Supplementation of Steelhead in Battle Creek, California: History, Strategy, Objectives, Biological Uncertainties, and a Proposed Genetic Monitoring and Evaluation Plan

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Executive Summary

Human caused disturbances, including operation of the Battle Creek Hydroelectric Project, have adversely affected fishery resources in Battle Creek for over a century. The Coleman National Fish Hatchery was created on Battle Creek in 1942 to partially mitigate for the effects of Shasta Dam. During the recent half-century, hatchery steelhead from the Coleman National Fish Hatchery and natural steelhead in Battle Creek were managed as a single, genetically homogeneous population. In 1995, the U.S. Fish and Wildlife Service began releasing hatchery steelhead upstream of the Coleman NFH barrier weir on an annual to spawn naturally and contribute to the reestablishment of a self sustaining population. Reevaluation of this activity has been prompted by the 1998 listing of Central Valley steelhead as threatened under the Endangered Species Act and, more recently, during the planning of a large-scale habitat restoration project of Battle Creek.

This document lays out the U.S. Fish and Wildlife Service's strategy for temporarily supplementing natural production of steelhead in Battle Creek, California, and for monitoring and evaluating the effects of that activity. Steelhead supplementation has the potential to confer long-term demographic, genetic, and scientific benefits. At the same time, supplementation can impose genetic, ecological, and demographic risks to the natural population. Information presented in this document states the case that the short term supplementation programs benefits outweigh the risks. We believe the unique set of circumstances offered at Battle Creek and the Coleman NFH provide an excellent opportunity to achieve conservation benefits and advance scientific understanding with very limited risks to the existing natural population.

Lastly, this document details a plan to monitor and evaluate the effects of steelhead supplementation program in a hypotheses testing framework. A monitoring program is currently in place to examine ancestral relationships of natural steelhead and hatchery steelhead from Coleman NFH, evaluate the demographic effects of supplementing natural production in Battle Creek, and determine the relative fitness of hatchery and natural steelhead in Battle Creek. Short-term continuation of this supplementation program and follow through of this monitoring plan will provide data that will directly allow us to evaluate effects of this activity, and also help to resolve biological uncertainties and contribute to better informed management decisions in the future throughout northern California and the Pacific Northwest.

TABLE OF CONTENTS

Introduction

The U.S. Fish and Wildlife Service's Coleman National Fish Hatchery (NFH) is located on Battle Creek, an east side tributary to the upper Sacramento River, near the town of Anderson, California. The hatchery was constructed in 1942 to offset, or partially mitigate, for impacts to salmon and steelhead populations caused by the construction of Shasta and Keswick dams. The construction of those dams eliminated almost 200 miles of salmon and steelhead habitat.

The principal objective of the Coleman NFH is to contribute to the Sacramento River sport fishery and maintain adequate escapement to Battle Creek to meet the hatchery's broodstock needs while, at the same time, minimizing negative impacts of the propagation program to natural salmonid populations. To accomplish this objective, Coleman NFH currently rears fall and late-fall Chinook salmon and steelhead. The steelhead propagation program at the Coleman National Fish Hatchery (Coleman NFH) was initiated in 1947.

Also in the Battle Creek watershed, a series of small hydropower dams were constructed in the early 1900's and are now owned and operated by the Pacific Gas & Electric Company (PG&E). The Battle Creek hydropower system blocked upstream access to salmon and steelhead and degraded spawning and rearing habitats by substantially reducing instream flow. Operation of the hydropower system in Battle Creek has severely impacted salmon and steelhead populations for more than a century. Since the early 1950's, a fish barrier weir located on Battle Creek at the site of the Coleman NFH has also precluded or controlled upstream passage of most salmon and steelhead.

Federal and state agencies, PG&E, a local watershed group, and other stakeholders are working cooperatively to help restore natural populations of salmon and steelhead to Battle Creek. On February 16, 1999 the California Department of Fish and Game (CDFG), U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Reclamation (USBR), National Marine Fisheries Service (NMFS), hereafter referred to as "The Agencies", and PG&E signed a Memorandum of Understanding stating the intent to decommission (i.e. remove) five PG&E dams and associated water conveyance facilities, improve instream flows, and provide improved fish passage at the remaining dams located within anadromous fish habitats in Battle Creek. These actions will partially "restore" approximately 42 stream miles of Battle Creek that were previously severely degraded or inaccessible to salmon and steelhead (Ward and Kier 1999). Since 1995, interim flow agreements between the Agencies and PG&E have been in place to temporarily increase instream flows until the stream restoration project is implemented.

To take advantage of increased stream flows resulting from the interim flow agreements the California Department of Fish and Game, in 1995, requested adult steelhead (hatchery and/or natural origin) in excess of numbers needed for the hatchery's broodstock be released above the Coleman NFH barrier weir. The intent of this action was that these fish would spawn naturally and recolonize improved habitats of upper Battle Creek. During the 1995–1996 return year 276 steelhead adults were released upstream. The practice of releasing both natural and hatchery origin steelhead above the hatchery's barrier weir has continued annually since that time. The USFWS considers this activity, which has the objective of promoting natural spawning, to be a

form of supplementation. The primary goal of steelhead supplementation in Battle Creek is to reestablish a self sustaining natural population, which is genetically adapted to the Battle Creek watershed. For the purpose of this document, hereafter "natural" refers to any progeny of naturally-spawning fish and "hatchery" refers to any progeny of fish spawned in a hatchery.

The extent to which hatchery steelhead can contribute to the restoration of a self sustaining natural population of steelhead in Battle Creek is unknown. Therefore, beginning with the 2002-2003 steelhead return season, the USFWS implemented a rigorous genetic monitoring program to evaluate the effects the supplementation program. The document presented here outlines the stock history of hatchery and natural steelhead in Battle Creek, the USFWS strategy and schedule for steelhead supplementation, and a plan for monitoring and evaluating outcomes of that activity.

Background

Summary of Endangered Species Act Listing Actions

During reviews conducted between 1994 and 1996, the National Marine Fisheries Service's (now NOAA Fisheries) steelhead Biological Review Team (BRT) concluded that steelhead native to the Central Valley of California represent an *Evolutionarily Significant Unit* (ESU) of the species (Busby et al. 1996). Steelhead produced at the Coleman NFH were included in the Central Valley steelhead ESU based largely on their broodstock history and genetic similarity to natural steelhead populations in Mill and Deer Creeks (Busby et al. 1996). In 1998, the Central Valley steelhead ESU was listed as *threatened* under the U.S. Endangered Species Act (ESA)(63 FR 13347). However, hatchery steelhead from the Coleman NFH were not included in the threatened listing because hatchery fish were considered "not essential for recovery" at that time. In 2000, critical habitat for Central Valley steelhead was designated, including all estuarine and freshwater habitats within the range and accessible to Central Valley steelhead, including Battle Creek (65 FR 7764).

In 2001, a U.S. Federal Court determined in the case *Alsea Valley Alliance vs. National Marine Fisheries Service* (a.k.a. "the Hogan decision") that NOAA Fisheries could consider only species, subspecies, and distinct population segments when making ESA listing determinations. In short, Judge Hogan determined that either the entire ESU had to be listed or not listed; the ESA does not allow only a portion of an ESU (or *distinct population segment*) to be listed. Accordingly, Judge Hogan ruled that if both natural and hatchery fish comprise an ESU, then both stocks should be considered when evaluating the risks of extinction to that ESU. In response to the Federal Court's decision, NOAA Fisheries is currently revising its hatchery policy consistent with the decision of the Federal Court. Additionally, NOAA Fisheries has undertaken status reviews of 27 ESU's of listed Pacific salmonids. Revised status reviews are anticipated in 2004. The USFWS anticipates that NOAA Fisheries will continue to include hatchery steelhead from the Coleman NFH within the Central Valley steelhead ESU. Therefore, if the Central Valley steelhead ESU continues to be listed under the ESA, then both natural and hatchery steelhead will be included in the listing.

History of Recent Management Decisions to Supplement Steelhead in Battle Creek
In 1995 the USFWS began releasing steelhead upstream of the Coleman NFH barrier weir on an annual basis. The action was initiated at the request of the California Department of Fish and Game with the intent that steelhead released upstream of the hatchery could spawn naturally, thereby taking advantage of improved spawning and rearing habitats created by interim flow agreements between the Agencies and PG&E. During the 1995–1996 steelhead spawning season 276 steelhead adults were released upstream of the Coleman NFH. Over the next two spawning seasons, releases of steelhead adults upstream of the Coleman NFH were 295 (1996-1997) and 418 (1997-1998). At that time, Central Valley steelhead were not yet listed under the ESA. Also at that time, hatchery and natural steelhead in the Central Valley could not be differentiated, so the steelhead released into upper Battle Creek were of unknown origins, but likely included both hatchery and natural steelhead, with a preponderance of hatchery steelhead.

In 1998, the ESA listing of Central Valley steelhead as *threatened* prompted the Agencies to reconsider the Battle Creek steelhead supplementation project in light of the potential impacts to the listed natural stock. Following a multi-agency reassessment of this activity, and recognizing that hatchery and natural steelhead could not yet be differentiated in Battle Creek, the Agencies agreed to continue releasing steelhead adults upstream of the hatchery's barrier weir. However, unlike previous years, the Agencies decided that all steelhead adults in excess of hatchery broodstock needs should be released upstream of the hatchery's barrier weir. This decision was made with consideration of the anticipated completion of the ozone water treatment system at the Coleman NFH, which substantially reduced concerns of releasing potentially infected fishes upstream of the hatchery's water supply. Additionally, three developments had occurred which allowed the effects of steelhead supplementation in Battle Creek to be monitored and evaluated: 1) beginning with brood year 1998 all hatchery juveniles released from the Coleman NFH were marked with an adipose fin-clip; 2) the USFWS implemented a video system (1995) and fish trap (1997) to monitor passage of adult salmonids; and, 3) beginning in 1998 the USFWS began a juvenile monitoring program in Battle Creek that could be used to estimate natural production upstream of the hatchery's barrier weir. Coupled with monitoring at the Coleman NFH during brood stock collection activities, the above actions would allow some measure of evaluation of the Battle Creek steelhead supplementation program.

Beginning in 2001, steelhead in Battle Creek and throughout the Central Valley could be reliably identified to hatchery or natural origin. This was the result of a comprehensive marking program that was implemented at all Central Valley hatcheries since 1998. As a result of this recent ability to distinguish between hatchery and natural steelhead, the Agencies again agreed to reconsider the action of using hatchery steelhead to supplement natural production in Battle Creek. To facilitate an in-depth review, the USFWS committed to producing a comprehensive review of this activity.

In 2002, the USFWS produced a comprehensive review of the Battle Creek steelhead supplementation project, which included a detailed passage plan, a report of genetic relationships of hatchery and natural steelhead in Battle Creek, and a draft plan to monitor and evaluate the impacts of the supplementation program. Following the review, and considering all available information, the Agencies again decided to continue to releasing hatchery and natural steelhead

to spawn naturally in upper Battle Creek. Given the past history of anadromous salmonids in Battle Creek and the opportunity to gain valuable scientific knowledge regarding the potential role of hatchery fish for restoring natural populations, the Agencies agreed that the benefits of the supplementation program outweighed the risks.

In October 2003, a Panel of independent scientists was assembled by the California Bay-Delta Authority (CBDA) on behalf a request from the Battle Creek Watershed Conservancy to review and evaluate potential effects of the Coleman NFH on the planned restoration of anadromous salmonid populations in Battle Creek. A report by the panel of scientists recommended the role and locations of programs at Coleman NFH be reviewed in the context of the goals being developed for the Battle Creek Restoration Program. The Panel also recommended an immediate reassessment of the Battle Creek steelhead supplementation program at the Coleman NFH. The reassessment of the Battle Creek steelhead supplementation program described here emanates from the Panel's recommendation.

History of Hatchery Broodstock

Founding Broodstock

The Coleman NFH stock of steelhead was founded from naturally spawning steelhead from the upper Sacramento River system. The steelhead program at the Coleman NFH was initiated in 1947 by trapping adult broodstock at the Keswick Dam fish trap in the upper Sacramento River. From this initial collection of nineteen adult females, 31,250 eggs were collected, resulting in a release of 11,000 fingerlings. Five hundred juveniles were retained from the release group and reared to maturity at the hatchery as captive broodstock. From 1949-1951 only captive broodstock steelhead were spawned at the Coleman NFH. The steelhead captive broodstock program at the Coleman NFH was terminated in 1952.

Integration with Natural Battle Creek Steelhead

Beginning in 1952, adult steelhead were collected for broodstock from Battle Creek, and broodstock have been collected at that location each year since. From 1952 through 2001 adult steelhead returning to Battle Creek and collected for broodstock have likely been comprised of both natural and hatchery fish. However, because hatchery and natural steelhead are not easily differentiable based on physical appearance, the proportion of each origin was not known until 2001.

Beginning in 2001, adult hatchery steelhead in Battle Creek have been identifiable by a missing adipose fin. During recent years, returns of natural steelhead to Battle Creek have ranged from 131 (2000-2001) to 410 (2002-2003), and comprised from 6% to 15% of the total run to Battle Creek (Table 1). Presently, from 10 – 20% of steelhead broodstock spawned at the Coleman NFH are of natural origin. Incorporation of natural steelhead is conducted to reduce the potential for genetic divergence of hatchery steelhead from and natural steelhead in Battle Creek and to maintain the fitness of the hatchery stock.

Table 1.—Numbers of hatchery origin (hatchery), natural origin (natural), and totals for steelhead trapped at the Coleman NFH, 1988 through 2004. Prior to 2001, hatchery and natural steelhead could not be differentiated. Data shown in this table includes steelhead collected at the Coleman NFH during broodstock collection operations and steelhead trapped or observed at the Coleman NFH barrier weir after broodstock collection had ended.

Return Year	hatchery	natural	Total
1987-1988	-	-	890
1988-1989	-	-	467
1989-1990	-	-	4,172
1990-1991	-	-	1,143
1991-1992	-	-	4,429
1992-1993	-	-	2,862
1993-1994	-	-	3,387
1994-1995	-	-	2,185
1995-1996	-	-	3,106
1996-1997	-	-	2,529
1997-1998	-	-	1,409
1998-1999	-	-	1,755
1999-2000	-	-	1,976
2000-2001	2,163	131	2,294
2001-2002	3,414	410	3,824
2002-2003	2,260	428	2,688
2003-2004	1,611	212	1,823

Integration with Natural Steelhead from the Upper Sacramento River

In addition to broodstock collections at Battle Creek, natural steelhead broodstock were trapped at the Keswick Dam fish trap during the years 1956-1965 (inclusive), 1970-72, 1974, 1977, and 1983-1986. Steelhead from the Keswick Dam fish trap were transported to the Coleman NFH, where they were spawned and their progeny were generally reared and released together with progeny of steelhead adults collected in Battle Creek. Natural steelhead from the upper Sacramento River were thus included into the hatchery broodstock for 21 brood years during the period 1947-1986.

Stock Transfers from Other Hatcheries

Current management practices at the Coleman NFH prohibit the transfer of steelhead broodstock or eggs to Coleman NFH from sources outside of the upper Sacramento River system. In the past, however, steelhead eggs were occasionally transferred to the Coleman NFH from other

locations; mostly from State-operated hatcheries in the Central Valley. Eyed eggs from Nimbus Hatchery on the American River were received in 1972, 1975-77, and 1984. A shipment of eyed eggs from the Feather River Hatchery was also received in 1989. The only transfer of steelhead eggs originating from outside the Central Valley Basin was received from the Mad River Fish Hatchery in 1978. For the eight years when steelhead eggs were transferred to the Coleman NFH from other locations, juvenile releases into the upper Sacramento River system are estimated to have consisted of an average of 35% non-local parentage (Range 5% - 72%).

In addition to steelhead, the Service propagated several strains of non-migratory rainbow trout at the Coleman NFH from 1950-1978. The goal of the Coleman NFH "catchable trout" program was to provide non-anadromous trout for put-and-take fisheries in Shasta and Whiskeytown Lakes and local military installations. At the Coleman NFH, non-anadromous and anadromous strains of rainbow trout were generally spawned and reared separately. However, during the early 1960's nearly 250,000 Gerrard strain rainbow trout (Kamloops) were released into the Sacramento River. The extent of hybridization between these fish and hatchery and natural steelhead cannot be determined. A complete compilation of sources of steelhead and rainbow trout broodstock at the hatchery can be found in the Service's section 7 ESA biological assessment of artificial propagation programs at the Coleman NFH (USFWS 2001a).

Current Operations at the Coleman National Fish Hatchery

Broodstock Collection and Spawning

Adult steelhead are blocked at the Coleman Barrier Weir and broodstock are collected at the Coleman NFH from October through February. Over half of the annual steelhead run typically enters the hatchery prior to January 1. The number of adult steelhead trapped at the Coleman NFH for brood years 1988-2004 ranged from 467 to 4,429 fish.

Approximately 800 adult steelhead are mated at Coleman NFH using a pair-wise strategy (i.e. each male is mated with a separate female). To achieve hatchery production targets, gametes from about 400 adults are required; however, the number of steelhead spawned at the Coleman NFH is doubled to increase the effective population size and maintain genetic variability of the broodstock. Additionally, approximately 10% of the broodstock spawned at the Coleman NFH are of natural origin (n=40). These natural steelhead are mated with hatchery adults to reduce genetic divergence from natural steelhead and maintain natural population characteristics (i.e. fitness) of the hatchery stock. Approximately 50% of the eggs from all hatchery x hatchery matings are culled at the eyed-egg stage so that hatchery production limits are not exceeded. All fertilized/eyed eggs resulting from crosses with natural broodstock are retained. These protocols are designed to maximize the potential genetic diversity of released fish and the genetic contribution from natural adults.

As numbers of natural steelhead in Battle Creek increase in future years, the Service proposes to increase the number of natural steelhead used as hatchery broodstock to 20% of the total number of fish needed to meet hatchery production targets. If this strategy is implemented, incorporation of natural broodstock will be accomplished using a 'sliding scale' that reduces the percentage of natural broodstock during years of low natural adult returns but increases the percentage during years of high natural returns.

Production and Release Targets

The Coleman NFH egg collection target is approximately 1.5 million green eggs. Inventory reductions result in the incubation of 783,000 green eggs. The juvenile release target for steelhead at the Coleman NFH is 600,000 yearling smolts. Steelhead juveniles are released in January at the Sacramento River at Bend Bridge (river mile 258). The target release size for steelhead is 200 mm, or approximately four fish per pound.

Naturally Produced Battle Creek Steelhead

Historical Abundance

Information to document the abundance of steelhead in Battle Creek prior to anthropogenic disturbances is not available. It is generally believed steelhead historically inhabited nearly all tributaries of the Sacramento River where they had access to higher elevations and cool water. Based on the type of habitats that exist in the Battle Creek watershed, we assume the tributary once supported a viable population of steelhead and nonanadromous rainbow trout; perhaps functioning as an important component of an upper Sacramento River steelhead metapopulation. Similarly, we assume that restoration actions occurring as part of the Battle Creek Restoration Project will again provide accessibility to habitats suitable for sustaining a viable steelhead population in that tributary.

Naturally Spawning Steelhead in Battle Creek

Operation of the Battle Creek Hydroelectric Project has substantially decreased flow in Battle Creek and its tributaries and is believed to have adversely affected aquatic habitats and fishery resources (USFWS 2001b, TRPA 1991). Prior to the interim flow agreements in 1995 the minimum required instream releases from the hydroelectric facilities were five cubic feet per second (cfs) in the South fork and three cfs and North fork of Battle Creek. The substantially reduced flows associated with the hydroelectric project, which likely occurred over many decades, likely negatively effected anadromous fish populations through reduced spawning success and/or survival of juveniles, leading to a reduction in population size. However, due to the lack of population size estimates for steelhead in Battle Creek prior to implementation of interim flows, we are unable to quantify these impacts.

The existing naturally spawning population of steelhead in Battle Creek is comprised of a mixture of hatchery and natural adults. Since the beginning of steelhead propagation at the Coleman NFH, reproductive and genetic mixing of hatchery and natural steelhead has likely occurred in Battle Creek as a result of interbreeding of hatchery and natural adult steelhead both in upper and lower Battle Creek and at Coleman NFH. For example, beginning in the early 1950's, an assumed mixture of hatchery and natural steelhead have been intermittently released above the hatchery's barrier weir. Specifically, hatchery records from 1953 through 1995 document frequent releases of adults (range: <100 to approx. 1,500 year) above the Coleman NFH barrier weir and it is likely that additional, undocumented releases also occurred. Releases of hatchery and natural steelhead adults above the Coleman NFH barrier weir have also occurred annually since 1995 to take advantage of increased instream flows resulting from interim flow agreements associated with the Battle Creek Restoration Project (Table 2). Based on these

records, it is therefore assumed that hatchery and natural have been released above the CNFH barrier weir and have potentially spawned together in upper Battle Creek for the past 50 years.

Table 2. Numbers of steelhead collected at Coleman National Fish Hatchery and released above the barrier weir in Battle Creek, return years 1995/1996 - 2003/2004. Data shown in this table includes steelhead collected at the Coleman NFH during broodstock collection operations and steelhead trapped or observed at the Coleman NFH barrier weir after broodstock collection had ended.

	Steelhead Released above the Coleman NFH Barrier Weir		
Return Year	Marked (Hatchery)	Unmarked (Natural)	Total
1995-1996			276[a]
1996-1997			295[a]
1997-1998			418[a]
1998-1999			1,163[a]
1999-2000			1,416[a]
2000-2001	1,352	131	1,483[b]
2001-2002	1,428	410	1,838
2002-2003	770	475	1,245
2003-2004	321	171	492[c]

a. A comprehensive marking program for juvenile steelhead produced at Coleman NFH began in 1998, therefore, differentiation between natural and hatchery adults based on mark status was not entirely possible until the 2001-2002 return year.
b. During 1997 approximately 75% of the juvenile steelhead released from Coleman NFH were marked with an adipose fin clip resulting in age-3 hatchery adults being marked at a rate of 75% during 2000-2001.
c. 2003-2004 Data does not include steelhead collected after March 1, 2004.

Hatchery and natural steelhead in Battle Creek are also able to escape past the Coleman NFH barrier weir when the upstream fish ladder is closed, especially during periods of high flow. Monitoring of fall Chinook salmon at the hatchery's barrier weir has shown that escapement past the Coleman NFH Barrier Weir increases as flows exceed 350 cfs. Steelhead are generally considered to have superior leaping abilities compared to fall Chinook and are therefore likely able to escape past the weir at lower flows and with greater frequency. During the principal period of steelhead migration in Battle Creek (October –February), average monthly flow ranges from 296 cfs in October to 727 cfs in February, suggesting that some escapement past the weir likely occurs throughout the timing of steelhead migration (Kier and Associates 1999). However, the number of steelhead escaping past the weir is unknown. When either the upstream or hatchery fish ladder is open, we believe that most steelhead use the ladders to travel upstream rather than attempting to jump over the Coleman NFH barrier weir. However, empirical evidence to support this is lacking.

Battle Creek Steelhead Supplementation

Overview

Program Goal

- The primary goal of the Battle Creek steelhead supplementation program is to use hatchery steelhead to assist in the restoration of a self-sustaining population of steelhead in Battle Creek and thereafter discontinue additional releases of hatchery adults into those habitats.

Working Hypothesis

The rate of restoration of steelhead in the Battle Creek watershed will be increased by temporarily using hatchery steelhead to reestablish a natural spawning population.

Supplementation Strategy

Hatchery and natural steelhead will be allowed to migrate upstream of the Coleman NFH Barrier Weir with the intent that they will spawn naturally in upper Battle Creek and undergo natural processes of mate selection, nest site selection, and redd building. Eggs and juveniles resulting from these matings of hatchery and natural steelhead will undergo similar influences of natural selection, thereby favoring the survival of individuals best fit to the natural environment of Battle Creek. A genetic monitoring program associated with this activity will be used to evaluate the relative reproductive success and return rate of natural adults resulting from hatchery and natural parents. Our genetic M&E Plan will also allow us to evaluate the number of returning, adult progeny produced by each of the four types of matings (e.g. NxN, HxH, NxH, HxN).

The Service will release both hatchery and natural steelhead above the Coleman NFH barrier weir for a period of five years, beginning with 2002/03, the first year of genetic monitoring. After the 2006/07 return year (i.e. approximately 1 steelhead generation), the Service will discontinue the release of hatchery steelhead above the Coleman barrier weir for at least five years, while continuing release natural steelhead to spawn naturally. Natural origin adults returning during this latter four-year period will include the progeny of both natural and hatchery adults passed upstream during the previous four years. During this period, the Service will continue to monitor and evaluate the steelhead supplementation program by collecting a sample of fin tissue from returning natural adults. At the end of this latter four year period, the overall natural population benefits of hatchery supplementation during the previous five-year period will be evaluated genetically and demographically. At the end of the second five-year period, a decision will be made whether to reinstitute the supplementation program or to continue passing only natural adults upstream.

Maximum Number to Release

The Service will restrict the number of adult steelhead released above the Coleman NFH barrier weir to a number less than can be supported within available spawning habitat in Battle Creek. By restricting the number of steelhead released above the barrier weir, the Service will attempt to reduce risks potentially associated with exceeding habitat carrying capacity (e.g., high stress

levels and redd superimposition).

Information from Payne and Associates (TRPA 1998) and Kondolf and Katzel (1991) have been analyzed by the California Department of Fish and Game to determine carrying capacity of steelhead spawning habitat in Battle Creek (Attachment 1). The analysis suggests available habitats in Battle Creek should be capable of supporting approximately 2,000 adult steelhead. Based upon these calculations, we established an upper limit of 2,000 steelhead to be released above the Coleman NFH barrier weir.

Minimum Number to Release

To maximize the benefits of available spawning habitats and increase the abundance of naturally spawning steelhead in upper Battle Creek the Service will make an effort to release a minimum of 1,000 adults upstream of the Coleman NFH barrier weir during each year that hatchery fish are used to supplement natural spawning. Steelhead released upstream of the Coleman NFH barrier weir may be comprised of both hatchery and natural origin. All natural steelhead that are not retained for hatchery broodstock will be released above the Coleman NFH barrier weir. Additionally, hatchery steelhead will be released to ensure that a minimum of 1,000 total adults are released into upper Battle Creek.

Passage Strategy

The strategy for managing the release of hatchery steelhead upstream of the Coleman NFH barrier weir will be dictated primarily by the number of natural adults available for passage. At the beginning of the run, when the size of the total natural return can not yet be determined, hatchery steelhead will be released upstream at a rate of 2 hatchery steelhead for every one natural steelhead. As the migration season progresses, in-season estimates of the total natural run size will be calculated as described below (see *Appendix A - Methodology to Predict natural Total Run Size*). Based on these estimates, the Service will use a sliding scale to increase or decrease the rate at which hatchery steelhead adults are released above the Coleman NFH barrier weir in order to achieve a seasonal total between 1,000 and 2,000 total adults in upper Battle Creek (Table 3). If the abundance of natural steelhead is predicted to equal or exceed 2,000 adults, passage of hatchery steelhead upstream of the Coleman NFH barrier weir will be discontinued, however, all natural steelhead that are not used as hatchery broodtock will continue to be released.

Potential Benefits of Battle Creek Steelhead Supplementation

Supplementation of steelhead in Battle Creek has the potential to confer long-term demographic and genetic benefits associated with restoration of a self sustaining steelhead population and maintenance of a genetically-integrated hatchery program. A major demographic benefit of the supplementation program comes from utilizing Coleman NFH to bypass the high mortality that occurs in the wild during the fresh water life phase. This decreased mortality results in a greater return to smolt ratio for the hatchery fish than naturally spawning fish. The overall increase in spawner abundance due to the supplementation program thus reduces demographic risks of extinction and aids in the establishment of a self sustaining steelhead population in Battle Creek.

The large effective population size of the hatchery component, due to the number of fish

spawned and the spawning protocols, suggests that the overall effective population size of the natural and hatchery components is greater than the natural component alone. Therefore during this restoration effort the supplementation program provides the genetic benefit of increasing the overall effective population size of the Battle Creek steelhead population. However, these demographic and genetic benefits both rest on the assumption that hatchery fish spawn in the wild and produce viable progeny.

Table 3. Sliding scale for determining the number of hatchery-origin (hatchery) adults passed upstream of the Coleman NFH barrier weir. The basic guiding principles are: (1) pass a minimum of 1,000 adults upstream each year; and (2) stop passing hatchery adults upstream when the number of natural adults passed upstream exceed 2,000 adults.

Natural	Hatchery	TOTAL	% Hatchery
<200	>800	1000	>80%
250	750	1000	75%
300	700	1000	70%
350	700	1050	67%
500	1000	1500	67%
1000	1000	2000	50%
1500	500	2000	25%
1800	200	2000	10%
1900	100	2000	5%
2000	0	2000	0%
>2000	0	>2000	0%

Restoration of a self-sustaining steelhead population in Battle Creek will also benefit genetic management of hatchery and natural steelhead. Coleman NFH currently incorporates about 10% (n=40) natural steelhead as broodstock to reduce genetic divergence from natural steelhead and to maintain fitness of hatchery fish. Dependable availability of natural broodstock is contingent on a healthy naturally spawning population in Battle Creek. A restored steelhead population component in Battle Creek is expected to consist of a larger number of natural adults than exists currently, thereby allowing natural steelhead to be collected for hatchery broodstock with little impact to natural production. Rebuilding the natural population in Battle Creek is thus necessary to further reducing the demographic and domestication risks that the hatchery population segment may impart on the natural population segment.

In addition to the biological and management benefits mentioned above, information gathered through implementation of the Monitoring and Evaluation (M&E) Plan will provide valuable insights into the ability of a long-standing and native hatchery stock to assist with restoration of a self sustaining natural population. In a recent review of salmonid supplementation programs in western North America, Waples et al. (In press) stated "… the biggest gap in our knowledge about supplementation relates to the performance of hatchery –produced fish and their progeny in the natural environment. More research is critically needed in this area." The history of

steelhead management in Battle Creek provides a unique opportunity to study the effects of supplementation, and the "naturalization", of a longstanding and native hatchery steelhead stock. The M&E Plan will address three scientific uncertainties (see below), the results of which will be applicable to both the Battle Creek watershed and restoration programs elsewhere. The long-term goal is to maintain the hatchery and natural populations as one genetic stock with natural selection in the wild driving the genetic characteristics of the population as a whole.

Risks of Battle Creek Steelhead Supplementation

Substantial uncertainty exists regarding the ability of hatchery adults to supplement and restore natural populations of salmon and steelhead (Hindar et al. 1991; Hilborn 1992; Reisenbichler and Rubin 1999; ISAB 2003). Supplementation can impose genetic risks (e.g. reduced effective population size, domestication, loss of genetic variation), ecological risks (e.g. predation, competition, disease) and demographic risks (e.g. poor recruitment and reproductive success of hatchery fish) to the natural population (ISAB 2003). Salmonids have evolved in synchrony with their natural environments, and salmonid populations have adapted to the specific characteristics of their respective habitats (Scientific Review Team 1998). Spawning time, emergence timing, juvenile distribution, and marine orientation and distribution are not random processes, but occur in specific patterns of time and space for each population and are characteristics that represent adaptation to ecological and geographic factors that cannot be replicated or improved through culture in the hatchery environment. Changes within cultured populations for characteristics such as growth rate, age at smolting, spawn timing, and various social behaviors may result in increased performance in hatcheries but may reduce performance and survival in the natural environment.

The level of genetic risk to natural salmonid populations resulting from supplementation programs should be evaluated on a case-by-case basis, considering the multitude of factors that affect potential benefits and risks, including the level of similarity between hatchery and natural stocks. Most geneticists consider interbreeding among *exogenous or genetically diverged* hatchery and natural salmonid populations to be disadvantageous to the natural populations, resulting in a loss of fitness (see Waples 1991, Cuenco et al. 1993, Allendorf and Waples 1996, Reisenbichler and Rubin 1999, NMFS 2000, Einum and Fleming 2001). Several studies have shown genetic differences between hatchery and wild populations of Pacific salmonids resulting from artificial propagation (see review in Campton 1995), and many report evidence of decreased fitness of natural populations following hatchery introgression (e.g., Chilcote et al. 1986, Nickelson et al. 1986, Fleming and Gross 1992 and 1993, Currens et al. 1997, Unwin 1997, Unwin and Glova 1997). In many of these studies, however, interpretation of results are confounded because either: 1) phenotypic differences were initially apparent between hatchery and natural populations (e.g., Reisenbichler and McIntyre 1977, Nickelson et al. 1986); 2) hatchery stocks did not originate from local natural populations (e.g., Chilcote et al. 1986, Currens et al. 1997); or, 3) hatchery stocks had been propagated in isolation from natural populations (e.g., Chilcote et al. 1986, Fleming and Gross 1992 and 1993, Unwin 1997, Unwin and Glova 1997). In several of these studies, it is likely that a combination of these factors influenced the results.

While scientists are in general agreement on the genetic implications of interbreeding between

exogenous or genetically diverged hatchery and natural salmonid populations, the genetic effects of interbreeding between locally-derived and genetically integrated hatchery and natural salmonids is substantially less well understood. Reisenbichler and Rubin (1999) reported at least three studies that used hatchery and natural stocks from local populations and concluded that artificial propagation programs resulted in significant genetic change. In a recent review, however, Waples et al. (In press) evaluated 22 salmon supplementation programs from northwestern North America and found little information is available about the performance of hatchery fish in the natural environment, and almost no empirical information on the long-term effects of hatchery supplementation. The authors considered the premise that hatchery supplementation can provide a net long-term benefit to a natural population to be an untested hypothesis.

We believe the existing natural population of steelhead in Battle Creek should be considered *risk tolerant*. Considering this history of steelhead management in Battle Creek, we believe the majority of natural fish trapped at the Coleman NFH are likely the progeny of hatchery adults that were released upstream of the Coleman NFH barrier weir from two to four years earlier. Throughout the history of fishery management in Battle Creek, hatchery and natural steelhead have been managed as a single genetic stock. Hatchery steelhead have been released intermittently above the hatchery's barrier weir to spawn naturally since the inception of the steelhead program in the 1940's. Natural steelhead have likely been used as hatchery broodstock over the same timeframe. Therefore, hatchery and natural steelhead in Battle Creek are, in all likelihood, two components of a population that are separated by no more than one or two generations of natural spawning. Longstanding and persistent two-way gene flow between hatchery and natural steelhead in Battle Creek has likely created a genetically homogeneous steelhead stock in Battle Creek. Therefore, we believe that any potentially deleterious genetic effects of releasing hatchery steelhead upstream of the Coleman NFH barrier weir would already be manifested within the existing steelhead population in Battle Creek, and three additional years of this supplementation program is not likely to negatively impact steelhead in Battle Creek.

We believe the potential benefits of releasing hatchery fish upstream of the barrier weir for three more years outweigh the potential risks. Marking of all hatchery-produced steelhead smolts since 1998 now allows accurate assessments of the relative abundance of hatchery and natural fish returning to Battle Creek. Our proposed plan will provide data that will allow us to directly evaluate the ability of hatchery steelhead to contribute to restoration of a naturally spawning population in Battle Creek. Our plan will also help resolve biological uncertainties associated with using hatchery steelhead for recovery purposes, and thus contribute to better informed management decisions in the future throughout northern California and the Pacific Northwest.

We believe the unique set of circumstances offered at Battle Creek and the Coleman NFH provide an excellent opportunity to advance our scientific understanding of the role that hatcheries can play towards achieving long-term conservation objectives. In our opinion, the very limited risks of this program to existing natural populations should not preclude the opportunity for hatchery fish to potentially confer a net conservation benefit, especially when the actions will be conducted within a scientifically-based, hypothesis-testing framework. Indeed, *experimental* approaches to natural resource management offer opportunities to resolve

uncertainties, thus increasing the likelihood of achieving desired benefits in the future while further reducing unknown risks.

Monitoring and Evaluation Program

Recognizing the scientific uncertainties surrounding the use of hatchery fish to supplement natural production, the Service has implemented a comprehensive program to monitor and evaluate the demographic and genetic effects of the Battle Creek steelhead supplementation program. The Monitoring and Evaluation Program has been developed to achieve the following goals:

1. Examine ancestral genetic relationships between hatchery steelhead and natural steelhead from proximate locations within the upper Sacramento River system
2. Determine whether supplementation spawning by hatchery adults results in a net demographic benefit to the naturally spawning population in Battle Creek, as measured by spawner replacement rates and total adult returns of natural steelhead.
3. Address biological uncertainties associated with the use of hatchery-origin salmonids in restoration and recovery programs.

Scientific Uncertainties

Our genetic Monitoring and Evaluation Program will attempt to resolve three biological uncertainties associated with the working hypothesis. We will evaluate the benefits and risks of passing hatchery steelhead upstream of the barrier weir through three areas of monitoring and research.

I. Ancestral Relationships

We will (a) determine the ancestral relationships and molecular genetic similarity of hatchery and natural steelhead in Battle Creek and (b) compare those fish genetically to proximate steelhead populations in the upper Sacramento River system.

II. Fitness

We will estimate, via DNA markers, the relative reproductive fitness and genetic contributions of naturally spawning hatchery and natural steelhead in Battle Creek to returning natural adults in subsequent years.

III. Demographic Effects

We will evaluate the net demographic effects of passing hatchery fish upstream as measured by (a) the number of natural steelhead returning to Battle Creek in subsequent years and (b) the relative reproductive output of NxN, HxN, NxH, and HxH natural spawning crosses based on pedigree analyses of DNA markers.

I. - Ancestral Relationships

Do natural and hatchery steelhead in Battle Creek share a gene pool indicative of common ancestral origins relative to other natural steelhead populations in the upper Sacramento River

system? Molecular genetic markers (e.g. microsatellite nuclear DNA loci) allow one to quantitatively test the null hypothesis of a single gene pool. The null hypothesis to be tested is:

> ***Ho: Allele frequencies at molecular genetic loci are equal between hatchery origin and natural origin steelhead in Battle Creek.***

Research Assumptions

Based on our knowledge of the recent histories of hatchery and natural steelhead in Battle Creek, we believe the two groups of fish most likely represent a common gene pool. We believe hatchery and natural steelhead in Battle Creek share similar ancestral origins based on the following factors: (a) the continuous inclusion of wild fish into the hatchery broodstock; (b) genetic similarity between steelhead from the Coleman NFH and natural populations in Battle Creek (Nielsen 2003) and preliminary results from the first year of monitoring associated with this study (see *Preliminary Results* below); (c) the long-term practice of releasing hatchery-origin steelhead upstream of the Barrier Weir, and unintended escapement past the weir, with the presumption that a significant proportion of those adults above the Barrier Weir reproduced successfully.

Research Approach

We will use microsatellite nuclear DNA (nDNA) markers to test the null hypothesis that allele frequencies are equal between natural and hatchery adults returning to Battle Creek. Recent, preliminary data indicate that hatchery and natural steelhead in Battle Creek and the upper Sacramento River (i.e. as trapped at Keswick Dam) are more similar genetically than they are to steelhead inhabiting other tributaries to the upper Sacramento River (see *Preliminary Results* below). These data also indicate genetic structuring among natural and hatchery steelhead, possibly including a temporal component. For example, early-returning natural steelhead in Battle Creek are more similar genetically to hatchery steelhead, whereas late-returning natural steelhead, as sampled March-May 2003, were more similar to late arriving adults trapped at Keswick Dam as sampled May-June, 1999. Analyses of natural and hatchery steelhead will continue to examine genetic relationships between natural and hatchery steelhead, both temporally and spatially (i.e. geographically).

Methods

Samples of fin tissue will be collected from all the following groups of steelhead:

1. For five consecutive years, all hatchery steelhead collected at the Coleman NFH (October – June) and released upstream.
2. For ten consecutive years, all natural steelhead collected in the Coleman NFH barrier weir trap prior to release upstream or inclusion in the hatchery broodstock.
3. A temporally-representative sample of natural steelhead collected at the Keswick Dam fish trap throughout the period of late-fall and winter Chinook broodstock collections (January – July)

Additionally, fin tissue will be collected from samples of 50-100 juvenile steelhead in Mill and Deer Creeks, respectively. These populations will be used for out-group comparisons.

A representative subsample of fish from each group will be analyzed genetically to compare allele frequency variation between groups/populations and temporal genetic variation among years within groups/populations. We will test the null hypothesis that allele frequencies are equal for all sampled groups. Genotyping of all fish for this study will be completed at minimum of 12 microsatellite loci, as described in Ardren et al (1999). Briefly, DNA will be extracted from the fin clips in a Chelex 100 (Sigma Chemical Co.) resin solution as described by Miller and Kapuscinski (1996). Template DNA will be PCR-amplified in a MJ Research PTC-200 DNA engine thermocycler in 15 μL reactions containing 1x polymerase buffer (10 mM Tris-HCL, 50 mM KCL, 1% Triton X-100), 1.5 mM $MgCl_2$, 0.2 mM each dNTP, 0.5μM of each primer and 0.5 U Taq DNA polymerase (obtained from Promega Corporation). Genotypes will be determined by post-PCR multiplexing the amplified loci and using the ABI 3100 DNA sequencer with the G5 filter set to produce electropherograms. Genescan and Genotyper software from Applied Biosystems Incorporated (ABI) will be used to identify alleles at each locus and genotype each fish at those loci.

Preliminary Results

Initial results from 2002-2003 indicate that hatchery and natural origin steelhead in Battle Creek, including adult steelhead trapped at Keswick Dam in 1999, are more similar amongst themselves than any of those groups/populations are to natural populations in Deer and Mill Creek (USFWS unpublished data). However, some temporal genetic structuring of natural adults, based on return timing, suggest that hatchery adults may have made substantially greater genetic contributions to early returning natural adults (October-December) than late returning natural adults (March-May). Additional sampling and analyses are ongoing to determine the sources of the observed temporal genetic variation. Results of these analyses are currently being summarized and will be presented at the Battle Creek Steelhead Supplementation Workshop on 14 June, 2004.

II. - Fitness

What are the relative fitnesses of hatchery and natural steelhead in Battle Creek? Phenotypic fitness is the product of both genetic and environmental factors that influence the survival and reproductive success of individual fish. This study will examine the cumulative effects of genetic and environmental factors on the relative fitnesses of hatchery and natural adults passed upstream of the Barrier Weir (*spawners*) by estimating the number of progeny from each parentage group that return one generation later (*recruits*). The null hypothesis to be tested is:

> ***Ho: The mean numbers of natural adult recruits per adult spawner are equal for hatchery and natural adults released upstream of the hatchery's barrier weir in Battle Creek***.

Research Assumptions

We will measure and compare parent to progeny replacement rates as an indication of the cumulative effects of both genetic and environmental factors for hatchery and natural steelhead spawning naturally in Battle Creek. We presume that the number of natural adult recruits per

adult spawner is most likely less for hatchery adults spawning naturally than for natural adults spawning naturally. Results from several studies are consistent with this assumption. The magnitude of this presumed difference in Battle Creek is unknown, but it will determine the extent to which hatchery steelhead are capable of assisting with recovery of a naturally spawning population. For steelhead in Battle Creek, we believe genetic factors resulting in reduced fitness may be minimal because of the known histories of hatchery and natural origin steelhead in this stream. On the other hand, the environmental effects of hatchery culture may reduce the reproductive performance of returning hatchery adults relative to natural adults because of differences in spawn timing, redd site selection, age and size at return, adult fecundity, juvenile behaviors, etc.

Research Approach

The relatively recent advent of DNA-based methodologies and associated statistical methods allow us to estimate the relative number of progeny of individual fish, and collectively for hatchery and natural fish, by collecting genotypic data on both spawners released upstream of the Barrier Weir and recruits returning one generation later (Jones and Ardren 2003). We will compare multi-locus DNA genotypes of natural adults trapped at the Coleman NFH to the multi-locus genotypes of hatchery and natural adults passed upstream one generation earlier. Age data from scales and extracted DNA from fin clips will be used to identify parents of natural adults trapped at the Coleman NFH. By assessing and comparing replacement rates for hatchery and natural steelhead, we will estimate degree to which hatchery adults are contributing to the restoration and recovery of a naturally spawning steelhead population in Battle Creek.

Methods

We will collect samples of fin tissue and scales from all adult steelhead released upstream of the Coleman NFH Barrier Weir. The following data will be recorded for each steelhead released upstream of the Barrier Weir: length, date, gender, and mark status (e.g., ad-clip, CWT, floy tag, etc.). A fin sample from each fish released above the Coleman NFH Barrier Weir will be analyzed genetically. Allelic comparisons will be made for steelhead encountered at the Barrier Weir to their possible parent population sampled at the Barrier Weir from 2-5 years prior. For example, the genotype for steelhead encountered at the Barrier Weir during year t will be compared to the genotype of steelhead adults released upstream of the Barrier Weir in years t-2, t-3, and t-4 to assign possible parentage probabilities. We will attempt to correlate reproductive success of individual fish with their origin (hatchery or natural) length, age, and date of passage. We will test the null hypothesis that the mean number of natural adult recruits per fish released upstream of the weir is equal for natural and hatchery natural spawners.

As our "library" of archived fin clips develops over time, we will outline a specific study design for collecting genotypic data and reconstructing the pedigree of potential parents passed upstream of the weir and their natural, adult progeny trapped at the Coleman NFH two to five years later. A general description of genetic processes are described in Ardren et al (1999) and are summarized here: DNA will be extracted from the fin clips in a Chelex 100 (Sigma Chemical Co.) resin solution as described by Miller and Kapuscinski (1996). Template DNA will be PCR-amplified in a MJ Research PTC-200 DNA engine thermocycler in 15 μL reactions containing 1x polymerase buffer (10 mM Tris-HCL, 50 mM KCL, 1% Triton X-100), 1.5 mM

$MgCl_2$, 0.2 mM each dNTP, 0.5μM of each primer and 0.5 U Taq DNA polymerase (obtained from Promega Corporation). Genotypes will be determined by post-PCR multiplexing the amplified loci and using the ABI 3100 DNA sequencer (with the G5 filter set to produce electropherograms. Genescan and Genotyper software from Applied Biosystems Incorporated (ABI) will be used to identify alleles at each locus and genotype each fish at those loci.

Genotyping of all fish for this study will be completed at 10-15 microsatellite loci. A large number of nuclear DNA loci would allow genotypic identification of parents by *exclusion*, as opposed to *maximum likelihood* estimation (Jones and Ardren 2003). The exclusion approach will allow us to indirectly estimate the number of progeny returning from adult fish that either "jumped the weir" or reproduced as resident rainbow trout. If all males or females released upstream were excluded as potential parents of a particular natural returning adult, then both unknown parents would have presumably been fish that either "jumped the weir" or were resident rainbow trout. This genetic monitoring of natural reproductive success would need to occur each year for 8-10 years to span two full generations (one parental and one progeny generation), as described previously.

To determine the total number of loci needed to resolve parentage with 95% confidence, we will use simulations to determine the resolving power of the loci given the allele frequencies in each population (Marshall et al. 1998; Gerber et al. 2000). These simulations involve using the allele frequencies for each population to generate parent-offspring pairs or triplets and random genotypes representing unrelated candidate parents. From these simulated data sets, we will calculate the expected distribution of the test statistic, delta, which is the difference in likelihood ratios between the two parents (or parent pairs) most likely to have parented the offspring. From the distributions of delta scores generated in the simulations we can determine a set of loci that will produce 95% confidence in assignment of parentage.

III. - Demographic Effects

Do natural spawning hatchery steelhead confer a net demographic benefit to the naturally-spawning steelhead population in Battle Creek in terms of the number of natural fish returning to spawn one generation later? Even if the reproductive success of individual hatchery steelhead is, on average, less than that of natural steelhead, substantial numbers of hatchery fish spawning naturally could potentially increase the total number of natural smolts and returning adults one generation later. On the other hand, substantial numbers of released hatchery steelhead could suppress the mean reproductive success of natural fish if hatchery steelhead have, on average, a substantially lower mean reproductive success and they directly interbreed with natural steelhead. The demographic uncertainty is the following: Is the "natural population" enhanced or suppressed demographically by allowing hatchery fish to spawn naturally relative to no escapement of hatchery fish? The null hypothesis to be tested is:

> ***Ho: Hatchery fish spawning naturally confer no demographic benefit (or risk) towards restoration and recovery of a naturally spawning population in Battle Creek.***

Research Assumptions

Our working hypothesis, as stated previously, is that releasing hatchery and natural steelhead to spawn naturally in Battle Creek will confer a demographic benefit to the rebuilding population in that stream. While replacement rates for hatchery steelhead may be lower than those of natural steelhead, we believe that a net demographic benefit to naturally spawning steelhead should result from substantially increasing the total number of potential spawners upstream from the hatchery.

Overall, this working hypothesis is the principal hypothesis that needs to be tested. Moreover, Battle Creek provides an excellent scientific opportunity to test this hypothesis because of the risk tolerant nature of the natural population resulting largely from past impacts of the hydropower facilities and past hatchery influences. In short, the steelhead program at the Coleman NFH is being modified significantly to accommodate conservation goals and the restoration of a naturally spawning population in Battle Creek. Such changes are not unique to the steelhead program at the Coleman NFH but, instead, represent a major reform effort throughout the Pacific Northwest include similar conservation goals in hatchery programs (e.g. www.hatcheryreform.org).

Research Approach

Do hatchery-origin adults spawning naturally enhance or suppress the productivity of natural spawners and populations? To some extent, this question can be partially answered by addressing Hypothesis 2 above regarding reproductive fitness. However, successful natural spawning by hatchery-origin fish could, conceptually, reduce the reproductive success of natural adults via competition for spawning sites or other ecological interactions, thus resulting in little or no net demographic benefit.

Assessing the net demographic effects of passing hatchery-origin fish upstream is extremely difficult. Ideally, time-series changes in the abundance of natural adults in "treatment" streams, where hatchery-origin fish are released, would be compared to "control" streams where no hatchery fish are released. In the absence of control populations, it is difficult for one to draw valid interpretations regarding the causes of increases or decreases in the abundance of natural adults over time.

Consequently, in the absence of control streams or populations, we need to address demographic uncertainties indirectly. We will assess the demographic effects of hatchery fish spawning naturally with natural fish by comparing the adult productivity of NxN, NxH, HxN, and NxN crosses that occur naturally in Battle Creek relative to the number of natural and hatchery adults passed upstream. We will estimate the genetic contributions of naturally-spawning hatchery and natural steelhead to returning adult progeny one generation later. The relative magnitude of those reproductive successes relative to the number of hatchery and natural adults passed upstream will allow an overall indirect assessment of the demographic effects of hatchery adults spawning naturally in Battle Creek. For example, if the number of adult natural progeny resulting from HxN and NxH crosses is substantially less than predicted based on the number of returning NxN adult progeny and the number of hatchery and natural adults passed upstream, including substantially less than predicted numbers of HxH natural progeny, then the interbreeding of hatchery and natural adults may suppress the reproductive success of natural

adults relative to natural fish spawning only among themselves. Based on the relative reproductive success of natural and hatchery adults, and the relative numbers of natural adult recruits resulting from each of the four cross types, we will estimate the overall net demographic effects of releasing hatchery adults upstream to spawn naturally.

The actual numbers of hatchery and natural adults released upstream will be constrained by the estimated carrying capacity of the habitat upstream of the Coleman NFH barrier weir. Additionally, the number of returning hatchery fish released upstream of the Barrier Weir will be controlled relative to the number of natural fish released upstream, following the passage strategy described above.

Methods

To address demographic effects and the potential impacts of hatchery spawners (*H)* on the reproductive success of natural adults (*N*), we will use the DNA markers and pedigree data described previously to compare the number of natural recruits per adult spawner (R/S) for *N*x*N*, *N*x*H*, *H*x*N*, and *H*x*H* crosses that occur naturally in Battle Creek. By comparing the mean number of natural progeny for each cross type relative to the number of natural and hatchery adults passed upstream one generation previously, we will evaluate the mean reproductive success of natural spawners when they spawn with hatchery adults versus the reproductive success of natural adults when they spawn with each other. These data will allow us to compute the Recruit:Spawner ratio for each cross type and then predict the number of natural adult recruits that would have occurred in the absence of hatchery adults spawning naturally. We will also assume, under H_O, that random mating among hatchery and natural adults would occur naturally if the two groups were biologically equal or equivalent with respect to reproductive success. In this context, we expect the actual number of natural progeny resulting from HxH matings to be substantially less than predicted

Summary of the Proposed Actions and the Monitoring &Evaluation Program

- Spawn approximately 400 males and 400 females (750 hatchery-origin and a minimum of 50 natural adults). Cull and discard approximately 50% of the eyed eggs from each HxH cross. (Note: This latter approach nearly doubles the potential genetic diversity of the progeny while limiting the genetic contribution from hatchery-origin parents) Retain all eyed eggs from families with at least one natural parent (e.g. NxH crosses). This protocol will yield approximately 600,000 smolts for release, with natural adults making a minimum 10% genetic contribution to the broodstock each year. This latter percentage will be increased in later years if restoration goals are met and the abundance of natural adults increases.

- Collect fin clips, length data, and scale samples from all natural-origin steelhead trapped at the Coleman NFH. Pass all natural-origin adults upstream to spawn except for those fish retained for hatchery broodstock.

- Collect fin clips from all hatchery-origin adults passed upstream for five consecutive years.

- Collect multi-locus genotypic data at 10-20 nDNA microsatellite loci on 100 natural and 100

hatchery adults trapped at the Coleman NFH each year for three consecutive years. Obtain comparable data on natural adults trapped in the bypass ladder after March 1. Test the null hypothesis that allele frequencies are equal for the three groups of fish and compare to fish trapped at Keswick Dam, January 1 – June 30.

- Collect multi-locus genotypic data at 15-20 nDNA microsatellite loci on all natural fish trapped at the Coleman NFH and all hatchery fish passed upstream from the barrier weir.

- Reconstruct the pedigree of all fish passed upstream of the barrier weir and all natural adults trapped at Coleman NFH 2-5 years later based on their multi-locus genotypes at 15-20 nDNA microsatellite loci.

- Collate natural spawning success of individual fish passed upstream of the barrier weir with the total number of natural adults trapped at the Coleman NFH 2-5 years later.

- Continue implementation of the M&E plan for 8 to 10 years (2 full generations).

- Closely monitor the total number of natural adults trapped at the Coleman NFH. When the total number of natural steelhead exceeds 1,668, then the percent of the broodstock derived from natural adults will exceed the percent of natural spawners comprised of hatchery steelhead upstream of the weir (Table 1). This latter abundance threshold for natural trapped at the Coleman NFH would be a major milestone in the restoration of a naturally spawning population in Battle Creek.

REFERENCES

Allendorf, F.W. and R.S. Waples. 1996. Conservation and genetics of salmonid fishes, pp. 238-280 in J.C. Avise and J.L. Hamrick (eds.) Conservation Genetics, Case Histories from Nature. Chapman and Hall, New York.

Ardren, W.R., Borer, S., Thrower, F., Joyce, J.E., and Kapuscinski, A.R. 1999. Inheritance of 12 microsatellite loci in *Oncorhynchus mykiss*. Journal of Heredity **90**: 529-536.

ISAB (Independent Scientific Advisory Board). 2003. Review of Salmon and Steelhead Supplementation. Prepared for the Northwest Power Planning Council, the National Marine Fisheries Service, and the Columbia River Basin Indian Tribes. 851 SW 6th Avenue, Suite 1100 , Portland, Oregon 97204. ISAB@nwppc.org.

Busby P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz and I.V. Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon and California. National Marine Fisheries Service. NOAA Technical Memorandum NMFS-NWFSC

Campton, D.E. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: what do we really know? American Fisheries Society Symposium 15:337-353.

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transactions of the American Fisheries Society 115:726-735.

Cuenco, M.L., T.W.H. Backman, and P.R. Mundy. 1993. The use of supplementation to aid in natural stock restoration, pp. 269-293 *in* J.G. Cloud and G.H. Thorgaard (eds.), Genetic Conservation of Salmonid Fishes. Plenum Press, New York.

Currens, K.P., A.R. Hemmingsen, R.A. French, D.V. Buchanan, C.B. Schreck, and H.W. Li. 1997. Introgression and susceptibility to disease in a wild population of rainbow trout. North American Journal of Fisheries Management 17:1065-1078.

Sinum, S. and I.A. Fleming. 2001. Implications of stocking: ecological interactions between wild and released salmonids. Nordic J. Frwsw. Res. 75: 56-70.

Fleming, I.A. and M.R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (*Oncorhynchus kisutch*): does it differ? Aquaculture 103:101-121.

Fleming, I.A. and M.R. Gross. 1993. Breeding success of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. Ecological Applications 3(2):230-245.

Gerber S., S. Mariette, R. Streiff, C. Bodenes, A. Kremer. 2000. Comparison of microsatellites and amplified fragment length polymorphism markers for parentage analysis. *Molecular Ecology* 9:1037-1048.

Hilborn, R. 1992. Hatcheries and the future of salmon in the Northwest. Fisheries 17(1):5-8.

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. 48:945-957.

Jones, A.G. and W.R. Ardren. 2003. Invited Review: Methods of parentage analysis in natural populations. Molecular Ecology 12:2511-2523.

Kier Associates. 1999. Battle Creek Salmon and Steelhead Restoration Plan. Prepared for the Battle Creek Working Group by Kier Associates, Sausalito, California. 142 pp.

Kondolf and Katzel. 1991. Spawning gravel resources of Battle Creek, Shasta and Tehama Counties – Draft. Prepared for the California Department of Fish and Game.

Marshall T.C., J. Slate, L.E.B. Kruuk, and J.M. Pemberton. 1998. Statistical confidence for likelihood-based paternity inference in natural populations. *Molecular Ecology* 7:639-655.

Miller, L.M., and A.R. Kapuscinski. 1996. Microsatellite DNA markers reveal new levels of variation in northern pike. Trans. Am. Fish. Soc. 125:971-997.

Nickelson, T.E., M.F. Solazzi, and S.L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 43:2443-2449.

NMFS (National Marine Fisheries Service). 2000. Conservation of Columbia Basin Fish Final Basinwide Salmon Recovery Strategy, Vol. 2: Technical Information. Prepared by NMFS in consultation with the Federal Caucus. December 2000.

Nielsen, J.L., S. Pavey, T. Wiacek, G.K. Sage, and I. Williams. 2003. Genetic Analyses of Central Valley Trout Populations 1999-2003. Final Technical Report submitted to the California Department of Fish and Game Sacramento, Ca, and the U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office.

TRPA (Thomas R. Payne and Associates). 1991. Hydrologic Analysis for Battle Creek, Shasta and Tehama Counties. Prepared for the California Department of Fish and Game.

TRPA (Thomas R. Payne and Associates). 1998. A 1989 instream flow study: one of eight components. Prepared for the California Department of Fish and Game.

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmo gairdneri*. Journal of the Fisheries Research Board of Canada 34:123-128.

Reisenbichler, R.R. and S.P. Rubin. 1999. Genetic changes from artificial propagation of Pacific salmon affect thee productivity and viability of supplemented populations. ICES Journal of Marine Science 56:459-466.

Scientific Review Team. 1998. Review of artificial production of anadromous and resident fish in the Columbia River basin. Part I: Scientific basis for Columbia River production programs. Document number 98-33. Prepared for the Northwest Power Planning Council. 46 pp.

Unwin, M.J. 1997. Fry-to-adult survival of natural and hatchery-produced chinook salmon (Oncorhynchus tshawytscha) from a common origin. Canadian Journal of Fisheries and Aquatic Sciences 54:1246-1254.

Unwin, M.J. and G.J. Glova. 1997. Changes in life history paramenters in a naturally spawning population of chinook salmon (*Oncorhynchus tshawytscha*) associated with releases of hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 54:1235-1245.

USFWS (U.S. Fish and Wildlife Service). 2001a. 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 trout. Red Bluff Fish and Wildlife Service, Red Bluff, Ca. 96080.

USFWS (U.S. Fish and Wildlife Service). 2001b. Final restoration plan for the Anadromous Fish Restoration Program. Sacramento, California. 112 pp. plus appendices.

Ward, M.B., and W.M. Kier. 1999. Maximizing compatibility between Coleman National Fish Hatchery operations, management of lower Battle Creek, and salmon and steelhead restoration. Prepared for the Battle Creek Working Group by Kier Associates, Sausalito, California.

Waples, R.S., M.J. Ford, and D. Schmitt. In press. Empirical results of salmon supplementation: a preliminary assessment In T. Bert, ed. Ecological and Genetic Implications of Aquaculture Activities. Kluwer Academic Publishers.

Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 48 (Suppl. 1): 124-133.

Appendix A. Methodology to Predict natural Total Run Size

The run timing of natural steelhead returning to Battle Creek in 2001/2002 and 2002/2003 will be used to calculate in-season estimates of total run size of natural steelhead for the current return year (Figure 1). At several times during each season that releases of hatchery steelhead above the Coleman NFH barrier weir occur, we will predict the total seasonal run size of natural steelhead returning to Battle Creek by dividing the number of natural steelhead released above the Coleman NFH barrier by the cumulative percentage of historic passage at that week (Figure 1).

We estimate total natural steelhead run size by:

Total natural Run Size = (Current Number Passed / Historic Percent Passed)

Where:

Current Number Passed = the number of natural steelhead passed above the Coleman NFH barrier weir at week (w) during the current return year,

and;

Previous Percent Passed = the average cumulative percent of the natural steelhead run passed above the barrier weir at week (w) in return years 2001/2002 and 2002/2003 (Table 4).

Applying the formula to the current return year we will estimate the total number of natural steelhead expected to return to Battle Creek. For example, if 450 natural steelhead had returned by week 48, based on historic passage data, we would estimate that approximately 30.7% of passage had occurred by that week (Figure A-1) and predict a total run size of 1,466 natural steelhead. Total run size estimates will periodically be calculated throughout the season. The number of hatchery steelhead passed can then be adjusted to meet the minimum passage goal of 1,000 adults or ensure that the maximum steelhead habitat carrying capacity (~2000 adults) is not exceeded.

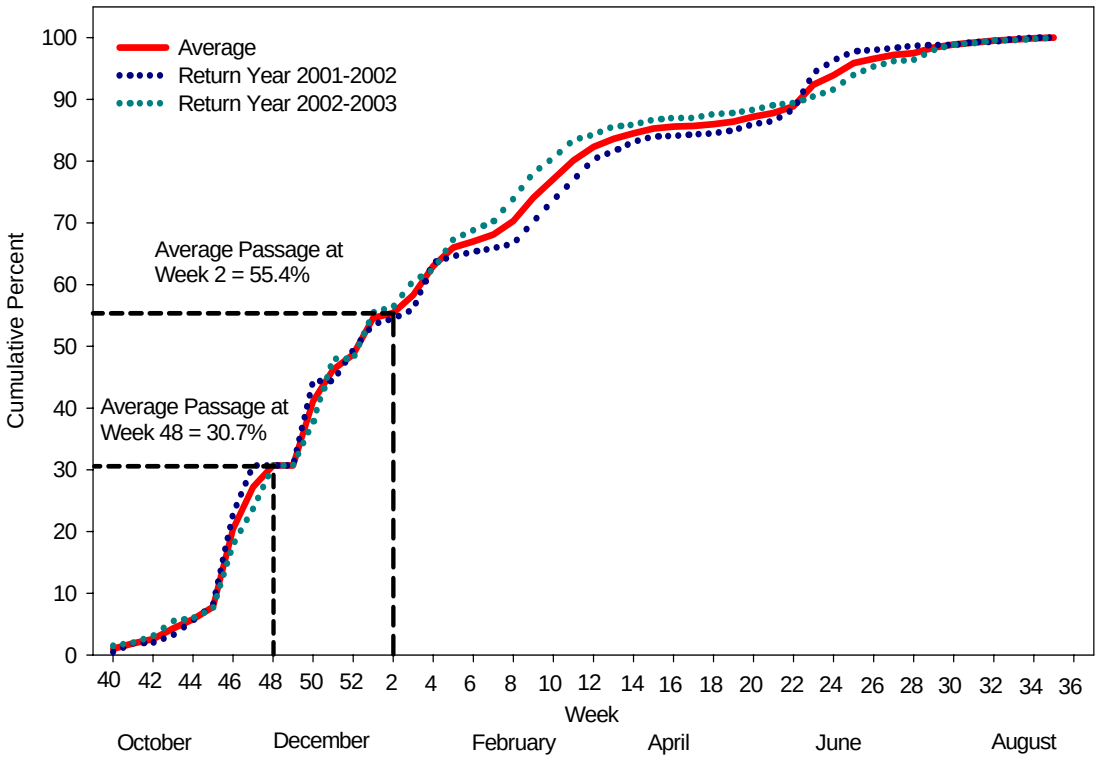

Figure A-1.-- Weekly cumulative percentage of natural origin steelhead returning to Battle Creek, Ca. during return years 2001/2002 and 2002/2003.

Attachment 1.

Draft Revised Steelhead Spawning Habitat Availability in Battle Creek

N.F. Battle Creek: Flow = 40cfs
Length (confluence to Eagle Canyon Dam) = 5.29 miles (27,930 ft.)
Estimated spawning habitat at 40cfs = 1100 sq.ft./1000ft.
Total estimated available habitat at 40cfs = 30,690 sq. ft.
Total possible redds (assume redd size 60 sq. ft.) = 512
Total possible adult steelhead (assume 2/redd) = 1024

S. F. Battle Creek: Flow = 15cfs
Length (confluence to Coleman diversion) = 2.54 miles (13,411 ft)
Estimated spawning habitat at 15 cfs = 250 sq.ft./1000 ft.
Total estimated available habitat at 15cfs = 3350 sq. ft.
Total possible redds (@ 60 sq. ft.) = 56
Total possible adult steelhead (2/redd) = 112

M. S. Battle Creek: Flow = 350cfs
Length (Coleman powerhouse to confluence) = 10.06 miles (53,117 ft)
Estimated spawning habitat at 350 cfs = 500 sq.ft./1000 ft.
Total estimated available habitat at 350cfs = 26,550 sq. ft.
Total possible redds (@ 60 sq. ft.) = 443 redds
Total possible adult steelhead (2/redd) = 886

Sum of available reaches = 1011 redds or 2,022 adult steelhead.

Based on weighted usable area curves presented in Battle Creek Fisheries Studies, Task 1: Instream Flow Study, prepared by Thomas R. Payne and Associates 1998.

Source: Transcribed from original calculations by Mike Berry, California Department of Fish and Game, Redding,

CA