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# California Hatchery Review
# Statewide Report

Prepared by the
California Hatchery Scientific Review Group

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# California Hatchery Review Statewide 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.

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 removed from the system or reconditioned and released; (2) unspawned females should be removed from the system or stripped of gametes and returned to the river; (3) spawned males should be removed from the system; and (4) spawned females should be released after spawning.

## 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 make up this 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 make up this 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 removed from the system or reconditioned and released; (2) unspawned females should be removed from the system or reconditioned and released; (3) spawned males should be removed from the system; and (4) spawned females should be removed from the system.

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 declined so precipitously 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.