concerning contributions of hatchery-origin fish to fisheries. Cohort analysis of CWT recoveries from releases of marked and tagged hatchery fish is typically used to estimate fishery impacts on marked and tagged fish. From estimated landings of fish with adipose fin-clip and CWT, expansions can assess total fishery contributions (marked plus unmarked) of hatchery fish based on the program mark-rate. Cohort analyses require estimates of recoveries of marked and tagged hatchery fish for each of the possible fates that a marked and tagged hatchery fish can encounter from ages two through five: (1) landed or non-landed mortality in ocean recreational or commercial fisheries, (2) capture in freshwater fisheries, (3) return to hatchery, or (4) return to (and possibly spawn in) natural area. Assessing numbers of marked and tagged fish that spawn naturally generally requires spawning escapement estimation programs in all of the major streams to which hatchery-origin fish may stray. Within each such stream, the fraction of escapement that originates from a particular marked and tagged group must be estimated. Spawning escapements (hatchery- plus natural-origin fish) should be evaluated as to whether spawner densities exceed the carrying capacity of natural spawning areas, thereby reducing reproductive success through competition and perhaps through displacement of natural-origin spawners to inferior spawning areas.

Coho salmon. Because coho salmon lacking an adipose fin-clip are not currently subject to directed harvest in ocean fisheries off the coasts of Oregon and California, and the species is ESA-listed as threatened in the Southern Oregon/Northern California Coasts ESU, monitoring programs should emphasize the demographic and genetic status of hatchery populations, and contributions to naturally spawning populations, rather than fishery contributions.

Steelhead. Monitoring programs for steelhead are necessarily more limited than for Chinook or coho salmon because steelhead spawning typically takes place during high flows and low visibilities, not all steelhead die after spawning (i.e., are iteroparous), and hatcheries use non-lethal spawning methods for steelhead. Spawning escapements (hatchery- plus natural-origin fish) should be evaluated to determine whether spawner densities exceed the carrying capacity of natural spawning areas, thereby reducing reproductive success through competition and perhaps through displacement of natural-origin spawners to inferior spawning areas.

The specific standards that adult monitoring programs must achieve are listed below, by species.

Chinook Salmon

- **Standard 4.10: Monitoring programs for Chinook salmon allow for estimation of the following on an annual basis.**

  a) Total recreational and commercial ocean harvest, and harvest of hatchery-origin fish at the age-, stock-, and release group-specific (CWT) level,

  b) Total freshwater harvest, and harvest of hatchery-origin fish at the age-, stock-, and release group-specific (CWT) level,

  c) Total returns (hatchery -and natural-origin) to hatchery, and returns at the age-, stock-, and release group-specific (CWT) level,

  d) Age composition of hatchery returns,

  e) Total escapement by tributary and by species/run,

  f) Proportion of hatchery-origin fish among natural area spawners (pHOS) by tributary and at age-, stock-, and release group-specific (CWT) level,

  g) Age composition of individual tributaries important for natural production.

Coho Salmon

- **Standard 4.11: Monitoring programs for coho salmon allow estimation of the following on an annual basis:**

  a) Probable fishery impacts in ocean and freshwater (recreational and tribal),

  b) Hatchery returns of hatchery- and natural-origin fish by age, stock and release type,

  c) Total escapement to individual tributaries important for natural production,

d) Proportion of hatchery-origin fish among natural area spawners (pHOS) in individual tributaries important for natural production.

Steelhead

- **Standard 4.12: Monitoring programs for steelhead allow estimation of the following on an annual or periodic (every 5 to 10 years) basis:**

  a) Annual: Freshwater recreational and tribal catch, ideally by hatchery and brood year,

  b) Annual: Hatchery returns by age and stock,

  c) Annual: Total escapement to individual tributaries important for natural production,

  d) Annual: Proportion of hatchery-origin fish among natural area spawners (pHOS), at the stock-specific level, in individual tributaries important for natural production,

  e) Periodic: Proportion of adult hatchery returns that have exhibited an anadromous life history.

Evaluation Programs

Monitoring programs primarily collect data needed to evaluate the performance of hatcheries with respect to their operational goals, to assess their impacts on natural fish populations, and to determine societal benefits realized from the production of hatchery fish. Mere collection of these data is not sufficient for program evaluation; therefore, fundamental standards for evaluation and analysis of data collected in monitoring programs are provided. These evaluation standards allow managers to assess whether or not hatchery programs are meeting their program goals and provide substantial insight into factors that may be responsible for failure to achieve program goals.

The specific needs and feasibility of evaluation differ substantially by species. For Chinook salmon, explicit guidelines for program evaluation are provided that rely on application of run reconstruction analyses based on CWT recovery data. Because similar data are not available for coho salmon and steelhead, prescriptive guidelines for those species are not presented.

- **Standard 4.13: Evaluation programs for Chinook salmon assess the following fundamental issues on a brood-specific basis:**

  a) Survival from release to pre-fishery recruitment,

  b) Age-specific maturation schedules,

  c) Straying (here defined as failure of hatchery-origin fish to return to the hatchery from which they originated or to the watershed in the immediate vicinity of the hatchery),

  d) Age-specific fishery contribution rates,

  e) Pre-fishery age-3 ocean recruitment.

Evaluation programs for Chinook salmon assess the following fundamental issues on a periodic basis (e.g., every 5 to 10 years):

f) The relationship of hatchery fish survival rates and maturation schedules to size and/or date of release;

g) Long-term trends in phenotypic traits (age, maturity, fecundity at size, run/spawn timing, size distribution) and genetic traits (divergence among year classes, effective population size, divergence from natural populations) of hatchery populations;

h) Spatial and temporal overlap and relative sizes of emigrating juvenile hatchery- and natural-origin fish and total (hatchery- plus natural-origin) spawner distribution and densities to assess the likelihood or magnitude of deleterious effects of hatchery-origin fish on naturally spawning fish due to competition, predation, or behavioral effects .

Guideline 4.13.1. Use tag recovery data and cohort reconstruction (cohort analysis) methods to estimate the following quantities. In the future, alternative technologies or analytical methods may generate other data suitable for estimating these quantities.

- Brood survival from release to ocean age-2 at the release group-specific (CWT) level,
- Brood maturation schedule (age-specific conditional maturation probabilities) at the release group-specific (CWT) level,
- Straying and geographic distribution of stray hatchery-origin fish at the release group-specific (CWT) level,
- Age-specific ocean and freshwater fishery contributions and exploitation rates at the release group-specific (CWT) level,
- Pre-fishery ocean recruitment of hatchery-origin fish at age-3 at the release group-specific (CWT) and program level.

➢ **Standard 4.14: Evaluation programs for coho salmon estimate the following attributes on a brood-specific basis:**

a) Age-3 recruitment (tributary escapements plus hatchery returns). If non-selective ocean fisheries for coho salmon are resumed, age-3 recruitment would include ocean catches at age-3.

b) Survival from release to age-3 recruitment.

Evaluation programs for coho salmon evaluate the following fundamental issues on a periodic basis (e.g., every 5 to 10 years):

c) Long-term trends in phenotypic traits (age, maturity, fecundity at size, run/spawn timing, size distribution) and genetic traits (divergence among year classes, effective size, divergence from natural populations) of hatchery populations.

d) Spatial and temporal overlap and relative sizes of emigrating juvenile hatchery- and natural-origin fish and total (hatchery- plus natural-origin) spawner distribution and densities to assess the likelihood or magnitude of deleterious effects of hatchery-origin fish on naturally spawning fish due to competition, predation, or behavioral effects.

- **Standard 4.15: Evaluation programs for steelhead estimate the following attributes on an annual basis:**

a) Age-specific freshwater adult returns (and half-pounders in the Klamath/Trinity Basin), in order of the following preference:

- River catch and catch-and-release adult mortality plus tributary returns of adults plus hatchery returns of adults,
- Tributary returns of adults plus hatchery returns of adults,
- River catch and catch-and-release adult mortality plus hatchery returns of adults,
- Hatchery returns of adults.

b) At facilities where kelts are reconditioned and released, determine the survival (return for subsequent spawning) of reconditioned and released kelts.

Evaluation programs for steelhead assess the following fundamental issues on a periodic basis (i.e., every 5 to 10 years):

c) The relationship of life history patterns (age at return, tendency to exhibit half-pounder life history pattern in the Klamath/Trinity Basin, residualization) to hatchery rearing and release practices with a focus on size and age at release.

d) Long-term trends in phenotypic traits (age, maturity, fecundity at size, run/spawn timing, size distribution) and genetic traits (divergence among year classes, effective population size, divergence from natural populations) of hatchery populations.

e) Spatial and temporal overlap and relative sizes of emigrating juvenile hatchery- and natural-origin fish (including juvenile salmon) and total (hatchery- plus natural-origin) spawner distribution and densities to assess the likelihood or magnitude of deleterious effects of hatchery-origin fish on naturally spawning fish due to competition, predation, or behavioral effects.

4.5 Direct Effects of Hatchery Operations on Local Habitats, Aquatic or Terrestrial Organisms

Operation of hatchery facilities can have adverse effects on local environments, thus affecting salmonid populations and other aquatic species. Hatchery facilities include adult collection, spawning, incubation, rearing and release facilities as well as structures to remove and discharge water. Intake structures, fish ladders, and weirs are typically located in riparian areas or within creek/river channels and can affect habitat quality and quantity. Hatchery structures can create obstacles to migration for juvenile and adult fish, change instream flow, alter riparian habitat and diminish water quality through hatchery discharges. Water for hatchery use is often drawn from nearby sources via pumps or gravity. Improperly designed and maintained water intakes can entrain migrant or resident juveniles on hatchery screens or cause fish to be trapped in hatchery facilities. Structures such as adult weirs and water intake dams can also block natural passage of salmonids to spawning or rearing areas. Water diverted from adjacent streams for fish culture purposes is often returned further downstream, reducing the amount of flow for juvenile rearing and upstream adult migration in the reach between the intake and discharge. Hatchery discharge can also diminish water quality below the point of discharge through changes in temperature, settleable and suspended solids, chemical composition, and presence of therapeutic drugs. If hatchery facilities and operations are not managed to mitigate these effects, additional loss of natural production can result, diminishing the net benefit of the hatchery program.

Throughout California, major watershed restoration actions and efforts are underway to benefit both listed and non-listed anadromous salmonids. These habitat restoration programs are often complex collaborative efforts between public and private organizations (e.g., state and federal agencies and local watershed groups). While hatcheries are not charged with habitat enhancement, the agencies responsible for their operation are often charged with habitat enhancement and protection. Therefore, where feasible, hatchery staff should be aware of and participate in habitat restoration planning processes and implementation. Such participation will inform them of efforts underway and assist them in determining how hatchery infrastructure or operations may need modification/alteration to appropriately integrate with local restoration actions and programs.

- **Standard 5.1: Hatchery operations/infrastructure is integrated into local watershed restoration efforts to support local habitat restoration activities.**

  Guideline 5.1.1. Hatchery staff should participate in local habitat restoration planning efforts to help assess the effects of current hatchery operations on future habitat enhancement or vice versa and to plan for operational changes that may become necessary.

- **Standard 5.2: Hatchery infrastructure is operated in a manner that facilitates program needs while reducing impacts to aquatic species, particularly listed anadromous salmonids.**

  Guideline 5.2.1. Water supply intake structures located in anadromous waters should conform with NMFS and CDFG fish screen criteria or other appropriate criteria that matches screen size and approach and sweeping velocity to the target organism requiring protection. Design and operation of facility water diversion/supply structures also should provide operational flexibility to avoid catastrophic facility water loss due to debris loading or other failure.

  Guideline 5.2.2. Consider screening needs of facility water supply intakes in non-anadromous waters to protect other ESA or CESA listed organisms. Design and operation of facility water diversion/supply structures also needs to consider operational flexibility to avoid catastrophic facility water loss due to debris loading or other failure.

  Guideline 5.2.3. Barrier weirs should effectively block adult passage either for broodstock congregation/collection or as required for in-river fishery management.

Guideline 5.2.4. Fish ladders used to circumvent barrier weirs or impoundment structures or that provide access to hatchery adult holding ponds should allow adequate capture of appropriate numbers of target species over the full spectrum of the run and limit passage delay and injury to target species and also to non-target organisms as required by in-river fishery management.

Guideline 5.2.5. Limit reach specific impacts of hatchery water diversions, such as diminishment of in-stream flows between diversion and discharge return points.

Guideline 5.2.6. All general facility construction and operations should limit effects on the riparian corridor and be consistent with fluvial geomorphology principles (i.e., avoid bank erosion or undesired channel modification).

- **Standard 5.3: Effluent treatment facilities are secure and operated to meet NPDES requirements.**

- **Standard 5.4: Current facility infrastructure and construction of new facilities avoid creating an unsafe environment for the visiting public and staff and provide adequate precautions (e.g., fencing and signage) where unsafe conditions are noted.**

5. Summary of Hatchery Program Recommendations

Major hatchery program recommendations are highlighted in this section which is organized by hatchery, beginning with facilities in the Klamath-Trinity Basin and proceeding to the Central Valley of California. For each hatchery, we provide facility and program overviews, followed by the California HSRG's major recommendations for each program operated at the hatchery. These recommendations were collaboratively developed by the California HSRG, reflecting facility or operational modifications that we view as necessary to protect and sustain California's salmon and steelhead resources. Appendix VIII includes a full suite of standards for each program along with guidelines that suggest implementation strategies to meet each standard. We note that among situations where program size is reduced or programs eliminated, in no case should such change result in relinquishment of mitigation responsibility.

5.1 Iron Gate Hatchery

Iron Gate Hatchery (IGH) was established in the late 1960s to mitigate for construction of Iron Gate Dam and the anadromous fish habitat lost between Iron Gate and Copco dams. For many years, fish were reared at both the Fall Creek and IGH facilities; however, current production is limited to IGH. IGH is located approximately eight miles east of Hornbrook, California; the primary spawning facility is at the base of Iron Gate Dam at RM 190. Hatchery operation and monitoring is fully funded by PacifiCorp.

Three programs are conducted at IGH, producing coho, fall Chinook and steelhead. Each program is briefly summarized below, followed by sections highlighting the California HSRG's major recommendations for all Iron Gate programs and then program-specific recommendations.

The Southern Oregon / Northern California Coasts coho salmon ESU was classified under the ESA as threatened in 1997. The ESU includes all naturally spawned populations of coho salmon in coastal streams between Cape Blanco, Oregon, and Punta Gorda, California, and the Iron Gate Hatchery, Trinity River Hatchery, and Cole River Hatchery coho programs.

Iron Gate Hatchery Coho Program

The integrated coho program goal is to produce 75,000 smolts at 15 fish per pound (fpp) for release between March 15 and May 1. All juvenile IGH-produced coho salmon are marked with a left maxillary fin clip and released at the hatchery.

Historically, IGH was operated to mitigate for blocked fish habitat; however, recently a conservation focus for the coho program has been deemed necessary to protect the remaining genetic resources of the Upper Klamath River coho population unit (CDFG 2011). Adult coho salmon returns to this population (and to the entire Klamath River) have been declining to the point where less than 60 adult fish returned to the hatchery and Bogus Creek, the largest tributary in this population unit (in terms of measured production) in 2009 (CDFG 2011).

According to the 2011 Draft HGMP, the coho salmon program is operated to protect and conserve the genetic resources of the Upper Klamath River coho population unit. As natural coho salmon production increases over time with implementation of habitat and other recovery actions, it is expected that the program will be operated as an integrated program.

Iron Gate Hatchery Fall Chinook Program

This integrated program at IGH has a goal to produce six million juvenile fall Chinook salmon annually. The production goal is to release 5.1 million subyearlings (“fingerlings”, at 90 fpp) between May 1 and June 15 and 900,000 subyearlings (“yearlings“, at 10 fpp) between October 15 and November 20. Fall Chinook are marked at a rate of 25 percent (constant fractional marking) with an adipose fin-clip and coded wire-tag, and released at the hatchery site.

Iron Gate Hatchery Steelhead Program

Broodstock for the Iron Gate steelhead program is collected from fish that volitionally enter the fish trap located at the base of the dam and currently includes fish that demonstrate either an anadromous or resident life history. The goal of this integrated program is to produce 200,000 steelhead smolts at 10 fpp for release between March 15 and May 1. All steelhead are released at the hatchery site and all are marked with an adipose fin clip.

During the past decade, the IGH steelhead program has failed to meet mitigation goals. Historically, thousands of steelhead migrated into the upper Klamath River and as late as 1982, juveniles released from IGH comprised up to seven percent of the half-pounder steelhead captured by seining in the lower Klamath River (CDFG unpublished data). Prior to the last decade, several thousand adult steelhead were trapped annually at IGH.

Steelhead production has varied substantially over the years, with a high of approximately 643,000 yearlings released in 1970 to a low of about 11,000 yearlings released in 1997. The 200,000 yearling production goal was met in most years prior to 1991; however, the production goal has not been achieved since that time.

5.1.1 Recommendations for All Iron Gate Hatchery Programs

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

- Adult holding facilities in hatcheries should be upgraded/expanded to provide adequate space, water flows and temperature regimes to hold the number of adults required for broodstock at high rates of survival (greater than 90 percent). Facilities need to be adequate to hold the expected number of unripe adults for extended periods with minimal hatchery-caused mortality.

- The adult spawning facility is inadequate to meet current needs for fish sorting, spawning and monitoring and should be upgraded.

- All outdoor raceways should be protected from predators with bird netting or similar protection to reduce predation rates on juvenile fish.

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

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

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

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

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

5.1.2 Iron Gate Coho -Major Program Recommendations

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

- The draft HGMP for the IGH coho program should be approved and implemented.

- Mating protocols should be reviewed for consistency with California HSRG recommendations for splitting egg lots.

- Water quality for egg incubation should be improved to remove organic debris and siltation that is likely affecting egg survival. If the air incubation solution tried in 2011 is ineffective, hatchery and fish health staff should continue studies to determine the cause of low egg survival rates.

5.1.3 Iron Gate Fall Chinook- Major Program Recommendations

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

- Managers should consider changes in the program, including reducing the size of the program, to mitigate disease issues. Large numbers of naturally spawning fish may increase the incidence of *C. shasta* disease through the release of myxospores from carcasses, which in turn increases the probability of perpetuating myxozoan infections in juvenile Chinook and coho salmon in the following spring and summer. We note that in any situation where program size is reduced or programs eliminated, in no case should such change result in relinquishment of mitigation responsibility.

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

- Jacks should be incorporated into the broodstock at a rate that does not exceed 50 percent of the total number of jacks encountered during spawning operations and in no case more than 5 percent of the total males spawned.

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

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

- CWT releases and recoveries of fall Chinook should be reported annually to RMIS in a timely manner.

- Water quality for egg incubation should be improved to remove organic debris and siltation that is likely affecting egg survival. If the air incubation solution tried in 2011 is ineffective, hatchery and fish health staff should continue studies to determine the cause of low egg survival rates.

5.1.4 Iron Gate Steelhead –Major Program Recommendations

The major recommendations of interest to resource managers for the Iron Gate Hatchery steelhead program are provided below. Those selected for presentation may represent major changes in operations, changes in approach or outcomes towards achieving harvest or conservation goals, or will require substantial investment of resources. The California HSRG's evaluation of program compliance with standards and guidelines and the group's comments about this program are presented in their entirety in Appendix VIII.

- This program should terminate use of the current broodstock and be reestablished with broodstock collected from an off-site location. The program has not consistently produced adequate numbers of anadromous steelhead returning to the hatchery and few adults in the broodstock show evidence of anadromy. The program currently provides little in the way of conservation benefits to the species or harvest benefits to the public.

- Non-anadromous fish typically should not be used as steelhead broodstock.

- The minimum release size for juvenile fish should be at least 8 fpp and a size at release study conducted to refine the release size target. Variability of fish size at release should be reduced.

- Hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

5.2 Trinity River Hatchery

The Trinity River Division of the Central Valley Project in California included construction of Trinity and Lewiston dams that divert a substantial portion of the river's flow to the Central Valley for agricultural, municipal and industrial uses. Lewiston Dam, completed in 1963, is the upstream limit of anadromy, blocking access to 109 miles of salmon and trout spawning and rearing habitat. Trinity River Hatchery (TRH) was constructed at river mile 110 at the base of Lewiston Dam to mitigate for the loss of this anadromous fish habitat. The Bureau of Reclamation funds operation and maintenance of the TRH, which is operated and managed by the CDFG.

Four anadromous programs are conducted here, producing coho salmon, fall Chinook salmon, spring Chinook salmon and steelhead. Each program is briefly summarized below, followed by sections highlighting the major recommendations for all Trinity River Hatchery programs and then program-specific recommendations.

Mitigation goals for lost adult production were determined from pre-project studies of anadromous fish populations in the basin. The USFWS and CDFG (1956) estimated that 5,000 coho; 3,000 spring Chinook, 8,000 summer Chinook and 24,000 fall Chinook; and 10,000 steelhead (no run timing was designated) passed above the Lewiston Dam site prior to its construction. Total annual adult production goals (catch plus escapement) for TRH were further defined in 1980 to be 7,500 coho, 6,000 spring Chinook, 70,000 fall Chinook and 22,000 steelhead (Frederickson et al. 1980). Escapement goals to the hatchery were further defined in 1983 as 2,100 coho, 3,000 spring Chinook, 9,000 fall Chinook and 10,000 steelhead (USFWS 1983).

The Southern Oregon / Northern California Coasts coho salmon ESU was classified under the ESA as threatened in 1997. The ESU includes all naturally spawned populations of coho salmon in coastal streams between Cape Blanco, Oregon, and Punta Gorda, California, and the Iron Gate Hatchery, Trinity River Hatchery, and Cole River Hatchery coho programs.

Trinity River Hatchery Coho Program

TRH coho salmon broodstock originated from an in-river weir, with some augmentation from out-of-basin sources to boost production. Only endemic Trinity River broodstock have been used at TRH since 1970 (CDFG 2004). Currently, this integrated coho program releases approximately 500,000 yearlings annually at 10 to 20 fpp from March 15 to May 15. All coho are released at the hatchery site and all are marked with a right maxillary fin clip.

Trinity River Hatchery Fall Chinook Program

TRH fall Chinook salmon broodstock originated from an in-river weir when hatchery operations began in 1964. No eggs or fish from outside the basin have been used to supplement this program in at least the last 10 years. This integrated fall Chinook program has a goal to release 2 million subyearlings (“fingerlings”, at 90 fpp) in June and 900,000 subyearlings (“yearlings”, at 10 fpp) in October. Fall Chinook are marked at a rate of 25 percent (constant fractional marking) with an adipose fin-clip and coded wire tag, and released at the hatchery site.

Trinity River Hatchery Spring Chinook Program

As with the fall Chinook program, TRH spring Chinook salmon broodstock originally were collected from an in-river weir in 1964. In the last ten years, no out-of-basin eggs or broodstock have been used to supplement the program. The goal of this integrated program is to release 1 million subyearlings (“fingerlings”, at 90 fpp) in June and 400,000 subyearlings (“yearlings”, at 10 fpp) in October. Spring Chinook are marked at a rate of 25 percent (constant fractional marking) with an adipose fin-clip and coded wire tag, and released at the hatchery site.

Trinity River Hatchery Steelhead Program

Broodstock used in the TRH steelhead program originated from the Trinity River watershed. From 1974 until at least 1994, some eggs were imported from Iron Gate Hatchery; however, no eggs or fish from outside the Trinity River watershed have been used to supplement this program in the last 10 years. This integrated program has a goal to release 800,000 six-inch-long steelhead smolts from March 15 to May 1. All steelhead are marked with an adipose fin clip and released at the hatchery site.

5.2.1 Recommendations for All Trinity River Hatchery Programs

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

- Adult holding facilities in hatcheries should be upgraded/expanded to provide adequate space, water flows and temperature regimes to hold the number of adults required for broodstock at high rates of survival (more than 90 percent). Facilities need to be adequate to hold the expected number of unripe adults for extended periods with minimal hatchery-caused mortality.

- The adult spawning facility is inadequate to meet current needs for fish sorting, spawning and monitoring and should be upgraded.

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

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

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

- Co-managers should develop and promulgate a formal, written fish health policy for the operation of the hatchery. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current fish health policy is inadequate to protect native stocks.

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

5.2.2 Trinity River Coho- Major Program Recommendations

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

- Co-managers should identify the purposes and goals of this program and determine appropriate program size given existing hatchery escapement goals for hatchery coho salmon, the ESA-listed status of the population, and the tribal trust issues raised by construction of Lewiston and Trinity dams. Adult returns to the hatchery have averaged over 7,000 adults, more than three times the hatchery escapement goal of 2,100 fish.

- Jacks should be incorporated into the broodstock at a rate that does not exceed 50 percent of the total number of jacks encountered during spawning operations and in no case more than 10 percent of the total males spawned.

5.2.3 Trinity River Fall Chinook- Major Program Recommendations

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

- Adult collection facilities should be operated throughout the entire temporal migration period of the run and should not exclude fish with particular life history characteristics, except when non-representative broodstock collection is necessary to achieve program goals. Currently, the trap is shut down for a period of approximately two weeks to minimize hybridization between separate spring and fall Chinook. Fish collected during this period should be euthanized without spawning.

- Tag analysis should be used to determine the number of fall and spring Chinook spawned during the suspected period of run overlap (e.g., fish spawned in the last two weeks of spring Chinook spawning and the first two weeks of fall Chinook spawning). Tags should be read and egg lots tracked and eliminated from production as appropriate to reduce introgression of the two runs. Incubation techniques should therefore allow for separation of eggs from individual parents/families (no more than two families per tray).

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

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

- CWT releases and recoveries of fall Chinook should be reported annually to RMIS in a timely manner.

- Jacks should be incorporated into the broodstock at a rate that does not exceed 50 percent of the total number of jacks encountered during spawning operations and in no case more than 5 percent of the total males spawned.

- Fish growth trajectories need to be monitored more closely to achieve the identified release target of 90 fpp for fingerlings and 10 fpp for yearlings. Data supplied by the hatchery indicate that average release size for the two respective groups has been 108 fpp and 15.4 fpp from 2000-2010.

5.2.4 Trinity River Spring Chinook- Major Program Recommendations

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

- Adult collection facilities should be operated throughout the entire temporal migration period of the run and should not exclude fish with particular life history characteristics, except when non-representative broodstock collection is necessary to achieve program goals. Currently, the trap is shut down for a period of approximately two weeks to minimize hybridization between separate spring and fall Chinook. Fish collected during this period should be euthanized without spawning.

- Tag analysis should be used to determine the number of fall and spring Chinook spawned during the suspected period of run overlap (e.g., fish spawned in the last two weeks of spring Chinook spawning and the first two weeks of fall Chinook spawning). Tags should be read and egg lots tracked and eliminated from production as appropriate to reduce introgression of the two runs. Incubation techniques should therefore allow for separation of eggs from individual parents/families (no more than two families per tray).

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

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

- CWT releases and recoveries of fall Chinook should be reported annually to RMIS in a timely manner.

- Jacks should be incorporated into the broodstock at a rate that does not exceed 50 percent of the total number of jacks encountered during spawning operations and in no case more than 5 percent of the total males spawned.

- Fish growth trajectories need to be monitored more closely to achieve identified release size targets.

5.2.5 Trinity River Steelhead- Major Program Recommendations

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

- Program goals should be measured as the number of anadromous hatchery-origin steelhead adults and half-pounders returning to freshwater each year. Adult steelhead mitigation goals for the program are described in various historical non-hatchery related documents. It does not appear that the program is operated to achieve these goals or adjusted if goals are not achieved.

- Hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

5.3 Nimbus Fish Hatchery

Nimbus Fish Hatchery (NFH) was constructed in 1955 at RM 22 of the American River, approximately 0.25 mile downstream of Nimbus Dam. Hatchery operation helps fulfill mitigation requirements for construction of Nimbus Dam as described in the "Contract between the United States and the State of California for the Operation of the Nimbus Fish Hatchery" (Reclamation 1956). Mitigation is provided for the American River reach between Nimbus and Folsom dams; it does not address lost habitat upstream from Folsom Dam. The CDFG operates a fall Chinook salmon and a steelhead program here. Each program is briefly summarized below, followed by sections highlighting the California HSRG's major recommendations for all Nimbus programs and then the program-specific recommendations.

The Central Valley fall/late fall-run Chinook salmon ESU was classified as a federal Species of Concern in 2004. The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait.

The Central Valley steelhead DPS was classified under the ESA as threatened in 1998. The DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait, and the Feather River Hatchery and Coleman National Fish Hatchery steelhead programs.

Nimbus Fall Chinook Program

The goal of the integrated fall Chinook program at NFH is to release four million smolts that average 60 fpp or larger. These fish are marked at a rate of 25 percent (constant fractional marking) with an adipose fin-clip and coded wire tag and then all are released in San Pablo Bay between mid-May and mid-June.

Nimbus Steelhead Program

The NFH segregated winter steelhead program traps and artificially spawns adult steelhead marked with an adipose fin clip. Unmarked fish are not included in the broodstock and are released back to the river. Broodstock has been derived from a number of different populations and presently appears to cluster genetically most closely with Eel River steelhead. Nielson et al. (2005) reported that juvenile fish from the lower American River and NFH were genetically similar in microsatellite allelic frequencies. Garza and Pearse (2008) reported similar results for fish sampled from the lower American River and NFH.

The program has a juvenile release goal of 430,000 yearling steelhead (at 4 fpp). All NFH steelhead are marked with an adipose fin clip. Fish are released from January through February approximately one mile above the confluence of the American and Sacramento rivers (at Jibboom Street) to reduce predation on natural-origin Chinook fry.

5.3.1 Recommendations for All Nimbus Hatchery Programs

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

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

- Adult holding facilities should be upgraded and/or expanded to provide adequate space, water flows and temperature regimes to hold the number of adults required for broodstock at high rates of survival (greater than 90 percent).

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

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

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

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

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

5.3.2 Nimbus Fall Chinook- Major Program Recommendations

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

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

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

- Program fish should be 100 percent coded wire-tagged and 25 percent adipose fin-clipped.

- The cause of the low egg-to-juvenile release survival rate (43.6 percent) should be determined.

5.3.3 Nimbus Steelhead Program- Major Recommendations

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

- The current broodstock for this program should be replaced with an alternative broodstock that is appropriate for the American River.

- Non-anadromous (resident) or unmarked fish should not be used as broodstock and the current 16-inch minimum length for broodstock should be continued. This recommendation to not use unmarked fish will no longer apply once the current broodstock is replaced.

- Because Nimbus steelhead currently are not part of the Central Valley steelhead Distinct Population Segment, all juvenile fish released should receive an adipose fin-clip plus an additional distinguishing external mark (non-adipose fin clip) or CWT, until a native broodstock is established. This additional distinguishing mark or tag will ensure that if these fish return to another hatchery, they can be excluded from its broodstock.

- With the current broodstock, all hatchery-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be removed from the system. With a native broodstock, hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system, or extended reconditioned and released.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

- An alternative cold-water source should be developed to reduce summer rearing water temperatures.

- The cause of the low egg-to-juvenile release survival rate (24.5 percent) should be determined. It is suspected that the low value is a result of egg-culling practices; however, this cannot be confirmed because of the way data are collected and reported.

5.4 Mokelumne River Hatchery

The Mokelumne River Fish Hatchery (MRFH) is located on the lower Mokelumne River just downstream of Camanche Dam. Funding for hatchery operations is provided by the East Bay Municipal Utility District (EBMUD) while the hatchery is operated and managed by the CDFG. The fall Chinook and steelhead hatchery programs were originally designed to comply with the 1961 requirements of the California State Water Resources Control Board. The 1961 agreement and related amendments directed the construction of a hatchery to rear 100,000 juvenile salmon and spawning channels with a capacity for up to 15 million Chinook salmon eggs.

In March 1998, EBMUD, CDFG and the USFWS entered into an agreement to resolve various FERC relicensing and state water right issues. EBMUD agreed to fund an expansion and upgrade of the MRFH as an integral part of a strategy to supplement the natural production and to meet the mitigation requirement for anadromous fish in the lower Mokelumne River. Hatchery reconstruction was completed in 2002. The fall Chinook salmon and steelhead programs are briefly summarized below, followed by sections highlighting the California HSRG's major recommendations for both Mokelumne programs and then the program-specific recommendations.

The Central Valley fall/late fall-run Chinook salmon ESU was classified as a federal Species of Concern in 2004. The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait.

The Central Valley steelhead DPS was classified under the ESA as threatened in 1998. The DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait, and the Feather River Hatchery and Coleman National Fish Hatchery steelhead programs.

Mokelumne Fall Chinook Program

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

Mokelumne Steelhead Program

The integrated steelhead program at Mokelumne has a goal to release 250,000 yearling steelhead at 4 fpp. The program has been experimenting with small releases (less than 2,000 fish) of two-year-old steelhead juveniles using a "natures" rearing strategy (i.e., presence of structure, low rearing density, shallow pond depth, cover and colored raceways). All steelhead are released from February through March and are marked with an adipose fin clip. Steelhead are released at New Hope Landing, approximately 10.5 miles downstream from the confluence of the Mokelumne and Consumes rivers.

5.4.1 Recommendations for All Mokelumne River Hatchery Programs

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

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

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

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

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

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

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

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

5.4.2 Mokelumne River Fall Chinook- Major Program Recommendations

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

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

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

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

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

5.4.3 Mokelumne River Steelhead- Major Program Recommendations

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

- Non-anadromous (resident) or unmarked fish typically should not be used as broodstock and the current 16-inch minimum length for broodstock should be continued.

- Hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system, or extended reconditioned and released.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

5.5 Merced River Hatchery

Merced River Hatchery (MRH) is located just below Crocker-Huffman Dam (the terminus of anadromy), north of Fresno. The original fish facility, completed in 1970 by the Merced Irrigation District (MID), was a Chinook salmon spawning channel designed to enhance salmon runs. To increase production, the facility was converted into a spawning and rearing hatchery during the 1980s and 1990s. Operational funding is provided by the CDFG and the MID; CDFG operates and maintains the hatchery. Fall Chinook salmon are the only species reared at Merced Hatchery.

The fall Chinook salmon program at MRH is considered an experimental program to test juvenile to adult survival rates for various release sites in the basin. The original purpose of the program was to mitigate for lost habitat from the construction of the Crocker-Huffman, Merced Falls, and Exchequer dams. This was to be achieved by producing 960,000 fall Chinook smolts and 330,000 yearlings. The yearling program was discontinued due to high fish losses from proliferative kidney disease (PKD), caused by *Tetracapsuloides bryosalmonae*, an endemic myxozoan parasite in the Merced River.

Current production goals for the integrated fall Chinook program are to take two million fall Chinook eggs and release one million smolts at 60 fpp (80 mm fork length) between late April and mid-May. Most releases of Merced River fall Chinook salmon are for experimental purposes. These fish have been marked (adipose fin-clipped, panjet marked) and coded wire tagged, and the remaining fish are currently marked at a 25 percent constant fractional marking rate with an adipose fin-clip and coded wire tag. Fall Chinook are released at the hatchery, at lower Merced River locations, and at various locations in the San Joaquin River and further downstream.

The Central Valley fall/late fall-run Chinook salmon ESU was classified as a federal Species of Concern in 2004. The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait.

5.5.1 Merced River Fall Chinook- Major Program Recommendations

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

A clear purpose and goal should be established for the program that appears to be dual purpose: experimentation and mitigation. If managers determine that the facility is to be operated for experimental purposes, operational guidelines should be developed consistent with the experiments being undertaken. If managers determine that the hatchery will be operated as a production hatchery to meet mitigation objectives identified in the program description, applicable hatchery standards and guidelines developed by the California HSRG, including the following recommendations should be implemented:

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

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

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

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

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

- Program fish should be 100 percent coded wire-tagged and 25 percent adipose fin-clipped.

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

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

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

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

5.6 Feather River Hatchery

In 1960, California voters authorized the Department of Water Resources (DWR) to construct and operate the State Water Project. Oroville Dam and Reservoir on the Feather River were completed in 1968 and are essential components of this development, providing water storage, hydroelectric power, flood control, and recreational benefits. The dam is five miles east of the City of Oroville. Feather River Hatchery (FRH) is a component of the Oroville Project that was constructed in the mid-1960s to mitigate for blocked Chinook salmon and steelhead spawning habitat. FRH is located downstream of Oroville

Dam and about 66 miles upstream from the confluence of the Feather and Sacramento rivers. An additional facility, the FRH Annex, is located 11 miles downstream adjacent to the Thermalito Afterbay.

The CDFG operates and maintains FRH under contract with the DWR. Although there are no other agencies, tribes, or cooperators directly involved in operating FRH, one advisory group, the Feather River Technical Team, advises FRH personnel on the integration of hatchery operations with management of the salmonid fisheries below Oroville Dam. Three programs are conducted here, producing fall Chinook, spring Chinook and steelhead. Each program is briefly summarized below, followed by sections highlighting the California HSRG's major recommendations for all Nimbus programs and then the program-specific recommendations.

The Central Valley fall/late fall-run Chinook salmon ESU was classified as a federal Species of Concern in 2004. The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait.

The Central Valley spring-run Chinook salmon ESU was classified under the ESA as threatened in 1999. The ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, and the FRH spring-run Chinook salmon program.

The Central Valley steelhead DPS was classified under the ESA as threatened in 1998. The DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait, and the Feather River Hatchery and Coleman National Fish Hatchery steelhead programs.

Feather River Hatchery Fall Chinook

This integrated program traps and spawns fall-run Chinook salmon from the Feather River for rearing and release as juveniles. There are no specific goals for the number of adult Chinook salmon annually trapped or artificially spawned; however, the production goal is to release six million fall-run Chinook salmon smolts that are 60 fpp or larger. Up to two million additional fish may be reared as part of a separate ocean enhancement program. The size at release goal for enhancement program fish is 30 fpp or larger. With the exception of some small on-site experimental releases, Chinook smolts are all released into the Carquinez Straits between April and June. Feather River fall Chinook are currently marked at a 25 percent rate (constant fractional marking) with an adipose fin-clip and a coded wire-tag.

Feather River Hatchery Spring Chinook

The spring Chinook salmon program at Feather River has two components with different purposes: (1) an integrated harvest program to mitigate for lost habitat and juvenile fish production in the Feather River; and (2) an integrated conservation program to aid in the recovery and conservation of spring Chinook salmon from Deer, Mill and Butte creeks. Adult hatchery-produced spring Chinook are intended to spawn naturally or to be genetically integrated with the natural population through artificial propagation. There are no specific goals for the number of adult spring Chinook produced by this program; however, the juvenile production goal is to release two million smolts sized at 60 fpp during April or May. Juvenile hatchery-produced spring Chinook are currently 100 percent marked with an adipose fin-clip and a coded wire-tag. These fish are all released into the Feather River south of Yuba City at the Boyd's Pump Boat Launch (44 miles downstream of the hatchery).

Feather River Hatchery Steelhead

The FRH steelhead program is an integrated harvest program that traps and artificially spawns both marked hatchery-origin and unmarked natural-origin steelhead. Only a few unmarked fish are trapped annually. FRH steelhead are intended to migrate to the ocean and return to provide recreational fishing opportunities and hatchery broodstock as mitigation for lost habitat and juvenile fish production capacity resulting from construction of Oroville Dam. From 1968 through 1987, steelhead eggs from Nimbus, Iron Gate and Skamania hatcheries were transferred to FRH and the juvenile fish reared and released. Since then, only fish returning to the Feather River Basin have been used for broodstock.

There are no specific goals for the number of adult steelhead produced by this program; however, the juvenile production goal is to release 450,000 yearling steelhead annually at three fpp during late January or February. Excluding the past three seasons, hatchery personnel have taken approximately 1.5 million eggs to produce 450,000 juveniles. During the past three seasons, the number of adults trapped and eggs taken have decreased dramatically to less than 615,000 eggs with a commensurate decrease in the number of fish released.

All FRH steelhead are marked with an adipose fin-clip prior to release. These fish are all released into the Feather River south of Yuba City at the Boyd's Pump Boat Launch (44 miles downstream of the hatchery) or at the confluence of the Feather and Sacramento rivers (Verona Marina).

5.6.1 Recommendations for All Feather River Hatchery Programs

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

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

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

- Adult holding facilities should be upgraded and/or expanded to provide adequate space, water flows and temperature regimes to hold the number of adults required for broodstock at high rates of survival (greater than 90 percent). In addition, because of a lack of adult holding space, fall Chinook are returned to the river to make room for late arriving spring Chinook. Evaluate the prospects of using the Thermalito Annex Facility for the long-term holding of spring Chinook broodstock. While the Annex water temperature is relatively high, a pilot study could be used to determine whether any associated increased holding mortality was sufficiently offset by the Annex's otherwise excellent water quality.

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

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

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

- CDFG should develop and promulgate a formal, written fish health policy for operation of its anadromous hatcheries through the Fish and Game Commission policy review process. Hatchery compliance with this policy should be documented annually as part of a Fish Health Management Plan. The current CDFG fish health policy is inadequate to protect native stocks.

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

5.6.2 Feather River Fall Chinook- Major Program Recommendations

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

- Use of the Feather River Annex for rearing should be discontinued unless juveniles are released in the vicinity of the Annex and an adult collection facility is installed in the downstream outlet of the Thermalito Afterbay.

- The program should limit the number of eggs taken to the number necessary to meet production goals (which would include a reasonable overage to account for egg loss and culling of spring x fall crosses). On average, the program takes about 20 million eggs to produce 6 million juveniles.

- Tag analysis should be used to determine the fall and spring hatchery-origin Chinook spawned during the suspected period of run overlap (e.g., fish spawned in the last two weeks of spring Chinook spawning and the first two weeks of fall Chinook spawning). Tags should be read and egg lots tracked and eliminated from production as appropriate to reduce introgression of the two runs. Incubation techniques should therefore allow for separation of eggs from individual parents/families (no more than two families per tray).

- Only unmarked fish should be spawned in the fall brood (FRH spring Chinook are 100 percent adipose fin-clipped, FRH fall Chinook are 25 percent adipose fin-clipped) to reduce the need for culling. Any spring x fall Chinook crosses of hatchery-origin fish (e.g., due to marking or mark detection errors) should be identified by coded wire-tag analysis and eggs should be culled soon after spawning.

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

- Program fish should be 100 percent coded wire-tagged and 25 percent adipose fin-clipped.

5.6.3 Feather River Spring Chinook- Major Program Recommendations

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

- Tag analysis should be used to determine the number of fall and spring Chinook spawned during the suspected period of run overlap (e.g., fish spawned in the last two weeks of spring Chinook spawning and the first two weeks of fall Chinook spawning). Tags should be read and egg lots tracked and eliminated from production as appropriate to reduce introgression of the two runs. Incubation techniques should therefore allow for separation of eggs from individual parents/families (no more than two families per tray).

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

5.6.4 Feather River Steelhead- Major Program Recommendations

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

- A Hatchery Coordination Team should be established to review the status of the FRH steelhead program.

- The number of eggs taken annually should be reduced to a level appropriate to produce 450,000 juveniles and the transfer of eggs to other programs terminated. Collection of excess eggs is permissible to increase effective population size as long as culling is done representatively.

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

- Non-anadromous (resident) fish should not be used as broodstock and the current 16-inch minimum length for broodstock should be continued.

- Hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system, or extended reconditioned and released.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

5.7 Coleman National Fish Hatchery

Coleman National Fish Hatchery (NFH) was completed by the USBR in 1943 to partially mitigate for habitat and fish losses caused by construction of two Central Valley Project features, Shasta and Keswick dams. The hatchery is funded by the USBR and operated by the USFWS. Coleman NFH occupies 75 acres adjacent to Battle Creek, a tributary to the Sacramento River, about 20 miles southeast of Redding.

Shasta Dam blocks 187 miles of salmonid spawning and rearing habitat. Fall Chinook, late-fall Chinook and steelhead are produced to mitigate for this habitat loss, to contribute to ocean and river harvest, and to provide adequate escapement to the hatchery for broodstock. These three programs are summarized below, followed by the California HSRG's major recommendations that apply to all Coleman programs and then sections presenting program-specific recommendations.

The Central Valley fall/late fall-run Chinook salmon ESU was classified as a federal Species of Concern in 2004. This ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait.

The Central Valley steelhead DPS was classified under the ESA as threatened in 1998. The DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, east of the Carquinez Strait, and the Feather River Hatchery and Coleman National Fish Hatchery steelhead programs.

Coleman NFH Fall Chinook Program

The fall Chinook salmon program is integrated with the natural spawning populations in Battle Creek and the Sacramento River. Program broodstock include returning hatchery-origin fish collected from the hatchery fish ladders, and natural-origin fish collected at the Battle Creek weir. Managers also use the barrier weir to block the movement of hatchery-origin fall Chinook into upper Battle Creek in order to protect the ESA-listed spring Chinook salmon spawning in that area, although the weir is ineffective during high flow events.

The program annually releases 12 million fall Chinook in April at a size of 90 fpp, which are expected to contribute a total of 120,000 fish to harvest and escapement over the life of the brood (60-75 percent for harvest). Released fish are constant fractionally marked at a rate of 25 percent (adipose fin-clipped and coded wire-tagged). Ninety percent of program fish are released at or near the hatchery in Battle Creek; ten percent are released into San Pablo Bay.

Coleman NFH Late-Fall Chinook Program

Late-fall Chinook salmon have been managed distinctly from fall Chinook salmon at Coleman since 1973. The late-fall Chinook salmon program is integrated with the natural spawning populations in Battle Creek and the Sacramento River. Program broodstock include returning hatchery-origin fish collected from the hatchery fish ladders and Battle Creek weir, and natural-origin fish collected at the Keswick Dam fish trap. Managers also use the barrier weir to block the movement of hatchery-origin late-fall Chinook into upper Battle Creek in order to protect the ESA-listed spring Chinook salmon spawning in that area, although the weir is ineffective during high flow events.

The program annually releases 1 million late-fall Chinook in December at a size of 13 fpp, which are expected to contribute a total of 10,000 fish to harvest and escapement over the life of the brood (50 percent to harvest). All released fish are adipose fin-clipped and coded wire-tagged, and released at or near the hatchery in Battle Creek.

Coleman NFH Steelhead Program

Until recently, the steelhead program was operated in an integrated fashion, incorporating into the broodstock natural-origin Sacramento River fish from 1947–1986, and natural-origin Battle Creek fish from 1952–2009. The use of natural-origin fish in the program was discontinued in 2009 due to the low abundance of Battle Creek natural-origin fish. If the abundance of the Battle Creek population recovers to sufficient levels in the future, the program will be re-integrated with this population.

The program annually releases 600,000 steelhead in January at a size of 4 fpp, which are expected to contribute a total of 3,000 fish to harvest and escapement over the life of the brood (33 percent for harvest). All released fish are adipose fin-clipped, and released into the Sacramento River at Bend Bridge (about 15 miles downstream of the Battle Creek confluence) to reduce predation on newly emerging Chinook in the upper Sacramento River and Battle Creek. Managers use the Battle Creek barrier weir to block the movement of hatchery-origin steelhead into upper Battle Creek, although the weir is ineffective during high flow events.

The adult return goal to the hatchery has been met in 7 of the last 11 years. Creel survey data indicate that approximately 500 steelhead are harvested annually in the upper Sacramento River, and that the majority of these fish were likely Coleman NFH steelhead since only adipose fin-clipped steelhead can be retained as harvest.

5.7.1 Recommendations for All Coleman Hatchery Programs

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

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

- The emergency backup water intake (#2) should be screened to prevent fish entrainment.

- The USFWS should develop a Hatchery Procedure Manual for each program at Coleman NFH that includes performance criteria and culture techniques presented in IHOT (1995), Fish Hatchery Management (Wedemeyer 2001) or comparable publications.

5.7.2 Coleman Fall Chinook- Major Program Recommendations

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

- Program fish should be 100 percent coded wire-tagged and 25 percent adipose fin-clipped.

5.7.3 Coleman NFH Late-Fall Chinook – Major Program Recommendations

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

- It is recommended that managers investigate the feasibility of collecting natural-origin adult fish at alternate locations, including collecting and retaining fish from Battle Creek.

5.7.4 Coleman NFH Steelhead- Major Program Recommendations

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

- Adult steelhead holding facilities should be upgraded and/or expanded to provide adequate space, water flows and temperature regimes to hold the number of adults required for broodstock at high rates of survival (greater than 90 percent).

- This program should be converted back into an integrated program with a minimum pNOB of 10 percent which thus requires 40-50 natural-origin adults. In recent years, due to the current low abundance of Battle Creek natural-origin steelhead and the concern that collecting these fish for natural-origin broodstock is likely to negatively affect population viability (Standard 1.13), no natural-origin fish have been incorporated into the spawning matrix. It is recommended that managers investigate the feasibility of collecting natural-origin adult fish at alternate locations (e.g., Keswick Dam fish trap) until the abundance of natural-origin steelhead returning to Battle Creek has sufficiently increased to resume their incorporation into the program.

- Current efforts should be expanded to determine the cause of low smolt-to-adult returns for this program. Possible residualization, high in-river mortality, high mortality in the delta/estuary or the ocean, straying as adults, and under-reported catch may be factors.

- Hatchery-origin adult steelhead returns to the hatchery should be treated as follows: (1) unspawned males should be extended reconditioned and released; (2) unspawned females should be stripped of eggs, extended reconditioned and released; and (3) spawned fish should be removed from the system, or extended reconditioned and released.

- Natural-origin adult steelhead returns to the hatchery, whether spawned or unspawned, should be released. Fish may be reconditioned prior to release.

5.8 Livingston Stone National Fish Hatchery

Livingston Stone National Fish Hatchery (NFH), a substation of Coleman NFH, was constructed by the Bureau of Reclamation in late 1997 to produce ESA-listed winter-run Chinook salmon to assist in population recovery. The hatchery is located at the base of Shasta Dam on the Sacramento River (above the terminus of anadromy).

The Sacramento River winter-run Chinook salmon ESU was classified under the ESA as endangered in 1994. The ESU includes all naturally spawned populations of winter-run Chinook salmon in the Sacramento River and its tributaries, the Livingston Stone NFH winter-run Chinook program, and the University of California Bodega Marine Laboratory winter-run Chinook captive broodstock program.

Artificial propagation of winter-run Chinook salmon at Livingston Stone NFH is intended to be a temporary measure that will cease when the naturally spawning population is recovered. A captive broodstock component of the winter-run Chinook salmon program operated from 1991 to 2007, after which it was discontinued because the abundance of natural-origin adults increased. If the abundance level again falls to critically low levels, the captive broodstock element of this program could be reconsidered (USFWS 2011). The Livingston Stone winter-run Chinook salmon program is supported in the NMFS draft Recovery Plan for winter-run Chinook salmon (NMFS 2009; USFWS 2011). No other salmon species are reared here, although the hatchery also rears ESA-listed Delta smelt.

The Livingston Stone NFH program is a conservation-oriented program integrated with the natural population of winter-run Chinook salmon in the upper Sacramento River to provide a demographic boost to aid in population recovery (USFWS 2011). Hatchery-origin winter-run Chinook salmon are intended to return as adults to the upper Sacramento River, spawn in the wild, and become reproductively and genetically assimilated into the natural population. Although there is no adult production goal, Livingston Stone NFH releases up to 250,000 winter-run Chinook salmon at 60 fpp (or a minimum size of 80 fpp) each year in late January or early February. Winter-run Chinook salmon are released at the pre-smolt stage and are intended to rear in the freshwater environment prior to smoltification. All juvenile winter-run Chinook salmon produced at Livingston Stone NFH are adipose fin-clipped and coded wire-tagged. They are released into the Sacramento River at Caldwell Park in Redding (RM 299), about 10 miles downstream of the hatchery.

5.8.1 Livingston Stone Winter Chinook – Major Program Recommendations

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

- Program production goals should be expressed in terms of the number of adult recruits just prior to harvest (age-3 ocean recruits for Chinook).

- It is recommended that managers investigate the feasibility of collecting natural-origin adult fish at the fish ladder at Anderson-Cottonwood Irrigation District (ACID) Dam near Caldwell Park in Redding. The existing trapping location (Keswick Dam) is very limited in its ability to capture fish representing the entire spectrum of winter-run Chinook salmon life history diversity. Only fish that migrate to the furthest upstream reaches are susceptible to capture. Habitat conditions in the uppermost reaches where the trap is located are substantially different from the primary winter-run Chinook salmon spawning area.

- A biosecurity plan (see Standard 3.9) that protects individual programs (winter-run Chinook salmon and Delta smelt) should be prepared and implemented.

- The USFWS should develop a Hatchery Procedure Manual for the program at Livingston Stone NFH, which includes performance criteria and culture techniques presented in IHOT (1995), Fish Hatchery Management (Wedemeyer 2001) or comparable publications.

6. Implementation and Research

Hatchery management and related activities change due to new regulatory mandates and funding opportunities. Management goals and objectives are often inconsistent due to multiple political and regulatory jurisdictions. If hatchery benefits and risks are scientifically assessed, a common language and framework is needed to ensure critical work is effectively developed, efficiently implemented, and reported in a timely manner. The framework consists of a set of premises (Section 1.2) that are the foundation of the statewide issues and recommended standards and guidelines for operating hatchery programs (Chapter 4). The California HSRG strongly urges fishery and hatchery managers to implement the specific standards and guidelines and the resulting program-specific recommendations for hatchery operations. We believe that institutionalization of this implementation framework is critical to achieve meaningful and sustained improvements in hatchery operations, and optimize long-term management of California's anadromous fishery resources.

In the process of this review, the California HSRG was made aware of several internal California State issues that we think limit the ability of state-operated hatcheries to meet program goals. We strongly recommend that the State of California address these specific issues to improve and properly evaluate program performance:

- The California HSRG repeatedly heard that recent State contract issues have prevented hatcheries from using optimum feed. It is essential that all hatcheries have access to the most appropriate feed to ensure meeting readiness-to-smolt and growth trajectory goals.

- Research on a variety of hatchery-related topics (see below) is essential to identify and implement effective hatchery management goals and actions. We recommend that the CDFG develop streamlined and centralized protocols for review, coordination, and timely approval of appropriate or necessary research at all of the hatcheries it operates.

- The CDFG should develop a means to consistently apply best management practices and conservation principles at all of its hatcheries.

- Many of the specific recommendations in this report depend on the collection of biological data both within and outside of hatcheries. We suggest that the State of California provide sufficient, appropriately trained staff at each hatchery to collect this information.

6.1 Implementation Recommendations

Implementation of the Standards and Guidelines and program-specific recommendations will have implications to resource managers (including fishery, hatchery, tribal, and perhaps habitat managers); funding authorities such as utilities, and state and federal agencies; and regulators such as the NMFS. All of these entities will have a role in the implementation of these new recommendations for hatchery operations. In some instance, the California HSRG's recommendations address both in-hatchery reform and out-of-hatchery issues including additional monitoring and research needs.

The California HSRG's review can add significant value to current hatchery practices and the sustainability of existing natural anadromous fish populations only if the principles and recommendations are integrated into the appropriate aspects of hatchery and resource management.

To this end, the following recommendations for implementation are provided:

- Successful implementation of the California HSRG's recommendations will require regular programmatic performance reviews of hatchery programs. While Hatchery Coordination Teams should review programs annually, the California HSRG recommends periodic regional performance reviews of hatchery programs that assess program performance against resource management agencies' goals. These reviews could be undertaken at the regional level and scheduled so that hatchery programs in each region are publicly evaluated no less frequently than every 10 years. The reviews could accomplish necessary oversight for a number of processes, including funding, ESA regulation, independent scientific oversight, and public accountability. As part of the scientific oversight, each hatchery program should be rated on its conservation and harvest performance objectives and the degree to which California HSRG recommendations have been implemented.

- The California HSRG recognizes that Hatchery and Genetic Management Plans (HGMPs) coupled with timely and complete annual fish hatchery reports, are required for effective program management and evaluation. Responsible agencies and the NMFS should apply California HSRG recommendations in the preparation and review of HGMPs (Section 4.4, HGMPs). Resource management agencies should review these recommendations and make reasonable efforts to incorporate them into their management programs. Additionally, the California HSRG recommends that responsible agencies place a high priority on providing the resources for and commit to providing needed monitoring and evaluation information and data as a requirement and integral component of hatchery programs.

- The California HSRG encourages the regional hatchery funding entities (utilities, California Department of Water Resources, US Bureau of Reclamation, USFWS, and the State of California) to adopt the California HSRG's standards and guidelines as a basis for future funding and accountability of their respective hatchery mitigation or enhancement programs.

- Staff with specific highly technical expertise (e.g., fish health specialists) should be tasked with addressing specific highly technical problems in the California hatcheries. Recent consolidation of state classifications (e.g., all "Biologist" classifications subsumed under an "Environmental Scientist" designation) may make it difficult to identify staff with this specific technical expertise.

- Detailed, standardized protocols for monitoring of hatchery programs are currently lacking in the anadromous salmonid hatcheries of California. Section 4.4, Monitoring and Evaluation, lists attributes that need to be monitored and specifies approximate sample sizes that seem appropriate, but standardized protocols for many of these attributes remain to be developed. The same protocols should be adopted at all hatcheries so that data can be directly compared across facilities.

- We recommend that a similar review process be undertaken for the programs in the two state-operated hatcheries in coastal basins, Warm Springs (Russian River) and Mad River hatcheries. Since these programs were not formally part of the purview of the California HSRG, we are not familiar with all aspects of them, but we note that the two steelhead programs at these facilities share many similarities with the programs that were reviewed, and that many of the recommendations in this report are therefore relevant to the operation of these steelhead programs. We recommend that, in the interim period, resource management agencies implement the standards and guidelines specified in this report when they are clearly applicable to these programs.

- Finally, the publicly-accessible website housing the California HSRG's reports will require a permanent host and long-term funding. As of this publication date, the Pacific States Marine Fisheries Commission has indicated a willingness to permanently house and manage this data and information.

6.2 Areas of Needed Research

Deliberations and observations by the California HSRG, while developing recommendations for the 19 anadromous salmonid hatchery programs under review, led to the recognition of areas in particular need of scientific research to guide future management of these and other hatchery programs. In this section we outline these topics, recognizing that there are many more areas in need of information. These topics are all considered to be high priority and are not listed in order of importance.

Identify Populations and Delineate Population Boundaries with which Hatcheries Should be Integrated

For ESA listed stocks, populations and population boundaries have already been established and should be used to determine the appropriate populations and boundaries over which hatchery programs should be integrated. However, many salmonids in California are not ESA-listed and do not have explicitly defined populations and population boundaries. For example, explicit definitions of populations and population boundaries are not available for economically important fall run Chinook salmon in both the Klamath-Trinity basin and the Central Valley. Research is needed to delineate boundaries for all populations that may be affected by a given integrated hatchery program. This should include estimation of rates of straying and genetic migration of hatchery-origin fish released on-site into natural populations and the geographic distribution of such migration.

Determine Relative Reproductive Success of Hatchery- and Natural-origin Salmonids Spawning Naturally

Studies have shown loss of fitness for natural spawning and rearing in hatchery steelhead, coho salmon, and yearling outmigrant populations of Chinook salmon, and the magnitude of this loss appears to vary among species and populations. No such studies have been done for subyearling Chinook salmon released as "fingerlings", where the hatchery fish spend only a few months in the hatchery and their subsequent life history closely matches that of the natural-origin fish, and limited work has directly compared the relative reproductive success of hatchery and natural-origin salmonids in California, with the exception of the steelhead study conducted by USFWS in Battle Creek. Research is needed to evaluate relative reproductive success for hatchery and natural-origin fish spawning naturally and to determine the importance of genetics (domestication) versus developmental history in causing any differences in reproductive success. Since subyearling Chinook salmon released at the fingerling stage have less opportunity for domestication selection, the reduction in reproductive success for such fish may be less than for other hatchery salmonids in California. Therefore, studies of the relative reproductive success of subyearling hatchery Chinook salmon released as fingerlings and natural-origin fish should be a top priority.

Assess Ecological Effects of Hatchery-origin Fish on Naturally Spawning Populations

Research is needed to evaluate whether or where hatchery programs have negative effects on natural populations through competition (in river, estuary, or nearshore ocean), predation (direct or through attracting predator aggregations), behavior effects (e.g., premature emigration of natural-origin fish), or disease and other effects.

Development of Anadromy in Landlocked O. mykiss

While it is clear that life history variation in *O. mykiss* has a heritable component, little is known about the genetic basis of anadromy versus resident behavior, or perhaps more importantly, the potential for induction of genetic changes leading to heritable anadromous behavior in landlocked populations. In many cases, particularly in the Central Valley, resident *O. mykiss* above existing barriers to migration may be more genetically similar to ancestral anadromous *O. mykiss* than contemporary *O. mykiss* found below these barriers. The California HSRG recommends that appropriate agencies implement studies to address this issue.

Potential Uses and Limitations of Parentage Based Tagging

Parentage Based Tagging (PBT) has emerged as a new technology to enhance our understanding of the life histories of hatchery salmon and steelhead through the use of molecular genetic tags to follow the passage of genes over multiple generations. However, the prospects and limits of this technique are not yet well understood. For example, theoretical studies are needed to evaluate how PBT could be used to: 1) improve understanding of survival, maturation schedule and other attributes of hatchery steelhead on a brood year-specific basis, 2) determine the survival of reconditioned kelts, 3) determine the rates of inbreeding (and fitness consequences) for salmon and steelhead hatchery programs, and 4) improve understanding of trait variation in hatchery stocks. Studies are also needed to determine if Chinook salmon hatchery spawning and rearing practices, coastwide sampling programs in fisheries and on spawning grounds, and recovered tag decoding programs could be practically and cost-effectively implemented to completely fulfill the California HSRG Chinook salmon monitoring and evaluation standards.

Assess Long-term Changes in Productivity of Naturally Spawning Populations of Anadromous Salmonids Under Continuing Hatchery Supplementation

Even under situations where hatcheries are operated as integrated programs and PNI exceeds 0.5, as we recommend, the California HSRG remains concerned that the productivity of naturally spawning fish under continuing "supplementation" by hatchery fish may continuously decline in a manner that it not sustainable in the long term. It is therefore recommended that high priority be given to long-term studies of productivity (e.g., smolts produced per spawner) that would be carried out in a stream or streams where, ideally, habitat conditions for spawning and rearing are excellent, but where a substantial fraction (say greater than 20 percent) of spawners are of hatchery origin. Such a study would likely require use of modern genetic methods which could establish the identity of downstream migrants with respect to their parentage (NOxNO, NOxHO, HOxHO). It is important that the habitat conditions in selected streams are unlikely to experience dramatic changes so that any observed changes in productivity could be attributed to the long-term consequences of continuous infusion of hatchery spawners rather than changes in habitat conditions that might otherwise cause productivity to change through time.

Investigate Causes of Decline in Returns of Anadromous Fish in Steelhead Programs

Most of the steelhead programs in California have generally low smolt to adult return ratios. Adult returns to two steelhead hatchery programs (Iron Gate and Mokelumne River hatcheries) have been so low in recent years that it has led to functional failure of these programs. The specific causes of these declines are not well understood. However, several fish culture issues may contribute to the low ratios; IHOT (1995) guidelines recommend release times for juvenile steelhead that are much later than currently practiced at most California hatcheries. Early release may lead to residualism and cause generally low survival rates of released fish. Research should be initiated to elucidate the causes of low adult returns and inform changes in hatchery protocols and procedures to avoid future failure to meet program goals.

Investigate Hatchery Domestication Selection and Development of Mitigation Strategies

The loss in fitness of both hatchery-origin fish and the natural populations with which they are integrated is perhaps the most important negative effect of salmonid hatchery programs. The primary mechanism for such loss of fitness is believed to be domestication selection, which is a general term to describe a variety of selective processes due to hatchery operations or ancestry that typically cause loss of fitness of hatchery-origin fish in natural spawning areas. However, the exact mechanisms that cause this domestication and loss of fitness are poorly understood. Careful research and monitoring should be undertaken to understand domestication selection and propose mitigation measures.

Develop Adaptive Framework for Habitat Carrying Capacity and Production Goals

Diminished carrying capacity of freshwater or ocean habitats can lead to adverse effects on natural populations and/or reduction in societal benefits. Research is needed to evaluate the ability of available freshwater and saltwater habitat to support salmonids at different life history stages and use this information to assist in setting hatchery production goals to avoid adverse effects. Ideally, such a framework would incorporate information on inter-annual and decadal scale variability to adaptively manage hatchery program operations.

Determine the Effects of Hatchery Spawning and Mating Protocols on Age Distribution

The use of age-based selection of fish as broodstock and the subsequent selection of mating partners is likely to have substantial effects on the age distribution of maturing adult salmon and steelhead. For example, two-year-old male salmon (jacks) typically have lower reproductive success than older males in natural spawning areas (although this has not been demonstrated in California), but the magnitude of the difference is not clear. Hatchery spawning protocols most likely fail to replicate the relative reproductive success of different age classes. Age of maturity in salmonids has a heritable component and over- or under-representation of different age classes in hatchery production may cause a selective shift in the age distribution of both the hatchery stock and the natural population with which it is integrated. A mating strategy has been suggested for Chinook salmon (Section 4.1.1) whereby no female is ever mated with a smaller male (except when the male is a jack). The California HSRG is intrigued by this concept but did not fully endorse it, instead preferring to experimentally evaluate the protocol in a selected stock (late-fall Chinook salmon at Coleman NFH). Research is needed on the effects of using different protocols for incorporation of two year old fish into broodstock on the age distributions of the associated hatchery and natural populations, as well as on the effects of using size-based protocols to choose mating partners, and how both of these interact with known effects of hatchery growth rates and harvest on age distribution.

7. Literature Cited

Anderson, E.C. and J.C. Garza. 2006. The power of single-nucleotide polymorphisms for large-scale parentage inference. Genetics 172:2567 – 2582.

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.

Atkinson, S.D., and J.L. Bartholomew. 2010. Spatial, temporal and host factors structure the *Ceratomyxa shasta* (Myxozoa) population in the Klamath River basin. Infection, Genetics and Evolution Volume 10(7): 1019-1026.

Banks, M.A., V.K. Rashbrook, M.J. Calavetta, C.A. Dean, and D. Hedgecock. 2000. Analysis of microsatellite DNA resolves genetic structure and diversity of Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley. Canadian Journal of Fisheries and Aquatic Sciences 57:915-927.

Beamish, R.J., and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Sciences 50(5): 1002-1016.

Beauchamp, D.A., A.D. Cross, J.L. Armstrong, K.W. Myers, J.H. Moss, J.L. Boldt, and L.J. Haldorson. 2007. Bioenergetic responses by Pacific salmon to climate and ecosystem variation. N. Pac. Anadr. Fish Comm. Bull. 4: 257–269.

Campton, D. 2004. Sperm competition in salmon hatcheries: The need to institutionalize genetically benign spawning protocols. Transactions of the American Fisheries Society 133:1277-1289.

CDFG (California Department of Fish and Game). 2004. Recovery strategy for California coho. Report to the Fish and Game Commission. 594 pp.

CDFG (California Department of Fish and Game). 2011. Hatchery and genetic management plan for Iron Gate Hatchery. Prepared by the California Department of Fish and Game (Northern Region) for submittal to NOAA Fisheries. February 2011.

CDFG/NMFS (California Department of Fish and Game/National Marine Fisheries Service Southwest Region Joint Hatchery Review Committee). 2001. Final report on anadromous salmonid fish hatcheries in California. December 2001.

Chapman, D., C. Carlson, D. Weitkamp, G. Matthews, J. Stevenson, and M. Miller. 1997. Homing in sockeye and Chinook salmon transported around part of their smolt migration route in the Columbia River. North American Journal of Fisheries Management 17:101-113.

Chilcote, M.W., K.W. Goodson, and M.R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Can. J. Fish. Aquat. Sci. 68: 511-522.

Clark, G. H. 1929. Division of Fish and Game of California. Fish Bulletin No. 17. Sacramento-San Joaquin salmon (*Oncorhynchus tshawytscha*) fishery of California. 73 pp., 32 figs.

Cuenco, M.S., T.W.H. Backman and P.R. Munday. 1993. The use of supplementation to aid natural stock restoration. Pages 269-293 *in* J. G. Cloud and G.H. Thorgard (eds), Genetic conservation of salmonid fishes. Plenum Publishing Co., New York, New York.

Duffy, E.J. 2009. Factors during early marine life that affect smolt-to-adult survival of ocean-type Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*). Ph.D. dissertation, University of Washington, Seattle.

Fisher, F.W. 1994. Past and present status of Central Valley Chinook salmon. Conservation Biology Volume 8: 870-873.

Ford, M.J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology. 16: 815-825.

Frankel, O.H., and M.E. Soule. 1981. Conservation and evolution. Cambridge University Press, Cambridge, UK.

Frederikson, Kamine and Associates. 1980. Proposed Trinity River basin fish and wildlife management program. Prepared for USDOI Water and Power Resources Service. Contract # 8-07-02-V0035.

Garza, J.C. and E. Anderson. 2007. Large scale parentage inference as an alternative to coded wire-tags for salmon fishery management. *In*: PSC genetic stock identification workshop (May and September 2007): Logistics workgroup final report and recommendations. p.48-55. Pacific Salmon Commission, British Columbia, Canada.

Garza, J.C. and D.E. Pearse 2008. Population genetic structure of *Oncorhynchus mykiss* in the California Central Valley. Final report for the California Department of Fish and Game. Contract No. PO485303 with University of California, Santa Cruz and NOAA Southwest Fisheries Science Center. 54 p.

Hallock, R.J., and R.R. Reisenbichler. 1979. Evaluation of returns from Chinook salmon, *Oncorhynchus tshawytscha*, released as fingerlings at Coleman and Nimbus hatcheries and in the Sacramento River estuary. California Dept. of Fish and Game. Anadromous Fisheries Branch office report. 10 p.

Hamilton J.B., G.L. Curtis, S.M. Snedaker, and D.K. White. 2005. Distribution of anadromous fishes in the upper Klamath River watershed prior to hydropower dams—A synthesis of the historical evidence. Fisheries Vol. 30, No. 4.

Hankin, D. G. 1990. Effects of month of release of hatchery- reared Chinook salmon on size at age, maturation schedule and fishery contribution. Oregon Dept. of Fish and Wildlife. Information Report 90-4. 37 pp.

Hankin, D., and J.E. Logan. 2010. A preliminary analysis of Chinook salmon coded-wire tag recovery data from Iron Gate, Trinity River and Cole Rivers hatcheries, brood years 1978-2004. Contract report prepared for Hoopa Tribal Council, Bureau of Reclamation. 65 pp.

Hankin, D.G., J.H. Clark, R.B. Deriso, J.C. Garza, G.S. Morishima, B.F. Riddell, and C. Schwarz. 2005. Report of the expert panel on the future of the coded wire tag recovery program for Pacific salmon. Pacific Salmon Commission Technical Report No. 18. 230 pp.

Hankin, D.G., J.W. Nicholas, and T.W. Downey. 1993. Evidence for inheritance of age of maturity in Chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Fish. Aquat. Sci. 50: 347-358.

Hankin, D.G., J. Fitzgibbons, and Y. Chen. 2009. Unnatural random mating policies select for younger age at maturity in hatchery Chinook salmon populations. Can. J. Fish. Aquat. Sci. 66: 1505-1521.

Harada, Y., M. Yokota, and M. Iizuka. 1998. Genetic risk of domestication in artificial fish stocking and its possible reduction. Research Population Ecology 40(3):311-324.

Hedrick, P.W. and S.T. Kalinowski. 2000. Inbreeding depression in conservation biology. Annual Review of Ecology and Systematics 31:139-162.

Horner, R.W., and R. L. Eshenrodr [EDS]. 1993. Protocol to minimize the risk of introducing emergency disease agents with importation of salmonid fishes from enzootic areas. Great Lakes Fish. Comm. Spec. Pub 93-1: 39-54.

HSRG (Hatchery Scientific Review Group). 2004. Assessing the potential for predation on wild salmonid fry by hatchery-reared salmonids in Washington. Appendix B. p. B-51 – B-67 *in* Hatchery reform: Principles and recommendations of the HSRG. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from www.hatcheryreform.org).

HSRG (Hatchery Scientific Review Group). 2009. Columbia River hatchery reform system-wide report. Bonneville Power Administration and NOAA Fisheries. February 2009 http://hatcheryreform.us/hrp/uploads/C1EKAOMVHURK/01_HSRG%20Final%20Systemwide%20Report.pdf

IHOT (Integrated Hatchery Operations Team) 1995. Policies and procedures for Columbia Basin anadromous salmonid hatcheries. Annual Report, 1994. Report to Bonneville Power Administration, Contract No. 1992B160629; BPA Report DOE/BP-60629. http://www.hatcheryreform.us/hrp/uploads/VAGREAJSVIM5/IHOT%20STANDARDS.pdf.

Johnson, S.L., M.F. Solazzi, and T.E. Nickelson. 1990. Effects on survival and homing of trucking hatchery yearling coho salmon to release sites. North American Journal of Fisheries Management Volume 10(4): 427-433.

Keeley, E.R., and J.W.A. Grant. 2001. Prey size of salmonid fishes in streams, lakes, and oceans. Can. J. Fish. Aquat. Sci. 58: 1122-1132.

Kinziger, A.P., E. J. Loudenslager, D.G. Hankin, E.C. Anderson, and J.C. Garza. 2008. Hybridization between spring-run and fall-run Chinook salmon returning to Trinity River, California. N. Am. J. Fish. Manage. 28: 1426-1438.

Kinziger, A.P., M. Hellmair, D.G. Hankin, and J.C. Garza. *in prep*. Retention of genetic structure in Klamath Basin Chinook salmon (*Oncorhynchus tshawytscha*) despite extensive within-basin transplantation.

Kostow, K. 2009. Factors that contribute to the ecological risks of salmon and steelhead hatchery programs and some mitigating strategies. Rev. Fish. Biol. Fisheries. 19:9-31.

Lackey, Robert T. 2000. Restoring wild salmon to the Pacific Northwest: chasing an illusion? *In*: What We Don't Know about Pacific Northwest Fish Runs - An Inquiry into Decision-Making. Patricia Koss and Mike Katz, Editors, Portland State University, Portland, Oregon, pp. 91 - 143.

Lande, R. 1995. Mutation and conservation. Conservation Biology 9(4):782-791.

Lawson, P. and D. Sampson. 1996. Gear-related mortality in selective fisheries for ocean salmon. North American Journal of Fisheries Management 16: 512-520.

Leitritz, E. and E. Lewis 1976. Trout and salmon culture (hatchery methods). California Department of Fish and Game, Fish Bulletin 164.

Lichatowich, J.A. and J.D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. American Fisheries Society Symposium 1:131-136.

Liermann, M.C., R. Sharma, and C.K. Parken. 2010. Using accessible watershed size to predict management parameters for Chinook salmon, *Oncorhynchus tshawytscha*, populations with little or no spawner-recruit data: a Bayesian hierarchical modeling approach. Fisheries Management and Ecology 17(1): 40–51.

Limborg,M.T., S.M. Blankenship, S.F. Young, F.M. Utter, L.W Seeb, M.H.H Hansen, and J.E. Seeb. 2012. Signatures of natural selection among lineages and habitats in *Oncorhynchus mykiss*. Ecology and Evolution 2:1-18.

Lindley, S.T., R. Schick, B.P. May, J.J. Anderson, S. Greene, C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2004. Population structure of threatened and endangered Chinook salmon ESUs in California's Central Valley basin. NOAA Technical Memorandum NMFS-SWFSC-360.

Lindley, S.T., C.B. Grimes, M.S. Mohr, W. Peterson, J. Stein, J.T. Anderson, L.W. Botsford, , D.L. Bottom, C.A. Busack, T.K. Collier, J. Ferguson, J.C. Garza, A.M. Grover, D.G. Hankin, R.G. Kope, P.W. Lawson, A. Low, R.B. MacFarlane, K. Moore, M. Palmer-Zwahlen, F.B. Schwing, J. Smith, C. Tracy, R. Webb, B.K. Wells, and T.H. Williams. 2009. What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council. March 18, 2009.

McEwan, D.R. 2001. Central Valley Steelhead. *in* Contributions to the biology of Central Valley salmonids, R. L. Brown, editor. California Department of Fish and Game Fish Bulletin 179. Pg 1-44.

Miller,M.R., J. P. Brunelli, P.A. Wheeler, S. Liu, C.E Rexroad III, Y. Palti, C.Q. Doe, G. H Thorgaard. 2012. A conserved haplotype controls parallel adaptation in geographically distant salmonid populations. Molecular Ecology 21:237-249.

Mobrand, L. E., J. A. Lichatowich, L. C. Lestelle, and T. S. Vogel. 1997. An approach to describing ecosystem performance "through the eyes of salmon". Canadian Journal of Fisheries and Aquatic Sciences 54:2964-2973.

Moffett, J.W., and S.H. Smith. 1950. Biological investigations of the fishery resources of Trinity River, California. U.S. Fish and Wildlife Service. Spec. Sci. Rep. Fish. 12, 71 p.

Moyle, P. B. 2002. Inland Fishes of California, Revised Edition. University of California Press, Berkeley.

Neff, B.D., S.R. Garner, and T.E. Pitcher. 2011. Conservation and enhancement of wild fish. Can. J. Fish. Aquat. Sci. 68:1139-1154.

Nickelson, T. 2003. The influence of hatchery coho salmon (*Oncorhynchus kisutch*) on the productivity of wild coho salmon populations in Oregon coastal basins. Can. J. Fish. Aquat. Sci. 60(9): 1050-1056.

Nielson, 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).

NMFS (National Marine Fisheries Service). 1996. Factors for decline: A supplement to the notice of determination for west coast steelhead under the Endangered Species Act. NMFS Protected Species Branch, Portland, OR, 82 p. + app.

NMFS (National Marine Fisheries Service). 2009. Public draft recovery plan for the evolutionarily 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.

Parravano vs. Babbit. 1995. 70 F.3d 539, 544 (9th Circuit)

Pearse, D.E., C.J. Donohoe, and J.C. Garza. 2007. Population genetics of steelhead (*Oncorhynchus mykiss*) in the Klamath River. Environmental Biology of Fishes 80(4):377-387.

Quinn, T.P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18(1-2): 29-44.

Reclamation (U.S. Bureau of Reclamation). 1956. Contract between the United States and the State of California for the operation of Nimbus Fish Hatchery. Central Valley Project. 3 pages.

Reisenbichler, R.R. and McIntyre. 1986. Requirements for integrating natural and artificial production of anadromous salmonids in the Pacific Northwest. *In* R.H. Stroud [ed.] Fish culture in fisheries management. American Fisheries Society. Bethesda, MD. p. 365-374.

Reisenbichler, R.R., F.M. Utter, and C.C. Krueger. 2003. Genetic concepts and uncertainties in restoring fish populations and species. Pages 149-183 in R.C. Wissmar and P.A. Bisson [editors]. Strategies for restoring river ecosystems – sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, MD.

Reynolds, F.L., T.J. Mills, R. Benthin and A. Low. 1993. Restoring Central Valley streams: A plan for action. California Department of Fish and Game, Sacramento, CA. 129pp.

Scheuerell, M.D., R. Hilborn, M.H. Ruckelshaus, K.K. Bartz, K.M. Lagueux, A.D. Hass, K. Rawson. 2006. The Shiraz model: a tool for incorporating anthropogenic effects and fish-habitat relationships in conservation planning. Can. J. Fish. Aquat. Sci. 63:1596-1607.

Senn, H., J. Mack, and L. Rothfus. 1984. Compendium of low-cost Pacific salmon and steelhead trout production facilities and practices in the Pacific Northwest. Fish Management Consultants.

Stocking R.J., and Bartholomew J.L. 2007. Distribution and habitat characteristics on *Manayunkia speciosa* and infection prevalence with the parasite *Ceratomyxa shasta* in the Klamath River, Oregon-California. J. Parasitology 93(1):78-88.

USFWS (US Fish and Wildlife Service). 1983. Trinity River basin fish and wildlife management program. Final Environmental Impact Report.

USFWS (US Fish and Wildlife Service). 1995. Working paper on restoration needs: Habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 2. May 9, 1995. Anadromous Fish Restoration Program Core Group. Stockton, CA.

USFWS (US Fish and Wildlife Service). 2004. Aquatic animal health policy (713 FW 2). http://www.fws.gov/policy/e1713fw2.html

USFWS (US Fish and Wildlife Service). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: Program description and incidental take of Chinook salmon and steelhead. Coleman National Fish Hatchery Complex, Anderson, CA. July 2011.

USFWS and CDFG (US Fish and Wildlife Service and California Department of Fish and Game). 1956. A plan for the protection and maintenance of fish and wildlife resources affected by the Trinity River Division, Central Valley Project. November 1956.

Weber, E.D. and K.D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Canadian Journal of Fisheries and Aquatic Sciences. 60(8):1018-1036.

Weber, E.D., and K.D. Fausch. 2005. Competition between hatchery-reared and wild juvenile Chinook salmon in enclosures in the Sacramento River, California. Trans. Am. Fish. Soc. 134: 44-58.

Wedemeyer, Gary A. [Ed] 2001. Fish hatchery management, second edition. American Fisheries Society, Bethesda MD, 733 pp.

Williams, J.C. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science. 4(3). 416 p.

Williams, T.H., E.P. Bjorkstedt, W.G. Duffy, D. Hillemeier, G. Kautsky, T.E. Lisle, M. McCain, M. Rode, R.G. Szerlong, R.S. Schick, M.N. Goslin, and A. Agrawal. 2006. Historical population structure of coho salmon in the Southern Oregon/Northern California coasts evolutionarily significant unit. NOAA Technical Memorandum NMFS-SWFSC-390. 71 p.

Williamson, K. and B. May. 2005. Homogenization of fall-run Chinook salmon gene pools in the Central Valley of California. North American Journal of Fisheries Management 25: 993-1009.

Williamson, K. E., A. R. Murdoch, T. N. Pearsons, E. J. Ward, and M. J. Ford. 2010. Factors influencing the relative fitness of hatchery and wild spring Chinook salmon (*Oncorhynchus tshawytscha*) in the Wenatchee River, Washington, USA. Can. J. Fish Aquat. Sci. 67: 1840-1851.

Winton, J.R. 2001. Fish health management. Pages 569-639 *in* G. Wedemeyer (Editor) Fish hatchery management, second edition. American Fisheries Society, Bethesda MD.

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

Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter B. Moyle. 2000. Chinook salmon in the California Central Valley: an assessment. Fisheries. 25(2): 6-20.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71-176 *in* Contributions to the biology of Central Valley salmonids, R. L. Brown, editor. California Department of Fish and Game, Fish Bulletin 179.

California Hatchery Review Report

California Hatchery Scientific Review Group

June 2012

Prepared for:

Cover photos by Mary Edwards Photography, Joseph, Oregon