

State of California
The Resources Agency
Department of Fish and Game

FISH BULLETIN 179

CONTRIBUTIONS TO THE BIOLOGY OF CENTRAL VALLEY SALMONIDS

VOLUME 1

Edited by

Randall L. Brown
Department of Water Resources
Sacramento, California



2001

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Preface

The Salmonid Symposium was organized by an ad hoc committee of state and federal fishery biologists concerned with the management of Central Valley (CV) salmon and steelhead trout (*Oncorhynchus* spp.) populations and their habitats. It was held at Bodega Bay, California on October 22–24, 1997. Topics covered included research on various CV salmon and steelhead populations, ocean fishery management, history of upper Sacramento River hatchery operations, and steelhead management policy.

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Dedication

Fish Bulletin 179 is dedicated to the memory of Nat Bingham. Zeke Grader penned the text, but the feelings and inspiration come from the California community of fishermen, salmon biologists and managers.

It was about 10 years ago, the news had just come out that only 191 winter-run chinook had returned to the Sacramento River that year, when, in a call, Nat said something to the effect: “We’ve got to do something. This run will not go extinct on our watch.” With that pronouncement, he set in motion a whirlwind of activity that, although we weren’t certain in what direction, determined this magnificent run of salmon, spawning in the tributaries of the Upper Sacramento in the heat of the summer, those fish Livingston Stone chronicled more than a century before, would not be lost.

The campaign to save the winter-run began, and the eventual captive broodstock program and all of the products of that effort, was much like FDR’s approach to the depression. That is, try something, do something, but just don’t sit there. Nat Bingham, an ardent student of history may well have thought of that. Nat was going to do something. Initially, he considered a pen-rearing program at the National Marine Fisheries Service’s Tiburon Laboratory, but after gathering the agencies and scientists together an alternate plan began to evolve. The fact that his original concept was rejected didn’t bother him. He cared more that an action plan to save the run was now in motion.

Nat also knew that to save fish—again, as a student of history—the battle had to be engaged on many fronts. A captive broodstock program might prevent extinction of the winter-run, but action had to be taken to correct the problems that had led to the drastic decline of these fish. In a score of years the number of spawners had plummeted from almost 120,000 to less than 200. Litigation, lobbying Congress, cajoling farmers and water districts became Nat’s almost daily activity until he died.

Nat had come from a famous old Connecticut family and started commercial fishing in the Bahamas as a teenager. He arrived in Berkeley in the sixties and shortly after that began commercial fishing salmon and albacore out of the East Bay. A few years later he ended up on California’s north coast where, as a salmon troller, he began to take an interest in the factors affecting salmon productivity. He familiarized himself with the watersheds and the streams and was soon working with groups such as the Salmon Unlimited and the Salmon Trollers Marketing Association. He helped install and operate hatch box programs aimed at jump-starting runs that had nearly been extirpated from damage to the watershed. He saw first hand that logging, road building and a host

of other land use activities were decimating the runs. Unlike most of his contemporaries, he would speak out. And, he railed against what he described as the “code of silence” among those in fisheries who would not actively defend the fish. “No more silence” was his mantra.

Outspoken yes, but Nat was also a gentle person who did not see those across the table as enemies but merely people who needed to be educated about the fish, who needed to understand what the fish needed. He never personalized a fight. He was never anti-logging, anti-grazing, anti-farming, or anti-urban water usage, he was just pro-fish. He never saw winning for the fish as defeating someone else. He was the practitioner of what many now call “win-win.”

He was also tireless. In the early 1980s, at the height of an El Nino, he took over as president of a beleaguered Pacific Coast Federation of Fishermen’s Associations (PCFFA), a more or less coastwide umbrella group of family-based fishing organizations. Ocean conditions associated with El Nino had devastated salmon production and left the group’s coffers nearly empty. Over the next decade he found himself fishing less and spending more time helping with the organization and working on battles to save salmon from the Central Valley to the Columbia. He worked with tribes and ranchers in the Klamath Basin and with the timber industry in coastal watersheds—always trying to save, to rebuild salmon runs. He built alliances with conservation organizations and he looked for opportunities to work with those generally considered his adversaries—from timber industry executives, to power companies, to heads of agricultural and urban water districts. There were few meetings on salmon where Nat was not present.

In the early 1990s seeing no end to the fight for salmon survival, Nat decided to step down as President of PCFFA, a job he could very well have held for life, to sell his boat and dedicate himself exclusively to efforts to restore salmon habitat and rebuild the runs. PCFFA was able to cobble some monies together from government and private foundation contracts and grants and put Nat on the road. For the next seven years his beat-up Toyota pickup, held together it seems by bumper stickers, could be seen up and down the Central Valley, in the Sierra or the Trinity or in some coastal watershed. Nat the salmon disciple, the crusader would be working patiently and in his quiet way to convince people to do things differently so salmon could not only survive, but thrive.

In the spring of 1998, things were looking up for Nat. Quietly working behind the scenes he was able in six-month’s time to help establish a winter chinook conservation hatchery on the mainstem of the Sacramento, just below Shasta Dam. Nat called it the Livingston Stone Hatchery, a name that has stuck. Moreover, negotiations with Pacific Gas & Electric were progressing for the removal of dams on Battle Creek to establish an additional “homestream” for

the winter run. But it was also a tiring period, the Pacific Fishery Management Council meetings (to which Nat was appointed to a few years before) were particularly arduous. At the end of the April Council meeting Nat's wife Kathy was diagnosed with terminal cancer and by the end of the month she was gone. Nat kept his spirits up, but he was exhausted physically and mentally and within a week of Kathy's death, he was gone too.

Nat's life is the stuff of a great book. The important thing, however, for those of us left working for the survival of the salmon to remember what he did and how he did it—and, how he lived his life. With Nat's life as our inspiration, we will win.

Zeke Grader

In Appreciation

With the release of this Fish Bulletin, we extend our appreciation and those of our fellow biologists to its editor, Dr. Randall L. Brown. As local readers are aware, Randy retired last year from State service where he was employed for over 34 years by the California Department of Water Resources.

He will be forever remembered for his great devotion to improving our understanding of salmon biology in the Central Valley and San Francisco Bay-Delta Estuary of California. Randy's professionalism, support, encouragement and friendship to all of us in the salmon community is greatly respected and appreciated. His tireless efforts to enhance salmon monitoring and research as a coordinator in the Interagency Ecological Program, Chief Biologist for the Department, member of numerous committees related to salmon and their management, and as a leader in conducting multiple workshops, meetings, conferences, and symposiums on salmon has greatly improved our knowledge of salmon. Our progress in the area of salmon population genetics, salmon-hydrodynamics interactions, monitoring and evaluation techniques, population dynamics, data management and other fields are directly related to his personal efforts and accomplishments.

We join together to thank Randy as a friend and colleague for his excellent work and wish him the best in his retirement and all future endeavors.

Marty Kjelson
Terry J. Mills

Acknowledgements

Pulling this volume together would not have been possible without the support of Marty Kjelson and Terry Mills. We first discussed the concept over Chinese food a year or so before the Bodega meeting. Periodic meetings before and after Bodega kept me on track – to the extent that is possible.

Special thanks to the symposium presenters for converting their talks to papers. Joe Miyamoto of the East Bay Municipal Utility District receives the award for being, by far, the first to submit a manuscript.

I would also like to acknowledge several authors who did not present papers at Bodega but who were willing to contribute material to help make this a more balanced compendium.

Several anonymous peer reviewers took their valuable time to review the articles and their comments made for a better product.

L.B. Boydstun, of the California Department of Fish and Game, deserves recognition for allowing us to use the Department's Fish Bulletin series and to serve as the DFG sponsor. This is in keeping with L.B.'s long history of working with his agency, NMFS and the commercial and recreational fishing industry to scientifically manage a resource of special significance to California.

Finally, we should all thank Lauren Buffaloe (DWR) for a tremendous job of editing and formatting the articles and to Barbara McDonnell (DWR) and Sam Luoma (CALFED) for funding publication of the Fish Bulletin.

Randall L. Brown

Foreword

The impetus for publication of this Fish Bulletin came from conversations among several biologists working on salmonid issues in the Central Valley and the Sacramento-San Joaquin Estuary. These discussions centered on the idea that more information being developed about these economically, environmentally, and aesthetically important species needed to be available in the open literature. Marty Kjelson, Terry Mills and I developed the concept of a symposium followed by published proceedings. The Interagency Ecological Program's Central Valley Salmonid Team endorsed the concept and a successful symposium was held at the Bodega Marine Laboratory in October 1997.

Originally Marty and Terry agreed to co-edit the proceedings. Due to the press of other work, they were unable to take on much of the day-to-day work on the volume but did provide guidance and suggestions for ways to move the publication from concept to reality. I take responsibility for the final selection of papers and the final technical editing of the papers.

As you will find, I selected papers with varied writing styles. Some papers, such as the ones by Yoshiyama and others and by Black, are longer than would be typically found in journals. I believe they make a significant contribution to our understanding and decided to publish them without major revision. Others are more succinct and could be published in the open literature.

Those readers that attended the Bodega symposium will find that not all the papers presented have been included in this volume and that papers not presented are included. Several of the presenters were unable to find the time to prepare a manuscript. On the other hand, other authors had information of interest. The blend seemed to make the best sense in view of the objective of making a wide variety of information available to salmonid biologists and managers.

This volume also includes some material that could be considered duplicative in that two different papers may discuss the same question—for example, through-Delta survival of juvenile salmonids. I included these papers to provide different perspectives on important questions. I ask the reader to consider the papers, and the data, and reach his or her conclusions as to the interpretations. As with most difficult environmental issues, one must carefully consider all the available data before deciding to accept or reject a hypothesis.

I do recommend that you consider recommendations, made specifically by L.B. Boydstun, Peter Baker, Emil Morhardt, Wim Kimmerer and others, and John Williams about the need to (1) better coordinate salmonid related work in the Valley, the estuary and the ocean; (2) focus more on collecting and analyzing data that can be used to validate conceptual and mechanistic models; and (3) make the information more readily available in the open literature. Along those lines I suggest that symposium such as this be held every two to three years, including publication of the proceedings. Authors should not stop with publication in proceedings but should also publish in appropriate journals. Hopefully the next symposium will have more than one paper dealing with steelhead.

Randall L. Brown
Fair Oaks, California
September 1, 2001

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Central Valley Steelhead

Dennis R. McEwan

Abstract

Before extensive habitat modification of the 19th and 20th centuries, steelhead (*Oncorhynchus mykiss*) were broadly distributed throughout the Sacramento and San Joaquin drainages. Historical run size is difficult to estimate given the paucity of data, but may have approached 1 to 2 million adults annually. By the early 1960s run size had declined to about 40,000 adults. Natural spawning populations currently exist in the Sacramento and San Joaquin river systems but at much lower levels. Coastal rainbow trout populations can be polymorphic in their life-history, and progeny of one life-history form can assume a life-history strategy different from that of their parents. A polymorphic population structure may be necessary for the long-term persistence in highly variable environments such as the Central Valley. Despite the substantial introduction of exotic stocks for hatchery production, native Central Valley steelhead may have maintained some degree of genetic integrity. Primary stressors affecting Central Valley steelhead are all related to water development and water management, and the single greatest stressor is the substantial loss of spawning and rearing habitat due to dam construction. Central Valley anadromous fish management and research is primarily focused on chinook salmon (*Oncorhynchus tshawytscha*) and has led to less emphasis on steelhead monitoring and restoration. Much of the information on historical abundance and stock characteristics that exists for Central Valley steelhead is derived from an intensive DFG research program in the 1950s. Since this time there has been relatively little research directed at steelhead in the Central Valley, and efforts to restore Central Valley steelhead have been greatly hampered by lack of information. The National Marine Fisheries Service cited the ongoing conservation efforts of the Central Valley Project Improvement Act (CVPIA) and CALFED as justification for listing Central Valley steelhead as a threatened species under the Endangered Species Act, rather than endangered as proposed. Restoration actions identified in these programs are largely directed at chinook salmon recovery with comparatively little emphasis on specific actions needed to recover steelhead, or have not yet been implemented. The structure of rainbow trout populations has important management implications that can only be addressed through an integrated management strategy that treats all life-history forms occupying a stream as a single population. However, management

agencies have generally failed to recognize this, as exemplified by the federal government's decision to exclude the non-anadromous forms in the ESA listing for steelhead, despite their recognition that they are important to the persistence of the anadromous forms. Steelhead need to be managed separately from chinook salmon stocks if recovery is to be successful, and recovery strategies must include measures to protect and restore the ecological linkages between the different life-history forms and measures to restore steelhead to some of their former habitat.

Introduction

Steelhead are the anadromous form of rainbow trout¹ (*Oncorhynchus mykiss*), a salmonid species indigenous to western North America and the Pacific coast of Asia. Recognized as a prized and sought-after game fish, steelhead are also highly regarded as a quality-of-life indicator among the non-angling public. The California Department of Fish and Game (DFG), the U.S. Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service (NMFS) all assert some form of management authority over rainbow trout populations.

In this paper I discuss important aspects of steelhead ecology and population biology that have direct bearing on management effectiveness (and ineffectiveness), historical abundance and current status of Central Valley steelhead, factors that are responsible for their decline, and assessment of current monitoring and research efforts. I conclude with a description of current management and recovery efforts, a discussion of the dominant paradigm of Central Valley steelhead management and associated problems, and what I believe to be necessary if recovery is to be successful.

-
1. The terms "rainbow trout" and "resident rainbow trout" are often used to identify non-anadromous forms of *O. mykiss*. This convention is confusing and technically inaccurate because "rainbow trout" is the common name of the biological species *O. mykiss*, and the term "resident," used in this sense, ignores other, non-anadromous life-history forms and migratory behaviors. In this document, the term "rainbow trout" refers to the biological species *O. mykiss* regardless of life history, and the different life-history forms are referred to as anadromous (or steelhead), potamodromous, or resident, depending on their migratory behavior (or lack thereof in the case of residents). The term "non-anadromous" is used to refer collectively to all life-history types other than anadromous.

Biology and Status

Ecology, Life-History, and Structure of Rainbow Trout Populations

In North America, steelhead are found in Pacific Ocean drainages from southern California to Alaska. In Asia, they are found in coastal streams of the Kamchatka Peninsula, with scattered populations on the mainland (Burgner and others 1992) (Figure 1). In California, spawning populations are known to occur in coastal streams from Malibu Creek in Los Angeles County² to the Smith River near the Oregon border, and in the Sacramento and San Joaquin river systems. The present distribution and abundance of steelhead in California have been greatly reduced from historical levels (McEwan and Jackson 1996; Mills and others 1997).

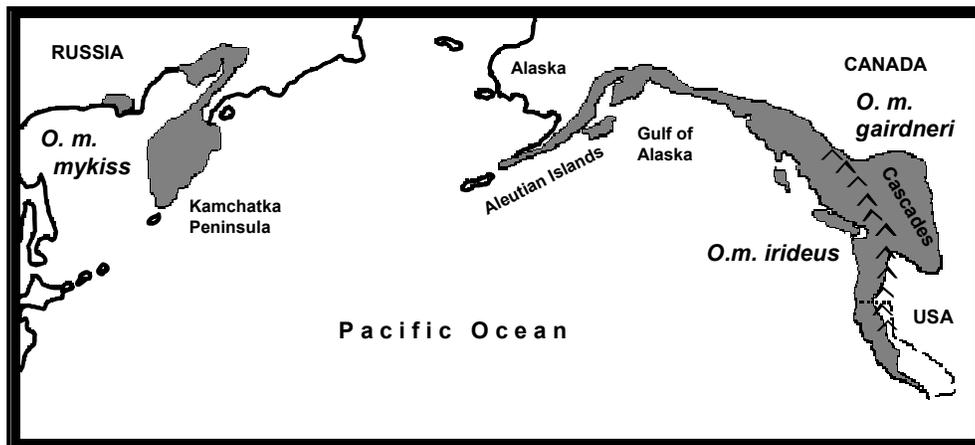


Figure 1 Endemic distribution of steelhead rainbow trout, *Oncorhynchus mykiss*. Modified from Burgner and others 1992.

2. The southernmost extent of steelhead distribution in North America is often reported as Malibu Creek because a known, persistent spawning population has been documented (McEwan and Jackson 1996; NMFS 1996a). However, streams south of Malibu Creek (for example, San Mateo Creek in San Diego County) appear to support at least occasional spawning and production (DFG 2000a) and most other streams are not adequately monitored to determine if steelhead are present. Thus, it is more correct to state that Malibu Creek is the known southern extent of persistent populations in North America.

Steelhead are similar to some Pacific salmon species in their ecological requirements. They are born in fresh water, emigrate to the ocean where most of their growth occurs, and return to fresh water to spawn. Unlike Pacific salmon, steelhead are iteroparous. Repeat spawning rates are generally low, however, and vary considerably among populations.

In California, peak spawning occurs from December through April in small streams and tributaries with cool, well-oxygenated water. The length of time it takes for eggs to hatch depends mostly on water temperature. Steelhead eggs hatch in about 30 days at 51°F (Leitritz and Lewis 1980). Fry usually emerge from the gravel four to six weeks after hatching, but factors such as redd depth, gravel size, siltation, and temperature can speed or retard this time (Shapovalov and Taft 1954).

The newly-emerged fry move to the shallow, protected areas associated with the stream margin (Royal 1972; Barnhart 1986) where they establish feeding stations (Fausch 1984) that they defend (Shapovalov and Taft 1954). Juveniles mainly inhabit riffles (Barnhart 1986) but they can use a variety of other habitat types (DFG Stream Evaluation Program, unpublished data). Relatively high concentrations occur in association with structural complexity, such as that provided by large woody debris (DFG Stream Evaluation Program, unpublished data). Juveniles also exhibit a significant movement to sites with overhead cover (Fausch 1993) and appear to select positions in streams in response to low light levels (Shirvell 1990). For juvenile steelhead, sites with light levels below a certain threshold, velocity refuges, and adjacent high velocity flows provide an optimal combination of safety from predators and aggressive conspecifics, as well as access to drifting invertebrate food resources.

The optimum water depth for steelhead spawning is approximately 14 inches and ranges from about 6 to 36 inches (Bovee 1978). Fry typically use water approximately 8 inches in depth and can use water 2 to 32 inches deep, while older juveniles typically use a water depth of about 15 inches but can use water 2 to 60 inches deep (Bovee 1978). In natural channels, water depth usually does not hinder adult migration because adult steelhead normally migrate during high flows. Depth can become a significant barrier or impediment in streams that have been altered for flood control purposes, especially those that do not have a low flow channel. It has been reported that seven inches is the minimum depth required for successful migration of adult steelhead (Thompson 1972, as cited in Barnhart 1986), although the distance fish must travel through shallow water areas is also a critical factor. Excessive water velocity and obstacles that impede swimming and jumping ability are more significant in hindering or blocking migration (Barnhart 1986).

Steelhead spawn in areas with water velocities ranging from 1 to 3.6 ft/s but most often in velocities of about 2 ft/s (Bovee 1978). The ability to spawn in higher velocities is a function of size: larger steelhead can establish redds and spawn in faster currents than smaller steelhead (Barnhart 1986). Steelhead have been reported to spawn in substrates from 0.2 to 4.0 inches in diameter (Reiser and Bjornn 1979). Based on the Bovee (1978) classification, steelhead use mostly gravel-sized material for spawning but will also use mixtures of sand-gravel and gravel-cobble. The gravel must be highly permeable to keep the incubating eggs well oxygenated.

Water temperature requirements for various life stages of steelhead have been studied (Bovee 1978; Reiser and Bjornn 1979; Bell 1986), although there are relatively little data specific to California (Myrick 1998). Egg mortality begins to occur at 56°F (Hooper 1973, as cited in Barnhart 1986), thermal stress has been reported at temperatures beginning at 66°F, and temperatures demonstrated to be lethal to adults have been reported at 70°F (Rich 2000). In California, low temperatures are not as much of a concern as high temperatures, particularly during adult migration, egg incubation, and juvenile rearing. The ability of steelhead to tolerate adverse temperatures varies depending on physiological conditions such as life stage, stock characteristics, and ecological conditions such as acclimation time, food availability, and access to cold water refugia within the stream (Nielsen and others 1994; Myrick 1998). Thus, determination of suitable temperature targets in regulated rivers is often a complex issue.

It should be noted that the preceding descriptions of habitat criteria are presented mainly as rough guidelines as determined by steelhead researchers on specific streams or under laboratory conditions. Often, temperature targets are established or proposed on regulated rivers based on laboratory studies that focus on temperature maxima that cause lethal and sublethal effects. Effects on growth rates, long-term survival, increased predation rate, and ecology usually are not addressed in these studies. Also, experimental work under controlled laboratory conditions does not take into account ecological conditions that may affect thermal tolerances, such as predation risk, inter- and intraspecific competition, and flow characteristics (Moyle and Baltz 1985, as cited in Myrick 1998). Because laboratory studies cannot approximate the complex conditions found in natural environments, water temperature requirements for steelhead in the wild are often subject to considerable debate, due primarily to misapplication and misinterpretation of thermal physiology studies and lack of standardization of methodologies (Rich 2000).

As noted above, steelhead in California exhibit life-history characteristics that are generally similar to Pacific salmon but there are some major differences: juvenile steelhead typically rear in freshwater for a longer period (usually from one to three years) and both adults and juveniles are more variable in the

amount of time they spend in fresh and salt water. Throughout their range, steelhead typically remain at sea for one to four growing seasons before returning to fresh water to spawn (Burgner and others 1992). Boydstun (1977) found that most Gualala River steelhead migrated to sea as two-year old fish and returned after spending two years in the ocean. In Scott and Waddell creeks, the majority of adults returning to the stream to spawn had spent two years in fresh water and one or two years in the ocean. However, steelhead from these streams occasionally exhibited other life-history patterns: scale analysis of adults indicated that they spent from one to four years in fresh water and from one to three years in the ocean (Shapovalov and Taft 1954).

Steelhead have traditionally been grouped into seasonal runs according to their peak migration period: in California there are well-defined winter, spring, and fall runs. This classification is useful in describing actual run timing but is misleading when it is used to further categorize steelhead. Seasonal classification does not reflect stock characteristics, spawning strategies, and run overlap between summer and winter steelhead. Run timing is a characteristic of a particular stock, but, by itself, does not constitute race or ecotype.

There are two steelhead ecotypes: stream-maturing steelhead, which enter fresh water with immature gonads and consequently must spend several months in the stream before they are ready to spawn; and ocean-maturing steelhead, which mature in the ocean and spawn relatively soon after entry into fresh water. This corresponds to the accepted classification that groups steelhead into two seasonal "races": summer and winter steelhead (Withler 1966; Royal 1972; Roelofs 1983; Barnhart 1986; Burgner and others 1992). Stream-maturing steelhead (summer steelhead) typically enter fresh water in spring, early summer, and fall. They ascend to headwater tributaries, hold over in deep pools until mature, and spawn in winter. Ocean-maturing steelhead (winter steelhead) typically begin their spawning migration in fall, winter, and spring and spawn relatively soon after freshwater entry. Ocean-maturing steelhead generally spawn January through March, but spawning can extend into spring and possibly early summer months. Before the intensive water development of this century and the resultant loss of a considerable amount of holding habitat, summer steelhead were probably more common in California than they are today. At present, summer steelhead are found only in north coast drainages, mostly in tributaries of the Eel, Klamath, and Trinity river systems. Winter steelhead are also present in north coast drainages, and are also found in the Central Valley and central and south coast drainages.

The above classification scheme is based on behavioral and physiological differences and may not reflect genetic or taxonomic relationships (Allendorf 1975; Allendorf and Utter 1979; Behnke 1992). Genetic similarity appears to be mostly a reflection of geographical relationships. For example, summer steel-

head occupying a particular river system are more genetically similar to winter steelhead of that system than they are to summer steelhead in other systems. Allendorf (1975) found that summer steelhead from several coastal streams in Washington were genetically indistinguishable from coastal winter steelhead of the same streams, but showed no genetic affinities with inland (upper Columbia River) summer steelhead.

Rainbow trout have also been classified on the basis of life history. Steelhead and non-anadromous rainbow trout were classified as two different subspecies and even different species by early researchers (Jordan and Gilbert 1882; see Allendorf 1975, Behnke 1992). However, little or no morphological or genetic differentiation has been found between anadromous and non-anadromous forms inhabiting the same stream system (Behnke 1972; Allendorf 1975; Allendorf and Utter 1979; Busby and others 1993; Nielsen 1994). Anadromous and non-anadromous rainbow trout apparently did not arise from two distinct evolutionary lines (Behnke 1992), rather, the different forms reflect the phenotypic plasticity of the species.

Behnke (1972), Allendorf (1975), Allendorf and Utter (1979), and Wilson and others (1985) conclude that rainbow trout cannot be separated taxonomically by immigration timing and status of gonadal maturity (summer vs. winter steelhead) or their tendency for anadromy (steelhead vs. non-anadromous forms). Rather, rainbow trout are taxonomically structured on a geographic basis (coastal vs. inland forms). Similarly, Behnke (1992) identifies three subspecies of rainbow trout that have anadromous life-history forms: coastal rainbow trout (*O. m. irideus*), Columbia River redband trout (*O. m. gairdneri*), and *mikizha* or Kamchatka rainbow trout (*O. m. mykiss*). All steelhead life-history forms of *O. m. gairdneri* are summer steelhead (Behnke 1992; Burgner and others 1992) and occupy upper Columbia River tributaries east of the Cascades. *Oncorhynchus m. mykiss* is found in streams along the west coast of the Kamchatka peninsula of Russia. *Oncorhynchus m. irideus* is distributed along coastal rivers and streams from California to Alaska and consists of both summer and winter steelhead (Figure 1). All steelhead in California are *O. m. irideus* (Behnke 1992).

The present taxonomic classification recognizes the extreme polymorphism that occurs among rainbow trout populations (Behnke 1992). Rather than the different life-history forms comprising distinct taxa or populations, studies and observations indicate that coastal rainbow trout can form a single, panmictic population in streams systems where there is access to the ocean. These populations are comprised of individuals with different life-history traits and a continuum of migratory behaviors, the two extremes being anadromy (strongly migratory) and residency (non-migratory). Within these extremes are potamodromous, and possibly estuarine and coastal (weakly anadromous) forms that are typical of coastal cutthroat trout (*O. clarki*) populations

(Northcote 1997). This type of population structure has been observed in Kamchatka rainbow trout populations in several rivers in western Kamchatka, where steelhead, coastal, and riverine (potamodromous and resident) life-history polymorphisms have been identified, and appear to form a single interbreeding population within each river system (Savvaitova and others 1973, 1997). Mature male parr have been observed spawning with female steelhead in California streams (Shapovalov and Taft 1954; DFG Stream Evaluation Program, unpublished data). Lack of genetic differences provides additional evidence that anadromous and non-anadromous life-history types can form a single interbreeding population within the anadromous reaches of a stream system.

In trout populations that have anadromous life-history forms, it is not uncommon for males to assume a non-anadromous life history and mature in fresh water as parr (see Thorpe 1987; Titus and others forthcoming), or for progeny of one life-history form to assume a life-history strategy that differs from their parents. On the Santa Clara River in Ventura County, for example, an annual average of 172 steelhead smolts has been captured in a downstream migrant trap at the Vern Freeman Diversion Facility from 1994 through 1997, although apparently very few adult steelhead have returned to the river. In fact, less than five adult steelhead have been observed using the diversion dam fish ladder (Entrix, Inc. 1994, 1995, 1996, 1997). A recent study that examined the microchemistry of juvenile rainbow trout otoliths has provided additional evidence for this. By comparing the ratio of strontium (Sr) to calcium (Ca) in the primordia and freshwater growth regions of the otolith, the life-history form of the maternal parent can be determined. The study found conclusive evidence that, in some populations, non-anadromous females produce steelhead progeny and steelhead females produce non-anadromous progeny (Zimmerman 2000).

A polymorphic life-history structure and resultant flexibility in reproductive strategies allows for persistence in the face of unstable and variable climatic, hydrographic, and limnological conditions that frequently exist at the margins of a species' range. For rainbow trout, this includes stream systems in the Central Valley and those south of San Francisco Bay, and Kamchatka on the other end of the range. Stream systems in California are subject to extreme variations (both within and among years) in rainfall which can result in high volume, flash flood runoff, or droughts lasting several years. Natural stream flow in these streams can vary greatly, both seasonally and annually. It is not uncommon, even under unimpaired conditions, for the lower reaches of many streams to become interrupted during the dry season (and longer), restricting the population to the perennial headwaters, and these conditions may persist for years. Thus, a polymorphic population structure allows persistence in an environment that is frequently suboptimal and not conducive to consistent, annual recruitment of migrants to the ocean, and may be necessary for the

long-term persistence of a population in these types of environments. Having several different life-history strategies among a single population effects “bet-hedging” against extinction, and has been proposed as a reason for the occurrence of similar polymorphic population structure in coastal populations of cutthroat trout (Northcote 1997) and brown trout (*Salmo trutta*) (Jonsson 1985, as cited in Northcote 1997; Titus and Mosegaard 1992) occupying highly variable environments.

Life-History of Central Valley Steelhead

Presently, the Central Valley drainages are known to contain only winter steelhead. However, there are indications from fish counts made before the era of large dam construction that summer steelhead were present in the Sacramento River system as well (Needham and others 1941; USFWS and DFG 1953). The presence of suitable over-summering habitat, a stable hydrology strongly influenced by spring snowmelt runoff, and the widespread occurrence of spring-run chinook salmon (*Oncorhynchus tshawytscha*), which have a similar life history to summer steelhead, are further indications that summer steelhead occurred throughout the Central Valley system. Because of the need of adults to over-summer in deep pools in mid- to high-elevation tributaries, summer steelhead were probably eliminated with commencement of the large-scale dam construction period in the 1930s.

The peak period of adult immigration before the occurrence of large-scale changes to the hydrology of the system appears to have been in fall, with a smaller component immigrating in winter (Bailey 1954; Van Woert 1958; Hallock and others 1961; Hallock 1989) (Figure 2A). Hallock and others (1961) found that the peak migration into the upper Sacramento River above the mouth of the Feather River from 1953 to 1959 was in late September. Adult counts at Clough Dam on Mill Creek for a 10-year period beginning in 1953 indicated that the peak of adult migration into that stream occurred in late October, with a smaller peak about mid-February (Hallock 1989). Examination of adult steelhead counts at Red Bluff Diversion Dam indicates that run timing on the upper Sacramento River does not appear to have changed appreciably: adult counts from 1969 to 1982 also show this same pattern (Hallock 1989), as do counts from 1983 to 1986 (USFWS unpublished data) (Figure 2B).

Hallock and others (1961) found that juvenile steelhead migrated downstream during most months of the year, but the peak period of emigration occurred in spring, with a much smaller peak in fall. The emigration period for naturally-spawned steelhead juveniles migrating past Knights Landing on the lower Sacramento River in 1998 ranged from late December through early May, and peaked in mid-March (DFG unpublished data). Most naturally-produced Central Valley steelhead rear in freshwater for two years before emigrating to

the ocean. Scale analysis indicated that 70% had spent two years in freshwater before emigrating to the ocean, 29% had spent one year, and 1% had spent three years (Hallock and others 1961). A current generalized life-stage periodicity for Central Valley steelhead is shown in Figure 3.

Recent microchemical analysis of Sr:Ca ratios in otoliths extracted from three rainbow trout from the Calaveras River provides evidence that some Central Valley rainbow trout populations are polymorphic. All three fish were adults with spent gonads indicating they had recently spawned. One was a 25-inch female steelhead that was the progeny of a steelhead female; one was a non-anadromous male (but whose scale circuli showed accelerated growth that may be indicative of having undertaken an estuarine migration) that was the progeny of a steelhead female; and one was a non-anadromous male that was the progeny of a non-anadromous female (Titus 2000). Thus, in a sample of just three fish from the population, we see two, possibly three different life-history expressions, at least one of which was different from that of its mother.

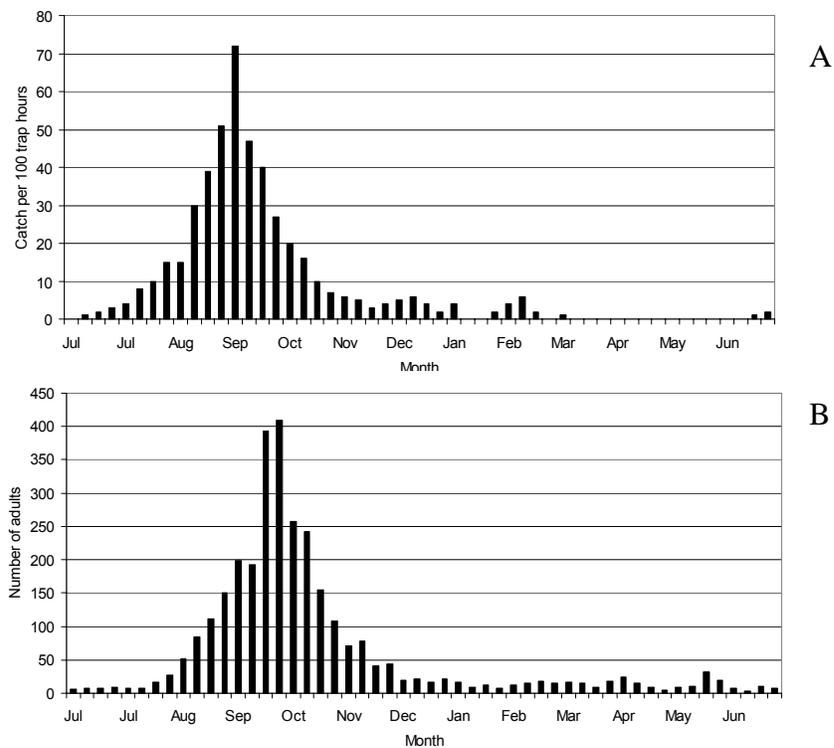


Figure 2 Time pattern of Sacramento River adult steelhead migration. Figure 2A shows migration timing from July through June of 1953 through 1959, determined by trapping upstream migrants in the Sacramento River just upstream of the confluence with the Feather River (from Hallock and others 1961). Figure 2B shows the weekly average number of adult steelhead counted at Red Bluff Diversion Dam from July through June of 1983 through 1986.

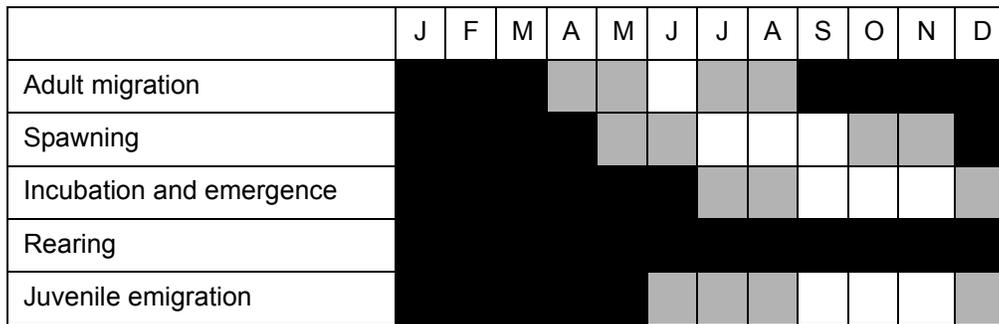


Figure 3 Central Valley steelhead life stage periodicity. Shaded areas represent months when the life stage is present; black shading indicates months of peak occurrence.

Table 1 Steelhead production in Central Valley anadromous fish hatcheries

<i>Facility (river system)</i>	<i>Purpose of mitigation</i>	<i>Production goal (yearlings)</i>	<i>Average annual production, 1984-1985 through 1993-1994</i>	
			<i>Fingerlings^a</i>	<i>Yearlings</i>
Coleman National Fish Hatchery (Sacramento R.)	Shasta Dam (USBR Central Valley Project)	700,000 to 800,000	245,378	526,602
Feather River Hatchery	Oroville Dam (DWR State Water Project)	400,000 to 450,000	489,366	406,421
Nimbus Hatchery (American R.)	Folsom Dam (USBR Central Valley Project)	430,000	407,381	369,870
Mokelumne R. Hatchery ^b	Camanche Dam (East Bay Municipal Utility District)	100,000	35,734	179,125
All Hatcheries			1,177,859	1,482,018

^a Includes fry, advanced fingerlings, and sub-yearlings.

^b Because the steelhead run in the Mokelumne River is so small, eggs are procured from Nimbus Hatchery.

Hallock and others (1961) reported that the composition of naturally-produced steelhead in the population estimates for the 1953-1954 through 1958-1959 seasons ranged from 82% to 97% and averaged 88%. This is probably not reflective of present stock composition in the Central Valley, due to the loss of spawning and rearing habitat and increase in hatchery production. During the period of the Hallock and others study, only Coleman and Nimbus hatcheries were in operation. Today, four Central Valley anadromous fish hatcheries (Mokelumne River, Feather River, Coleman, and Nimbus hatcheries) collectively produce approximately 1.5 million steelhead yearlings annually (Table 1, Figure 4)³.

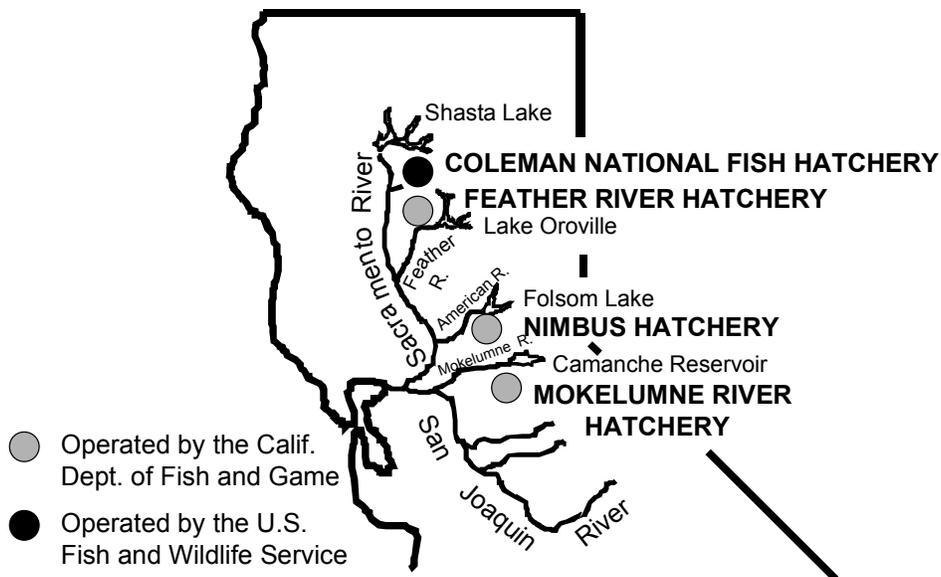


Figure 4 Central Valley anadromous fish hatcheries that raise steelhead

There has been substantial introduction of exotic steelhead stocks in the Central Valley (McEwan and Nelson 1991; NMFS 1996a). The degree of introgression or replacement of native stocks has not been determined, however, there is evidence that native Central Valley steelhead may have maintained some degree of genetic integrity. NMFS conducted a genetic analysis using allozymes from rainbow trout collected from Coleman, Nimbus, and Feather River hatcheries, Deer and Mill creeks, and the Stanislaus and American rivers. They found that the Stanislaus River, Coleman and Feather River hatcheries, and Deer and Mill creek populations formed a genetic group distinct from all

3. There are five anadromous fish hatcheries in the Central Valley; however, Merced River Hatchery does not have a steelhead program.

coastal samples of steelhead (Busby and others 1996; NMFS 1997a). In contrast, the American River samples (wild fish and those from Nimbus Hatchery) were genetically most similar to a sample from the Eel River (NMFS 1997a), which accurately reflects the founding history of Nimbus Hatchery (McEwan and Nelson 1991).

Distribution and Abundance

There is little documentation of historical steelhead distribution in the Central Valley. This is probably because it is difficult to assess or monitor steelhead (as will be discussed further). However, available information indicates that steelhead were well-distributed throughout the Sacramento and San Joaquin river systems. Steelhead were found from the upper Sacramento and Pit river systems south to the Kings River (and possibly Kern river systems in wet years) and in both east- and west- side tributaries of the Sacramento River (Clark 1929a; Wales 1939; Needham and others 1941; Murphy 1946, 1951; Beland and Braun 1952; Fry 1952; Vestal 1965; Painter and others 1977; DFG 1952, 1955, 1967, 1978a, 1978b, 1979; McEwan and Jackson 1996; Yoshiyama and others 1996; DFG unpublished data) (Figure 5).

The broad historical distribution of chinook salmon in the Central Valley (Yoshiyama and others 1996, 1998, this volume) corroborates the conclusion that steelhead were widely distributed. A comparison of the distributions of the two species in recent fish sampling in the lower Klamath River tributaries demonstrates that steelhead are present in all tributaries that contain chinook salmon, and, in nearly all cases, steelhead were found in tributaries and reaches further upstream (Voight and Gale 1998).

Further evidence supporting the assumption that steelhead distribution can be inferred from chinook salmon distribution is provided by an extensive review done by CH2M Hill (1985). In this review of salmonid distribution in the anadromous portions of the entire Klamath-Trinity river system, only one tributary containing chinook salmon but lacking steelhead was documented: all other tributaries that supported chinook salmon had steelhead as well and, in nearly all cases, steelhead were distributed at higher elevations in the stream than were chinook salmon. Thus, Yoshiyama and others' (1996) conclusion that steelhead were more broadly distributed than chinook salmon appears to be justified:

[Steelhead were] undoubtedly more extensively distributed [than chinook salmon in the Central Valley]. Due to their superior jumping ability, the timing of their upstream migration, which coincided with the winter rainy season, and their less restrictive preferences for spawning gravels, steelhead could have used at least hundreds of miles of smaller tributaries not accessible to the earlier-spawning salmon.

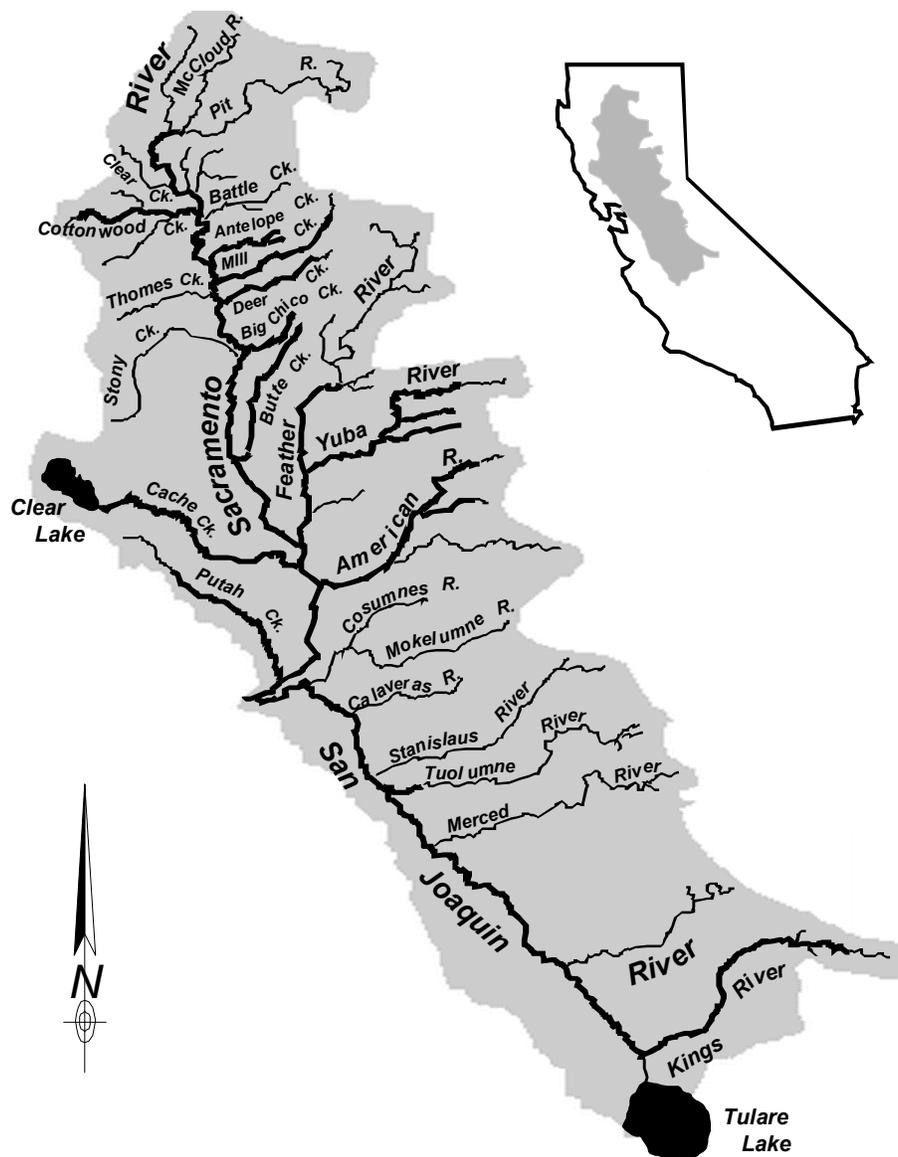


Figure 5 Historical distribution of steelhead in Central Valley drainages. Thick lines represent streams and stream reaches that have documented historical evidence of steelhead (see text for references). Thin lines represent likely distribution of steelhead based on documented occurrence of chinook salmon or lack of natural barriers above documented steelhead occurrences. Shading represents an estimation of historical range within which steelhead likely occurred in numerous small tributaries not shown on map.

The present distribution of steelhead in the Central Valley has been greatly reduced (Figure 6), mostly due to construction of impassable dams that block access to essential spawning and rearing habitat. Although a comparison of Figures 5 and 6 indicates a considerable reduction in distribution, it does not effectively convey the impact of the loss of habitat, because many of the stream reaches included as present distribution are at low elevations and were used by steelhead mostly as migration corridors. Clark (1929b) estimated that 80% of the spawning grounds in the Central Valley have been blocked due to power and irrigation dams. The California Advisory Committee on Salmon and Steelhead Trout (CACST 1988) estimated that there has been a 95% reduction in spawning habitat for Central Valley anadromous fish. Similarly, Yoshiyama and others (1996) estimated that 82% of chinook salmon spawning and rearing habitat in the Central Valley has been lost, and they state that the percentage of lost habitat for steelhead is undoubtedly higher because steelhead extended further into the drainage.

Naturally-spawning stocks of rainbow trout that support anadromy are known to occur in the upper Sacramento River and tributaries, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, Mokelumne, Calaveras, and Stanislaus rivers. The presence of naturally spawning populations appears to correlate well with the presence of fish monitoring programs, however, and recent implementation of monitoring programs has found steelhead smolts in streams previously thought not to contain a population, such as Auburn Ravine, Dry Creek (DFG unpublished data) and the Stanislaus River (Demko and Cramer 1997, 1998; Demko and others 1999). It is possible that naturally spawning populations exist in many other streams but are undetected due to lack of monitoring or research programs.

Until very recently, steelhead were considered by some to be extinct in the San Joaquin River system (see Reynolds and others 1990; Cramer and others 1995). However, this conclusion was based on little information and no field studies. The presence of steelhead in the San Joaquin River is controversial, however, substantial evidence shows there is an extant, self-sustaining steelhead run in the San Joaquin River system:

- Numerous yearling-sized steelhead exhibiting smolt characteristics have been captured during an annual chinook salmon Kodiak trawl survey on the lower San Joaquin River from 1987 to the present (DFG unpublished data; USFWS unpublished data).
- A small number of steelhead smolts has been captured in rotary screw traps in two locations in the Stanislaus River every year for the past six years (Demko and Cramer 1997, 1998; S.P. Cramer & Associates unpublished data) (Figure 7). These fish do not appear to be progeny of straying adult Mokelumne River Hatchery steelhead: recent genetic analysis of

rainbow trout (discussed previously) captured in the reach below Goodwin Dam show that this population has closest genetic affinities to upper Sacramento River steelhead (NMFS 1997a). In contrast, Nimbus Hatchery steelhead, the source of eggs for the Mokelumne River Hatchery steelhead program, appear to be genetically similar to coastal steelhead, which were used to found the Nimbus Hatchery steelhead program when the hatchery first began production. Mokelumne River Hatchery is the only steelhead hatchery in the San Joaquin River system, and juvenile steelhead are not stocked anywhere in the San Joaquin basin except the Mokelumne River.

- A DFG creel census on the Stanislaus River has documented the catch of rainbow trout greater than 20 inches (DFG unpublished data). Examination of scale samples from these larger trout by DFG biologists shows an accelerated growth period typical of estuary or ocean residence (DFG 1997). DFG (1985) also observed large numbers of juvenile rainbow trout in several age classes, including young-of-the-year.
- In 1996, DFG (unpublished data) observed large numbers of rainbow trout in the Tuolumne River during a snorkel survey. In 1997, naturally spawned young-of-the-year rainbow trout were captured in the Tuolumne River by beach seining. Rotary screw trap catches in the past few years also contain young rainbow trout.
- In January 2001, a 28-inch rainbow trout was captured by a DFG fisheries biologist while angling in the lower Tuolumne River. The fish was a male with a hooked kype and prominent red coloration along the lateral line and operculae, indicating that it was ready to spawn. An 11-inch steelhead smolt was captured by the same biologist a few days later near the same location (DFG 2001).
- A 24-inch rainbow trout was captured by electrofishing at the confluence of the Merced and San Joaquin rivers in 1996-1997.
- In February 2000, an angler caught a 31-inch rainbow trout in the Calaveras River downstream of New Hogan Dam. Several weeks later, one adult female and two adult male rainbow trout were collected from the river after a fish kill occurred. Microchemical analysis of the otoliths found that the female was a spawned-out steelhead and one of the males was the progeny of a steelhead mother, but itself was non-anadromous (Titus 2000). In April 2000 a 9-inch juvenile steelhead exhibiting obvious smolt characteristics was captured (DFG 2000b).



Figure 6 Present distribution of steelhead in Central Valley drainages. Shading represents an estimation of present range within which steelhead likely occur in numerous tributaries not shown on map. Question marks denote streams and stream reaches where steelhead currently have access but their presence is unknown.

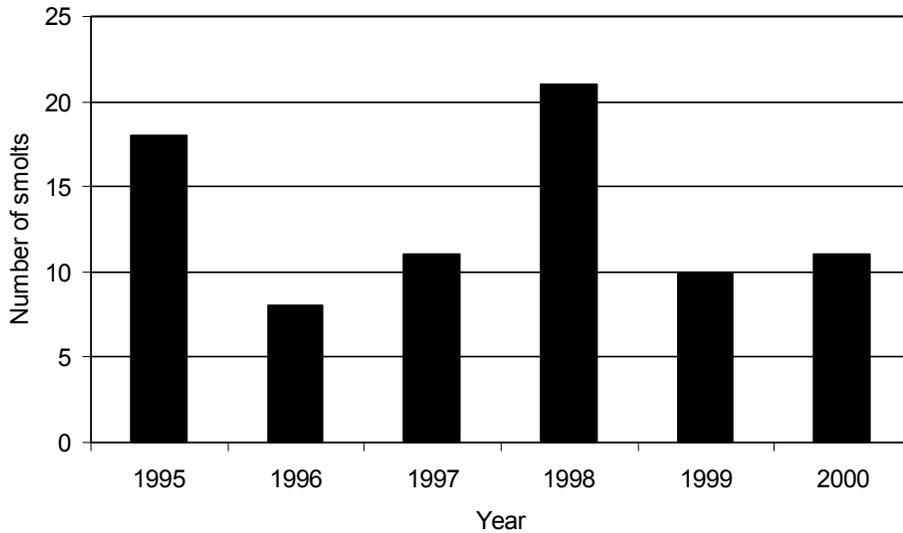


Figure 7 Number of smolt steelhead captured in rotary screw traps in the Stanislaus River. Data have not been adjusted for sampling effort, and effort has not been consistent between years. Data for 1999 is preliminary and data for 2000 is preliminary and partial.

The California Fish and Wildlife Plan (DFG 1965) estimated there were 40,000 adult steelhead in the Central Valley drainages in the early 1960s. In the 1950s, Hallock and others (1961) estimated the average annual steelhead run size was 20,540 adults in the Sacramento River system above the mouth of the Feather River. Estimating steelhead abundance before extensive water development and habitat modification is difficult given the paucity of historical information. However, historical steelhead abundance can be grossly estimated by examining chinook salmon and steelhead production in relatively unimpaired river systems.

From 1938 to 1975, counts were made of adult chinook salmon and steelhead at the Benbow Dam fishway on the South Fork Eel River. A decline in numbers of both chinook salmon and steelhead using the fishway began in the early 1960s, indicating that major effects to the Eel River probably occurred after 1960. Examination of the relative abundance of chinook salmon and steelhead during the years 1938 through 1960 shows, that of the 19 years of counts, there were two years when adult steelhead abundance was slightly less than chinook salmon, seven years when it was slightly more, and 14 years when steelhead abundance was more than twice that of chinook salmon. For the entire Eel River system, the California Fish and Wildlife Plan (DFG 1965) estimates the steelhead run size to be 160% of the chinook salmon run size.

Table S-3 of the California Fish and Wildlife Plan (DFG 1965) shows that for most northern California river systems, the steelhead run size in the early 1960s was at least that of the chinook salmon run size and in several streams steelhead were more than twice as abundant⁴. Even if a 50% ocean harvest rate for chinook salmon is considered, steelhead run size was only slightly less than chinook salmon in most streams and was the same or higher in some.

Thus, historical chinook salmon abundance may be viewed as an approximation of steelhead historical abundance. Assuming this is true, historical steelhead numbers in the Central Valley would have approached 1 to 2 million adults annually, which is the historical abundance of chinook salmon in the Central Valley estimated by Yoshiyama and others (1998). However, it should be noted that historical steelhead abundance in the Columbia River may have been significantly less than that of chinook salmon, based on historical commercial landings of chinook salmon and steelhead (R. Behnke, personal communication, see "Notes"). Also, given their larger size at ocean entry, juvenile steelhead would require greater resources than the smaller-sized salmon, therefore, fresh water habitat may not have been able to support as many juvenile steelhead as chinook salmon. The greater resource limitations for steelhead could have been attenuated by the fact that steelhead utilize the more numerous smaller tributaries for spawning and rearing than do chinook salmon, and greater ocean survival due to the larger size of steelhead smolts at ocean entry. Nevertheless, it is difficult to estimate historical abundance in the absence of any real data, so the above estimate of 1 to 2 million adult steelhead should be viewed as a best guess.

An accurate estimate of current steelhead abundance in the Central Valley is also not available. However, in the early 1990s, the total annual run size (hatchery and wild) for the entire system, based on Red Bluff Diversion Dam (RBDD) counts, hatchery counts, and past natural spawning escapement estimates for some tributaries, was estimated to be no greater than 10,000 adult fish (McEwan and Jackson 1996). A more reliable indicator of the magnitude of the decline of Central Valley hatchery and wild stocks is the trend in the RBDD counts. Steelhead counts at the RBDD have declined from an average annual count of 11,187 adults for the ten-year period beginning in 1967, to 2,202 adults annually in the 1990s (McEwan and Jackson 1996). Natural spawning escapement estimates above RBDD for the period 1967 to 1993 averaged 3,465 and ranged from 0 (1989 and 1991) to 13,248 (1968) (Figure 8). Natural escapement has shown a more substantial decline than hatchery (Coleman National Fish Hatchery) escapement.

4. The only exceptions were the Scott, Shasta, and Trinity rivers. Chinook salmon run size was estimated to be higher than steelhead in these rivers and might be explained by severely degraded conditions and blocked access in the Scott and Shasta river tributaries and chinook salmon hatchery production in the Trinity River.

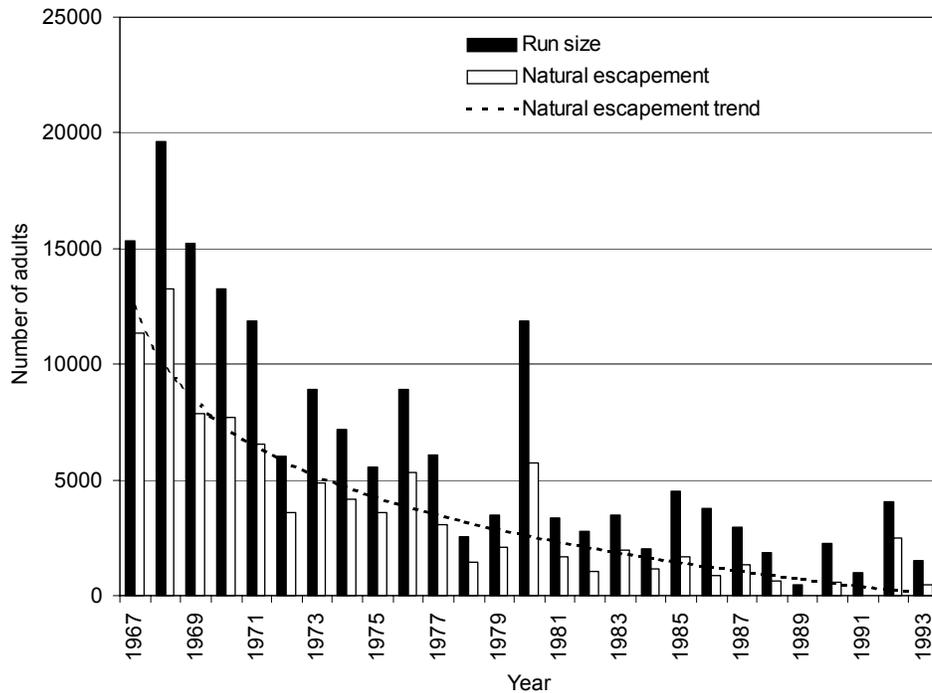


Figure 8 Steelhead population trends in the upper Sacramento River from 1967 to 1993. Run size is the adjusted steelhead counts at Red Bluff Diversion Dam and includes hatchery and natural spawners. Natural escapement was calculated by applying an estimated harvest rate of 16% (DFG unpublished data) to run size, then subtracting Coleman National Fish Hatchery escapement.

Factors Affecting the Decline of Central Valley Steelhead

Stressors affecting abundance, persistence, and recovery have been identified for anadromous fishes in the Sacramento and San Joaquin River systems and these apply reasonably well to Central Valley steelhead. Stressors affecting Central Valley anadromous fishes include water diversions and water management; entrainment; dams and other structures; bank protection; dredging and sediment disposal; gravel mining; invasive aquatic organisms; fishery management practices; and contaminants (Upper Sacramento River FRHAC 1989; Reynolds and others 1990, 1993; CALFED 2000; CMARP Steering Committee 1999). Stressors affecting steelhead on the west coast generally include the stressors listed above plus logging, agriculture, urbanization, disease, predation, and natural factors (NMFS 1996b; NMFS 1997b). McEwan and Jackson

(1996) state that the primary stressors specific to Central Valley steelhead are all related to water development and water management.

Most of the stressors commonly thought to affect Central Valley steelhead were first identified as factors that constrain chinook salmon populations and have been applied to steelhead secondarily because they are an anadromous fish with a somewhat similar life history. It is often assumed that steelhead have been affected by the identified stressors to the same degree as chinook salmon; hence, it is a common perception that alleviation of the stressor to the level that it no longer affects a chinook salmon population will result in steelhead population increases. However, some stressors cause greater effects to steelhead than they do to many chinook salmon populations. For example, high water temperatures affect juvenile steelhead to a greater degree than juvenile fall-run chinook salmon because most salmon have emigrated to the ocean by early summer before high water temperatures occur, whereas steelhead must rear through summer and fall when water temperatures are more likely to become critical.

The single greatest stressor on Central Valley steelhead is the catastrophic loss of spawning and rearing habitat due to construction of impassable dams (IEP Steelhead PWT 1999). Because juvenile steelhead must rear in fresh water for one year or longer, water temperatures must remain suitable year-round. For the most part, this occurred naturally only in the mid- to high-elevation reaches and tributaries, resulting in adult steelhead migrating higher into the drainage to spawn. Because 82% to 95% of their historical spawning and rearing habitat has been lost (Yoshiyama and others 1996; CACSST 1988), mostly due to dam construction, juvenile steelhead rearing is mostly confined to lower elevation reaches where high water temperatures during late-summer and fall are a major stressor (IEP Steelhead PWT 1999; CMARP Steering Committee 1999).

The creation of large impoundments with well-stratified waters has allowed better management of water temperatures in river reaches below large dams. However, hypolimnetic releases to create suitable water temperatures have been made mostly to benefit winter-run chinook salmon populations, and, until very recently, relatively little effort has been made to use this water to maintain suitable temperatures for rearing steelhead during the critical late summer and early fall periods. Although steelhead benefit from water temperature control actions in reaches where they are sympatric with the chinook salmon life stage that is the target of the action (such as rearing winter-run chinook salmon in the upper Sacramento River) focusing actions exclusively on chinook salmon can cause, and has caused, severe temperature effects for steelhead in tributaries where they are sympatric only with fall-run chinook salmon.

Some dams in the Central Valley were constructed with inadequate release structures that make it difficult to optimize releases from the hypolimnion. Other reservoirs may not have adequate minimum pool storage requirements. Consequently, many reservoirs currently are not able to provide releases necessary to maintain suitable temperatures for steelhead rearing through the critical summer and fall periods, especially during dry and critically-dry years. Water demands and power generation also affect the ability to provide suitable temperatures for steelhead.

In the early 1960s, all major Central Valley dams (except Oroville) and most minor dams were already in place, consequently the amount of spawning and rearing habitat available to steelhead probably has not changed appreciably from the late 1950s to the present. The greatest decline of natural steelhead in the system probably took place before the 1960s as a consequence of the reduction in habitat quantity as dam construction was incrementally isolating adults from the tributary spawning and rearing habitats. The decline since the 1960s can probably be mostly attributed to reduction in habitat quality, as increasing water demands – as reflected in the amount of water exported from the system by the State Water Project (SWP) and Central Valley Project (CVP) pumping facilities in the Sacramento-San Joaquin Delta-estuary (Figure 9) – and land use practices diminished the production capability of the existing accessible habitat. Before 1967 when the SWP began operation, the amount of water exported annually from the south Delta-estuary by the CVP pumping facility averaged 1,109,146 acre-feet per year. Since 1967 with both projects operating, the average has nearly quadrupled (4,133,516 acre-feet per year).

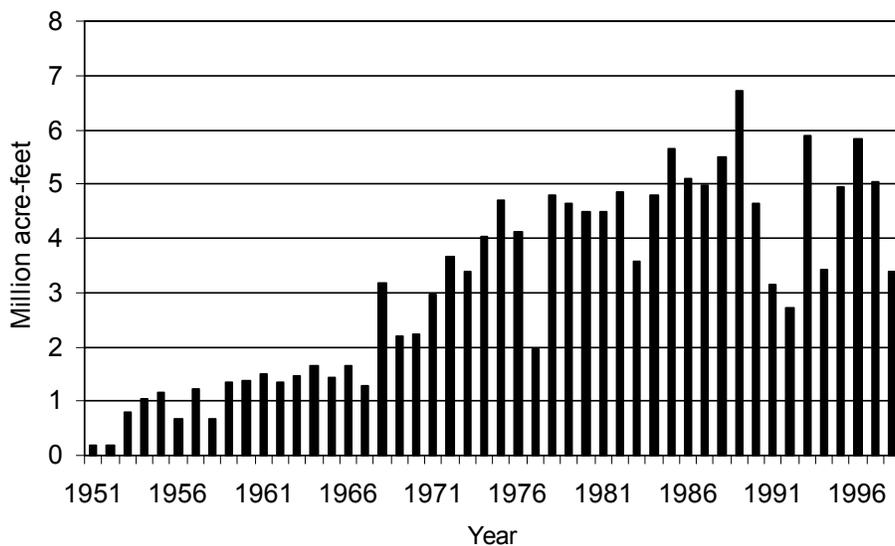


Figure 9 Combined State Water Project and Central Valley Project water exports from the Sacramento-San Joaquin Delta and Estuary, 1951 to 1998

A demographic shift towards the non-anadromous life-history forms brought about by anthropogenic effects could cause a decline in the relative abundance of the individual steelhead life-history forms, although this may not be a stressor on the population as a whole. Among polymorphic salmonid populations, the life-history fate of juveniles appears to be partially controlled by density-dependent factors: the growth rate during early life-history of a particular fish appears to be the factor that determines whether it will later smolt and migrate to the ocean, or become sexually mature in the stream as a parr (Thorpe 1987). Low juvenile densities or abundant resources leads to rapid growth rates, which triggers relatively rapid development which, in turn, leads to a higher frequency of parr maturation in the population, especially among males (Thorpe 1987; Titus and Mosegaard 1992). Conversely, it has been shown that high juvenile densities cause greater resource competition and juveniles that cannot establish and defend suitable stream positions are forced to migrate (Elliott 1994). The greater productivity and more abundant food resources in tailwater reaches may allow an increased growth potential among juvenile rainbow trout, which may skew the population towards the non-anadromous life-history forms. This may be a contributing factor in the growth of the non-anadromous "river trout" population in the upper Sacramento River below Keswick Dam.

Another potential population stressor is the disruption of interrelationships among Central Valley rainbow trout subpopulations. Due to highly variable natural conditions in the Central Valley, inter-population dynamics may be essential to the persistence of rainbow trout populations in the smaller stream systems. Historically, larger source populations occupying more stable habitats (for example, upper Sacramento, Feather, Yuba, and American rivers) provided a source for recolonization and gene flow to the smaller, less-persistent sink populations occupying more hydrologically unstable stream systems. Conversely, the long-term persistence of the source populations may be affected by the diversity and viability of the smaller subpopulations. The precipitous decline of Central Valley steelhead has been alarming not only from the standpoint of reduction in absolute numbers, but also in the elimination of the populations that occupied the many tributaries. A reduction in the large-river source populations may also explain the precipitous decline of steelhead in smaller streams, in spite of the large amount of quality habitat that still exists in these systems. Thus, restoration that focuses only on increasing absolute numbers and ignores the need to increase population diversity may be inadequate.

Monitoring and Research

Past Monitoring and Research Efforts

What is known about Central Valley steelhead is mostly due to a six-year monitoring and research program begun in 1953 by the DFG (Hallock and others 1961). The study, *An Evaluation of Stocking Hatchery-reared Steelhead Rainbow Trout (Salmo gairdnerii gairdnerii) in the Sacramento River System*, focused on hatchery steelhead but also provided valuable information on natural steelhead stocks, including status, abundance, and life history. Much of the baseline information that exists for Central Valley natural steelhead is derived from this study. Unfortunately, this program was canceled due to “lack of interest in steelhead...by administrators” (Hallock 1989). The cancellation of this program, and steelhead research programs in other areas of California, coincided with the implementation of monitoring programs to gather information to promulgate ocean harvest regulations for salmon. In more recent years, efforts to restore Central Valley steelhead has been hampered by a paucity of baseline information.

Other important steelhead investigations in the Sacramento River system include studies on the time pattern of migration of steelhead into the upper Sacramento River (Bailey 1954; Van Woert 1958); a survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin rivers (Hallock and Van Woert 1959); an evaluation of the steelhead fishery (Smith 1950); and an investigation into the status and potential effects of Shasta Dam on upper Sacramento River steelhead (Hanson and others 1940). In addition, several significant studies were undertaken in Sacramento River tributaries, including an assessment of the Yuba River steelhead run size and harvest rates (DFG 1984); an evaluation of the effects of the Oroville Project on the Feather River (Painter and others 1977); and an evaluation of steelhead angling on the American River (Staley 1976). Apparently, no studies or reports on San Joaquin River steelhead have been done.

Recent Monitoring and Research Efforts

In response to the recent listing of Central Valley steelhead under the ESA, steelhead monitoring and research efforts have increased. However, the Hallock and others (1961) study remains the only comprehensive investigation on Central Valley steelhead. Other recent studies and monitoring programs of a broad-based nature that have been completed include an evaluation of juvenile salmonid emigration in the upper Sacramento River (Snider and Titus 1996) and the aforementioned genetic analysis (NMFS 1997a). Significant ongoing investigations include abundance and distribution patterns in juvenile salmonids near the Red Bluff Diversion Dam; a Sacramento-San Joaquin

basin-wide angler survey; upper Sacramento River juvenile salmonid monitoring; and lower Sacramento River juvenile salmonid emigration studies. In addition to these, there are currently anadromous fisheries investigations ongoing on several major tributaries such as the Feather, American, and Mokelumne rivers, and minor tributaries such as Auburn Ravine and Dry Creek. The California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) recently completed a biological assessment of Central Valley water management operations on steelhead and spring-run chinook salmon. This document provides a good synthesis of available information on steelhead and potential impacts (DWR and USBR 1999).

The Interagency Ecological Program Steelhead Project Work Team (IEP Steelhead PWT) identified 82 Central Valley anadromous fish monitoring and research projects operating in 1998 and classified these projects into four categories based on the objectives of the project and the degree to which they obtained information on steelhead: "salmon exclusive," "salmon focused," "anadromous salmonid focused," and "steelhead focused" (IEP Steelhead PWT 1999). Of the four categories, only the latter three provided any meaningful information on steelhead.

"Salmon exclusive" monitoring and research projects had objectives aimed at obtaining information on chinook salmon, used methods and periods of operation to accomplish these objectives, and provided no meaningful information on steelhead. Of the 82 projects reviewed, 42 (51%) were of this type. "Salmon focused" projects were similar to "salmon exclusive" projects in design and scope, but some useful steelhead information was collected incidentally: 12 (15%) were of this type. "Anadromous salmonid focused" projects had objectives that were designed to collect both salmon and steelhead information and used methods and periods of operation to accomplish this: 20 (24%) were of this type. "Steelhead focused" projects had objectives designed to collect steelhead information and used methods and periods of operation designed to collect steelhead information exclusively: eight (10%) were of this type. This analysis demonstrates that despite the recent emphasis on obtaining information on steelhead, the focus of Central Valley anadromous fish monitoring and research efforts is still overwhelmingly on chinook salmon.

Constraints to Steelhead Monitoring and Research

Constraints to steelhead monitoring and research have led to significant knowledge gaps. These constraints fall mainly into two categories: institutional and biological. Institutionally, the lack of adequate funds for anadromous fish monitoring often necessitates that monitoring programs adopt a narrow focus. Because chinook salmon are commercially exploited, highly visible, and politically sensitive, they have received the majority of monitoring funds and effort. This narrow focus was reinforced by the belief among

resource agencies that steelhead suffer from the same level of impacts as do chinook salmon, and assessment of impacts would be similar for steelhead.

Life-history traits common to all Central Valley steelhead can hamper steelhead monitoring and research. Adults tend to migrate during high flow periods, making them difficult to observe. In addition, maintaining counting weirs and other monitoring equipment and structures during these high flow periods can be challenging. Carcass surveys, a reliable method to estimate chinook salmon spawning escapement, is not applicable to steelhead because many survive spawning and most others do not die on spawning grounds. Although steelhead redds can be discerned from salmon redds, they are hard to observe because steelhead spawn at higher flows than do chinook salmon. Trap efficiencies appear to be lower for juvenile steelhead because emigrating juveniles can probably escape trapping more readily because of their larger size, relative to chinook salmon (R. Titus, personal communication, see "Notes").

Knowledge Gaps

Significant knowledge gaps hinder our ability to design restoration actions and monitor their effectiveness. The most important knowledge gaps and monitoring elements needed to address them include the following.

Current Distribution and Abundance of Naturally Spawning Populations

Comprehensive Monitoring. Recent monitoring projects have shown that naturally spawning steelhead exist in the upper Sacramento River and tributaries, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, and Stanislaus rivers. Naturally spawning populations may exist in many other streams as well, but are undetected due to lack of monitoring or research programs. More comprehensive monitoring is needed to determine system-wide distribution.

Run Size Estimation. From 1967 to 1993, run size estimates were generated for steelhead using counts at the fishway on the Red Bluff Diversion Dam (RBDD). From these counts, estimates of natural spawning escapement for the upper Sacramento River above RBDD were made. Because of effects to winter-run chinook salmon, the operation of RBDD was changed so that the dam gates were raised earlier in the season, and this eliminated the ability to generate run-size estimates. Another method of generating run-size estimates for the upper Sacramento River system, or perhaps an index, needs to be developed.

Determination of Origin. Beginning with broodyear (BY) 1997, all steelhead produced in Central Valley hatcheries were marked with an adipose fin clip. This program will continue as a permanent hatchery practice at these hatcheries. Marked juvenile fish were captured in smolt emigration studies in 1998 and

marked adult steelhead began returning in winter 1999 (DFG unpublished data). Capture of non-clipped juvenile steelhead will help elucidate the location of naturally spawning populations.

Life Stage Determination. The IEP Steelhead PWT has developed a Steelhead Life Stage Assessment Protocol and is proposing that it be used by all Central Valley monitoring projects (IEP Steelhead PWT 1998). The protocol classifies rainbow trout by developmental life stage and includes diagnostics for determining the degree of smolting using a set of characteristics that is well-established (for example, Folmar and Dickhoff 1980; Wedemeyer and others 1980). Implementation of a standardized protocol to assign individual fish to one of several life-stage categories (yolk-sac fry, fry, parr, silvery parr, or smolt) will yield valuable information regarding behavior, development, and disposition of juvenile steelhead and distribution of steelhead throughout the Central Valley.

Spawning and Rearing Habitat Characteristics and Use

Assessment of Habitat Structure and Availability Below Dams. Because the majority of steelhead historical habitat is inaccessible to immigrating adult steelhead, research on habitat characteristics and suitability in tailwater reaches below dams needs to be done. A suite of studies on this subject should be initiated, which includes temperature modeling (both river and reservoir); instream flow evaluations to determine suitable migration, spawning, and rearing flows; habitat preference studies to determine how juvenile steelhead use microhabitat; and assessment of habitat conditions and factors limiting steelhead production.

Determination of Temperature Requirements in Specific Streams. To gain a better understanding of thermal requirements and the relationship between water temperature and juvenile steelhead survival, growth, and productivity, thermal bioenergetic investigations need to be conducted on a site-specific basis. Methods using data collected *in situ* have been developed and would provide more accurate site-specific thermal preference information based on field (rather than laboratory) studies (A.A. Rich & Associates 2000).

Population and Habitat Assessment in Low Elevation Tributaries. Steelhead and non-anadromous rainbow trout will use seasonal habitats of intermittent streams for spawning and rearing (Shapovalov 1944; Everest 1971, 1973; Erman and Leidy 1975; Erman and Hawthorne 1976; Maslin and McKinney 1994). Also, steelhead have been found in some small, low elevation Sacramento River tributaries (for example, Dry and Auburn Ravine creeks) that do not contain suitable habitat year-round, or are limiting in one or more suitable habitat characteristics (DFG unpublished data). Habitat characteristics and use, the extent of use of these streams by steelhead, and life-history characteristics

(spawning and emigration timing, size and age at emigration, and so on) need to be determined.

Genetic and Population Structure

Assessment of Maturation Status. Determining maturation status of rainbow trout captured by the various monitoring projects is incorporated into the Steelhead Life Stage Assessment Protocol. Parr maturation, especially in males, is common in steelhead and other polymorphic salmonid populations (reviewed by Titus and others, forthcoming.). When collected systematically throughout the system in conjunction with life stage and condition, these data will provide much needed information about developmental variation in steelhead and population structure.

Central Valley Steelhead Comprehensive Genetic Evaluation. The genetic analysis done by NMFS as part of the west coast steelhead Endangered Species Act status review provided useful information for delineation of Evolutionarily Significant Units (ESUs), but did not have the detail necessary to provide meaningful information within ESUs. More comprehensive information and analysis on the relationship of Central Valley steelhead to each other and to other populations of coastal rainbow trout is needed, as is information on the phylogenetic relationships between putative native rainbow trout, naturally spawning steelhead, and presumably non-native hatchery steelhead. This information will be useful in estimating the structure and genetic diversity within and among Central Valley rainbow trout populations.

Assessment of Reintroduction of Steelhead from Non-anadromous Forms. Provided that native Central Valley rainbow trout populations isolated above artificial barriers can be identified through the comprehensive genetic analysis described above, the next step would be to determine if the steelhead life-history form can be recreated and reintroduced into stream systems where they are presently extirpated.

Miscellaneous Research

Access Restoration Evaluation. Restoring access for steelhead above impassable dams needs to be considered on some streams to address the large-scale habitat loss that has occurred in the Central Valley. Restoration of access to the upper reaches of the Yuba and American rivers has been proposed. Also, the *CALFED Ecosystem Restoration Program Plan* (CALFED 2000) identifies the Yuba River and Battle and Clear creeks as locations in which passage above existing barriers is most feasible. An evaluation should be done in two phases. The first phase would assess spawning and rearing habitat availability above the dams. If suitable habitat can be identified or restored, then a feasibility study

of the best means to provide access (dam removal, passage facility installation, trap-and-truck operation, etc.) should be initiated.

Hatchery Evaluations. Intra- and inter- specific effects of hatchery fish on naturally spawning steelhead need to be investigated. This should include an evaluation of the degree of straying of hatchery steelhead both within and between basins. If there is a significant amount of in-river spawning of hatchery adults, then the potential exists for introgression of hatchery stocks with putative native populations. This is especially of concern for hatcheries that were founded with non-native broodstock, such as Nimbus Hatchery. The degree of straying of hatchery steelhead into other basins needs to be investigated as well. This can be accomplished by applying an external mark to a constant fraction of hatchery production or through thermal mass-marking and subsequent analysis of otolith microstructure. The use of native strains as broodstock needs to be evaluated.

Evaluation of Delta Water Operations on Steelhead Emigration and Rearing. SWP and CVP water diversions from the Sacramento-San Joaquin Delta-estuary have caused significant adverse effects to many riverine, estuarine, and anadromous species (Herbold and Moyle 1989). Attempts to mitigate these adverse effects have spawned much research and monitoring, particularly for chinook salmon, striped bass (*Morone saxatilis*), and delta smelt (*Hypomesus transpacificus*). However, no studies on the effect of the Delta water operations on steelhead in the Delta have been done. The effect of water operations on emigrating juvenile steelhead needs to be assessed. Specifically, timing of smolt emigration through the Delta, magnitude of diversion and entrainment of smolts toward the SWP and CVP pumping facilities, and the effect of the loss of estuary rearing habitat should be evaluated.

Recovery and Management

Endangered Species Act and Recovery Programs

In 1994, the Oregon Natural Resources Defense Council and 15 other organizations petitioned NMFS to list all steelhead stocks in Washington, Idaho, Oregon, and California under the ESA, citing declines in numerous west coast stocks resulting from water development, logging, drought, and other activities. NMFS found that the petition contained credible information and initiated a status review. In 1996, NMFS published a proposed rule designating 15 steelhead ESUs in the four states, ten of which they proposed to list, including all six ESUs in California. They proposed to list the Central Valley ESU, which includes all anadromous reaches of the Sacramento River system and the San

Joaquin system downstream of the confluence of the Merced River (including the Merced River), as endangered.

In August 1997, NMFS published a Final Rule announcing the listing of the Southern California ESU as endangered, and the South-Central California Coast and the Central California Coast ESUs as threatened. They deferred the decisions on the other California ESUs. In May 1998, NMFS listed the Central Valley ESU citing ongoing conservation efforts as justification for listing as threatened, rather than endangered, as originally proposed. Specifically cited were the Central Valley Project Improvement Act (CVPIA), an act passed by Congress in 1992 to remedy habitat and other problems associated with the operations of the Central Valley Project, and the CALFED Bay-Delta Program, a joint State and federal program to develop a long-term solution to address Central Valley ecosystem restoration, water supply reliability, and other issues.

The Anadromous Fish Restoration Plan (AFRP) was developed in 1995 to achieve the mandated CVPIA goal of doubling the natural production of anadromous fish by 2002 (USFWS 1997). The AFRP lists actions, such as specified increased flows below CVP reservoirs, intended to recover six species of anadromous fish, including steelhead. Some measures of the AFRP have been implemented, such as increased flows for fish.

Like many other management and restoration plans for Central Valley anadromous fisheries, actions identified in the AFRP are largely driven by chinook salmon restoration, and less emphasis is placed on specific actions needed to recover steelhead. For example, minimum flows in the San Joaquin River system were set according to the needs of fall-run chinook salmon, and because juvenile fall-run chinook have largely emigrated by early summer, no provisions of flows to maintain cold water temperatures through the summer were established. AFRP-specified flows for Clear Creek and the upper Sacramento River below Keswick were also designed specifically for chinook salmon. The AFRP needs to consider rearing flows and temperatures necessary to support over-summering juvenile steelhead.

The institutional predilection for chinook salmon in monitoring and assessment efforts discussed previously is also prevalent in recovery and management strategies, and this has been the dominant paradigm in steelhead management and restoration efforts initiated in the past ten years (see Upper Sacramento River FRHAC 1989; Reynolds and others 1990, 1993; USFWS 1997)⁵. Although most restoration measures designed to recover chinook salmon stocks do benefit steelhead or are benign in that regard, focusing restoration solely on chinook salmon leads to inadequate measures to restore steelhead because of their different life histories and resource requirements, particularly that of rearing juveniles.

The other large-scale ecosystem restoration action, the CALFED Bay-Delta Program, goes much farther than the CVPIA in recognizing the need to identify and implement actions to restore steelhead, separate from those to restore chinook salmon, especially in the San Joaquin River system:

It is important to note that all of the agreed upon or proposed flows (AFRP, Tuolumne River Settlement Agreement, FERC, VAMP, Davis-Grunsky, and DFG recommended flows) in the Stanislaus, Tuolumne, and Merced rivers were designed to facilitate chinook salmon recovery, and little or no consideration was given to steelhead recovery in the design of these flow strategies. Flow and temperatures requirements of steelhead will need to be evaluated and integrated into the proposed flow regimes (CALFED 2000).

CALFED has identified specific measures for steelhead recovery in the Ecosystem Restoration Program Plan, yet this program is in its infancy, and many of the identified actions are still in their initial stages. It may be several years in the future before many of these actions are implemented.

"New" Concepts for Steelhead Management

The diverse structure of rainbow trout populations described in the preceding sections is not a new concept: the extreme variability in life history and the close relationship between non-anadromous and anadromous forms was recognized early-on (Jordan 1894, 1895; Snyder 1928; Taft 1934; Shapovalov and Taft 1954) and is illustrated by the following quote from Jordan (1895):

It is said by anglers that the brook trout exist in the mountains and the salmon trout come up from the sea and "promiscuously mix with it." This

5. Another example of the chinook salmon emphasis in Central Valley anadromous fish programs was evident at the Salmonid Symposium—of the 18 papers presented at the symposium, 14 dealt with chinook salmon exclusively, three with anadromous fish in general, and only this one addressed steelhead.

*seems another way of saying that the brook trout (irideus) and the salmon trout (gairdneri) are but forms or states of the same fish.*⁶

Although classified originally as different species and later as different subspecies, the taxonomic relationship of the anadromous and non-anadromous rainbow trout forms posed considerable difficulties to early taxonomists (Jordan 1894; Kendall 1921; Taft 1934). Taft (1934) and Shapovalov and Taft (1954) aptly described the variability in rainbow trout population structure. In recent years, these concepts appear to have been largely ignored in the application of rainbow trout management, and non-anadromous and steelhead rainbow trout are usually treated as separate stocks in management schemes.

This management dichotomy is brought about not only by an incomplete understanding or appreciation of the complexity of rainbow trout population structure, but is also largely due to institutional limitations. In many cases, such as within the DFG, coordination of management and policy development for non-anadromous and steelhead rainbow trout are under the auspices of different organizational divisions, and in the case of federal ESA jurisdiction, two different cabinet-level departments (Interior and Commerce departments, respectively).

The latter example has led to a curious and biologically questionable decision by the federal government in the promulgation of the ESA for steelhead. NMFS stated in the Final Rule listing some ESUs of steelhead (NMFS 1997b) that “available evidence suggests that resident rainbow trout should be included in listed ESU’s...where resident *O. mykiss* have the opportunity to interbreed with anadromous fish below natural or man-made barriers...”; and “NMFS believes that resident fish can help to buffer extinction risks to an anadromous population.” Further, “NMFS believes that available data suggest that resident rainbow trout are in many cases part of steelhead ESUs.” Despite these findings, NMFS deferred to USFWS, who asserted their ESA jurisdiction for resident (non-anadromous) fish. USFWS stated that there was no evidence to suggest that non-anadromous rainbow trout needed ESA protection and concluded that only the anadromous forms of each ESU could be listed under the ESA by NMFS (NMFS 1997b). Because of this, non-anadromous rainbow trout were specifically excluded from the listing. Thus, we have a unique and potentially problematic situation (from a recovery standpoint) where some individuals of a listed species may be protected under the ESA, while their progeny are not. This is also problematic from an enforcement and protection standpoint because the life-history fate of a juvenile rain-

6. Use of the specific epithets *irideus* and *gairdneri* indicates that Jordan was referring to non-anadromous and steelhead rainbow trout, not *Salvelinus fontinalis* or other Pacific salmon species.

bow trout is indeterminable unless the fish has smolted, thus ESA protection may be denied for the component of the population that most needs it.

The likelihood that anadromous and non-anadromous rainbow trout can form a single interbreeding population in a particular stream has important management implications, which can only be addressed through an integrated management strategy that treats all rainbow trout occupying a stream or continuous stream reaches as a single population, regardless of life history differences within the population. Management of steelhead must include measures to protect and restore non-anadromous rainbow trout, and especially the ecological linkages between the different forms. The large-scale disruption of this linkage that has occurred in the Central Valley through the placement of impassable dams on many streams may go a long way in explaining the significant decline of Central Valley steelhead stocks.

The necessity of a strategy that integrates the management of non-anadromous and steelhead rainbow trout was recognized by Snyder (1928) long ago, who made this insightful, yet mostly unheeded statement:

We have steelheads and stream trout, and conservation of the one depends absolutely upon conservation of the other. We burn the candle at both ends when we overfish both the steelheads and stream trout. We are awakening to the fact that we can not both destroy the steelheads and maintain the rainbows.

We may have begun to awaken in the 1920s, but apparently we hit the snooze button and went back to sleep. If we are to effectively manage and recover Central Valley steelhead, we must bring our management and restoration strategies more in line with rainbow trout population structure and dynamics and we must recognize that steelhead need to be managed separately from chinook salmon stocks. Because most of their historical habitat is now inaccessible, the most effective recovery strategies will be those that focus on restoring access to former habitats, where natural conditions are conducive to spawning and rearing and the resiliency that is inherent in a diverse population structure can be fully expressed. This may have ancillary benefits to water users as well, given that in many regulated stream systems today, steelhead can only be maintained by providing suitable flows and cool water temperatures, and this can and does exact a significant water cost. Allowing steelhead to spawn and rear in their former habitats will likely alleviate the need to provide these conditions in the downstream reaches below dams.

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Applications of Population Genetics to Conservation of Chinook Salmon Diversity in the Central Valley

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Uses of Modern Population Genetics in Conservation

Population genetics is playing an increasingly important role in the conservation of salmonid resources in the Pacific Northwest. The National Marine Fisheries Service considers a salmon population worthy of conservation under the U.S. Endangered Species Act if it represents an Evolutionary Significant Unit (ESU), "...a population (or group of populations) that (1) is substantially reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species" (Waples 1991, 1995). Genetic data provide an important, though indirect means for establishing the degree of reproductive isolation between conspecific populations. Indeed, numerous studies of electrophoretically detectable protein polymorphisms carried out over the past 30 years on Pacific salmon species have shown that a high degree of spatial substructure and reproductive isolation results from their homing behavior (Utter 1991). With the advent of DNA markers, particularly mitochondrial and microsatellite DNA markers, resolution of reproductively isolated or partially isolated populations has become more precise. Here, we describe progress resolving chinook salmon diversity and stock structure in the Central Valley of California.

Modern tools of population genetics, for example, using polymorphic protein markers, also allow us to address problems that could not formerly be approached. Whereas protein markers had long supported the statistical allocation of catch in mixed ocean fisheries to contributing spawning populations (Utter and Ryman 1993), highly polymorphic microsatellite DNA markers now enable us to ascertain the origins of individual fish. We describe how individual assignment of salmon, first achieved for Central Valley chinook salmon, has become an integral part of a hatchery supplementation program for the endangered Sacramento River winter chinook salmon. Individual assignment is also being used to identify winter-run juvenile migration patterns through the Sacramento-San Joaquin Delta and in assigning ocean catches to various Central Valley stocks, some of which are threatened or endangered.

The use of highly polymorphic DNA markers has also enabled tremendous improvements in identifying parentage and kinship. Indeed, determining the parentage of hatchery-reared winter chinook in the supplementation program was our original motivation for developing microsatellite DNA markers. Since then, microsatellite markers have provided, aside from a description of genetic diversity within and among Central Valley stocks, an important validation of the demographic model used to assess the genetic effect of the hatchery supplementation program for winter run. Microsatellite markers also allow the assessment of kinship in juvenile samples, which often are the only material that can be collected from small, threatened, or endangered populations. In the past, population geneticists advised against using juvenile samples because of the potentially confounding effects of family structure on the estimation of adult allele frequencies (Allendorf and Phelps 1981). Now, however, highly polymorphic markers enable the kinship of juveniles to be detected and the effects of family structure to be removed. Such data not only allow the genotypes and allele frequencies of the unobserved adult population to be reconstructed but also shed light on the reproductive behavioral ecology of salmon populations.

Genetic Diversity of Chinook Salmon in the Central Valley

Phenotypic Diversity

Major spawning subpopulations among California's Central Valley chinook salmon have very similar anatomical and morphological features but marked differences in timing of spawning, juvenile emergence, early rearing and migration from the freshwater habitat to the ocean. Four runs have been named—winter, spring, fall, and late-fall—based on the season when most individuals from a subpopulation return to freshwater for spawning (Stone 1874; Fry 1961). Spawning not only occurs at a distinct time for each run, with only partial overlap between temporally adjacent runs, but, historically at least, often in a distinct habitat (for example, major rivers compared with higher elevation streams; see Fisher 1994). This natural, spatial and temporal isolation of the various spawning habitats has been greatly perturbed by human activity. For example, 150 years ago, spring and fall runs overlapped in spawning time but were geographically isolated; spring run spawned in the upper headwaters and fall run, in rivers and major streams of the lower valley floor. Forced co-existence of these two runs caused by substantial damming and loss of habitat in recent years, however, has led to concern for their genetic integrity (Cope and Slater 1957; Banks and others 2000).

Several studies have focused on genetic characterization of California's Central Valley chinook salmon using of a variety of genetic marker types. Results will be presented for each type, separately, followed by a synthesis across marker types. Wright's (1931) standardized variance of allele frequencies among subpopulations, F_{ST} , is used to measure genetic diversity among runs and to compare results from different marker classes.

Allozymes

A study of 39 allozyme loci (Bartley and others 1992) revealed little divergence between fall and winter-run chinook salmon, with Wright's standardized allele-frequency variance, $F_{ST} = 0.01$. However, the authenticity of winter-run samples used in this study has been questioned (D. Teel and G. Winans, personal communication, see "Notes"). A more recent study (Winans and others forthcoming), based on more extensive sampling, indicates significant genetic structure among Central Valley chinook runs, in accord with results based on other marker types (Figure 1A).

Mitochondrial DNA

Nielsen and others (1994) reported substantial divergence in frequencies of six mtDNA haplotypes ($F_{ST} = 0.24$) among recognized Central Valley chinook stocks (Figure 1B). However, the probability that any two Central Valley chinook haplotypes are identical is 0.7, precluding use of this marker alone for individual identification. Further, maternal inheritance of mtDNA limits use of this marker type for genetic inference related to family structure.

Microsatellites

The listing of winter run under the federal and California endangered species acts increased the need to discriminate among subpopulations of Central Valley chinook. Banks and others (1999) cloned and developed ten new microsatellites for this task, verifying that their inheritance was Mendelian. A subsequent study used these and other microsatellites from the literature to characterize 41 population samples taken throughout the valley between 1991 and 1997 (Banks and others 2000; Figure 2). Samples encompassed geographic and temporal variation within subpopulations. Maximum likelihood methods were used to correct for family structure among samples comprised of juveniles (see "Parentage and Kinship"), as well as to correct for run admixture in adult samples (see "Avoiding Hybridization in the Winter Run Supplementation Program"). This extensive sampling and sample adjustments established a database of accurate and precise estimates of microsatellite allele frequencies for Central Valley chinook.

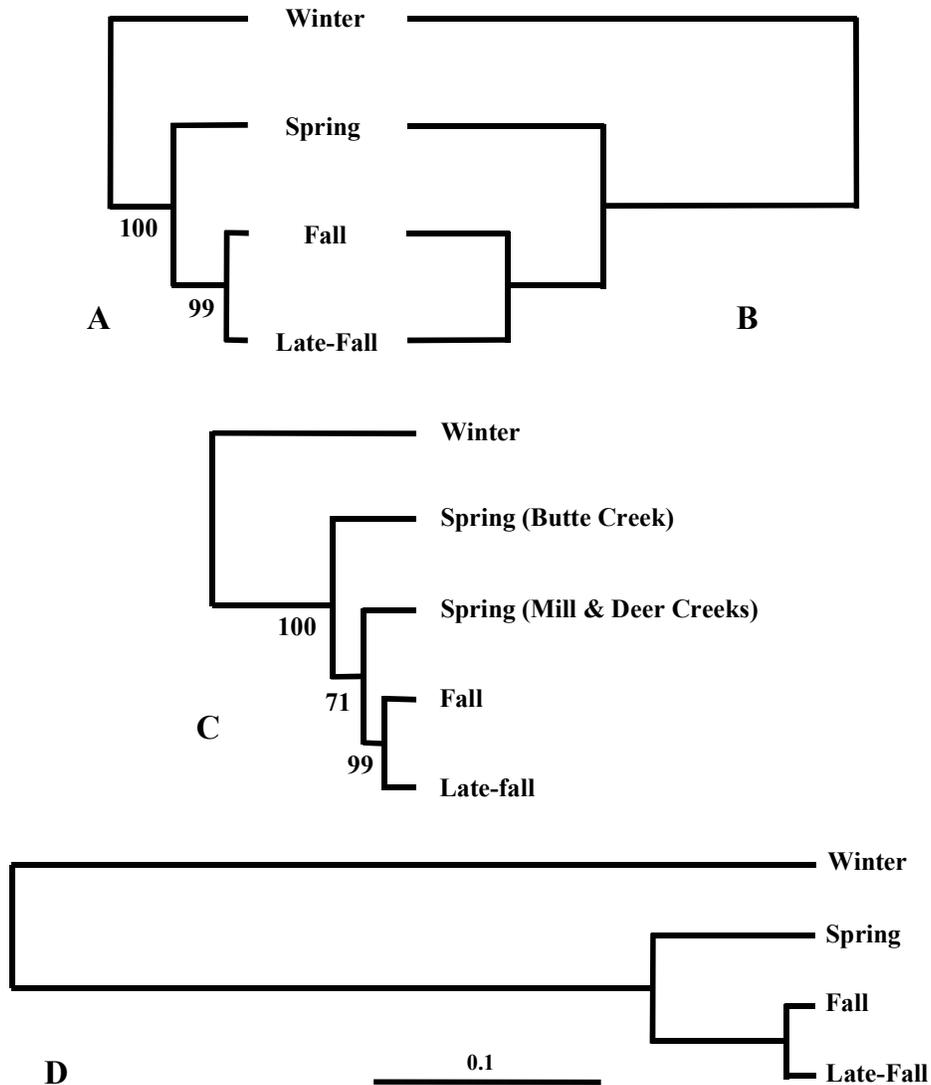


Figure 1 Genetic distances among subpopulations of Central Valley chinook salmon calculated from data on four genetic markers, (A) allozymes or proteins (after Winans and Teal, unpublished); (B) control region sequences of mitochondrial DNA (after Nielsen and others 1994); (C) microsatellite DNA markers (after Banks and others 2000); (D) a class II member of the Major Histocompatibility Complex (after Kim and others 1999). Numbers next to nodes in (A) and (C) are the percentages of 1,000 bootstrapped trees showing that same node.

The most important finding of this study is that chinook salmon of the Central Valley in California have substantial genetic diversity and structure (Figure 1C). Except for discovery of two distinct lineages of spring run, this study revealed a genetic structure congruent with the recognized winter, spring, fall and late-fall spawning runs (Fisher 1994). It is, perhaps, surprising but encouraging that such biological diversity has survived more than 100 years of massive habitat destruction, exploitation, and artificial propagation (Yoshiyama and others 1998, this volume). Moreover, the data retrospectively support the designation of winter run and spring run as Evolutionary Significant Units protected under the U.S. Endangered Species Act (Waples 1995; NMFS 1994, 1999). Winter run, whose blend of ocean- and stream-type life-history characteristics is unique in the species (Healey 1991), is the most distinctive of the subpopulations in the Central Valley. The next most distinctive subpopulations are the spring runs, particularly those in Butte Creek, which have unique life-history adaptations (Yoshiyama and others 1996). Formerly the most abundant chinook salmon throughout the Central Valley, spring chinook are presently found in only a few tributaries of the Sacramento River, primarily those considered in this study (Fisher 1994; Yoshiyama and others 1996, 1998). Finally, fall and late-fall runs, though closely related, are significantly different at 10 microsatellite markers (Figure 1C) and differ in geographic range, run timing, and size at maturity (Fisher 1994).

Winter run, and to a lesser extent spring run from Butte Creek, show lower levels of allelic diversity than other runs, suggesting that these populations experienced past reductions in size (bottlenecks). This may also explain a part of their divergence from the other runs in the Central Valley (Hedrick 1999). Despite spatial and temporal overlap of chinook salmon spawning runs in the Central Valley, no evidence for natural hybridization among runs was found by Banks and others (2000). A commonly held view is that most spring-run populations have hybridized with fall run and that Butte Creek spring run, in particular, has hybridized with the Feather River fall hatchery stock (Yoshiyama and others 1998). However, two observations contradict this hypothesis. First, genotypic proportions in the Butte Creek spring run mostly conform to random mating expectations. Second, Butte Creek spring clusters farther from the fall run than does spring run from Deer and Mill creeks (Figure 1C), not closer as expected under the hybridization hypothesis. Run-admixture can nevertheless occur and appears a likely cause for significant linkage disequilibrium in hatchery populations (see "Avoiding Hybridization in the Winter Run Supplementation Program") and, to a lesser extent, in samples from certain populations spawning in the wild.

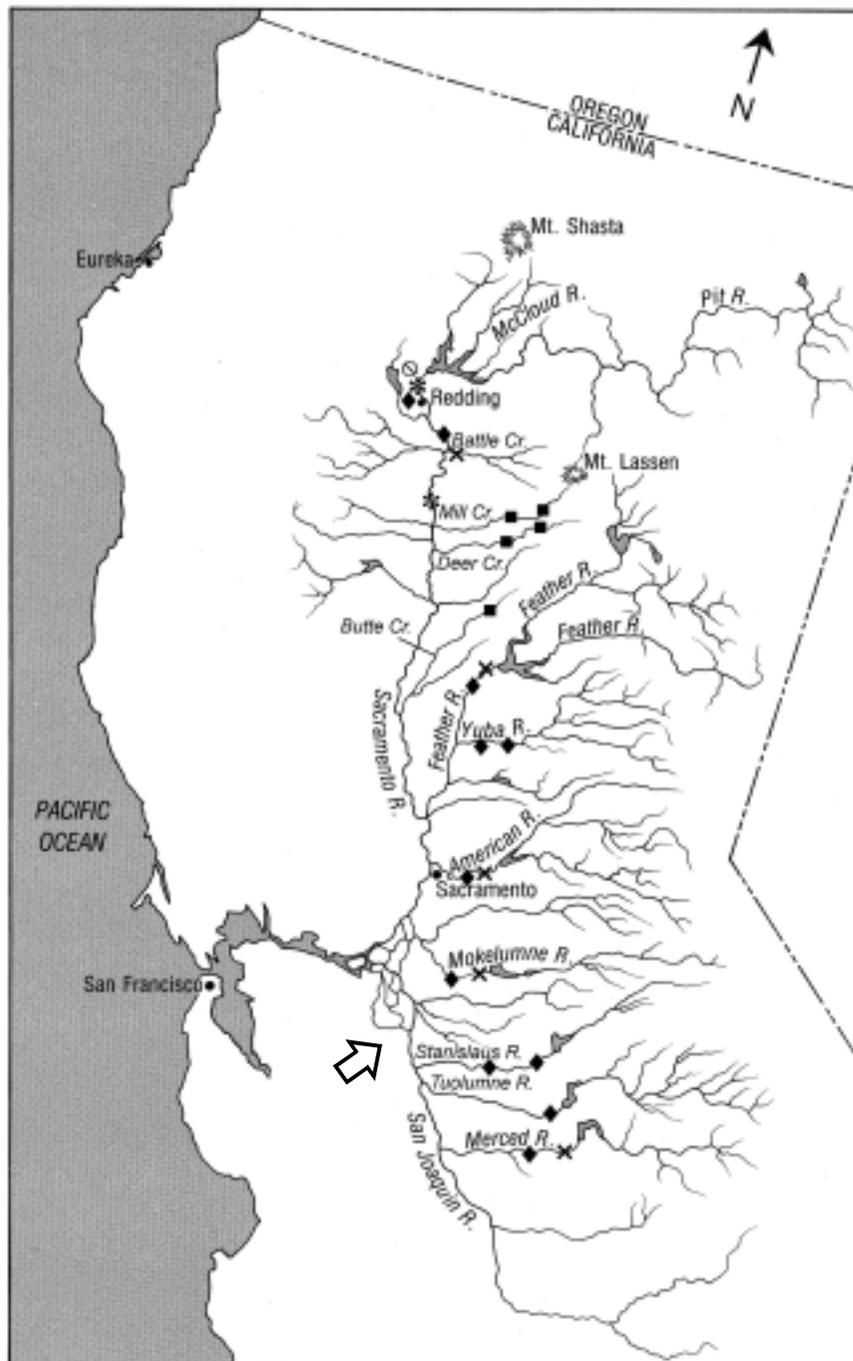


Figure 2 Map of the Central Valley, showing the localities from which chinook salmon were sampled for genetic analysis (from Banks and others 2000). The open arrow indicates the general location of the SWP and CVP water pumping plants in the Sacramento-San Joaquin Delta.

Nielsen and others (2000) also characterized Central Valley chinook using 10 microsatellites, five of which were in common with those used by Banks and others (2000). Overall relationships between major subpopulations revealed by this study were the same as described by Banks and others (2000), the two studies both verifying the distinctiveness of winter and spring runs. In contrast to Banks and others (2000), however, Nielsen and others (2000) found that year-to-year variation within runs was substantial (nearly 11% of the total variance) though not significant. Moreover, they found significant heterogeneity within fall-run hatchery samples as well as within spring run samples from Mill, Deer, and Butte creeks. However, Nielsen and others (2000) used samples of juveniles and did not correct for the potential effects of kinship within such samples.

A Class II Gene of the Major Histocompatibility Complex

Characterization of class II MHC variation for Central Valley chinook salmon also found significant frequency differences among runs ($F_{ST} = 0.129$) except between fall and late-fall (Kim and others 1999). Thus, in consensus with other marker types, MHC variation demonstrates the distinctiveness of the endangered winter run (Figure 1D), with no evidence for significant variation among winter run samples from different years.

Concordance Across Marker Types

The pictures of divergence among chinook salmon runs in the Central Valley painted by the above marker types are concordant. Winter run is the most distinctive subpopulation, followed by spring run, then fall and late fall. There is substantially less variation among the geographic samples within a subpopulation than among subpopulations, even for the fall run, which is presently the most widely distributed. Finally, most studies have not detected significant temporal variation within a spawning population.

Mitochondrial DNA and MHC appear, at first glance, to show greater divergence among runs than do microsatellite markers (compare Figures 1B and 1D with 1C). The average 0.078 F_{ST} estimate for 10 microsatellite loci from Banks and others (2000) is less than the F_{ST} of 0.24 from the mtDNA data of Nielsen and others (1994) or the 0.129 estimate from the MHC class II b1 exon (Kim and others 1999). However, some microsatellite markers do show comparable levels of divergence (for example, Ots-2 with F_{ST} of 0.169). Another difference among microsatellites, MHC, and mitochondrial DNA, which may account for different levels of among-subpopulation divergence, is in numbers of alleles. The last two marker types have substantially fewer alleles than is typical of microsatellites. Several researchers (Hedrick 1999 and references therein) have shown that, for highly variable loci such as microsatellites, F_{ST} is constrained by high within-population diversity. This problem can be overcome

to some extent by using different distance metrics, including the percentage of individuals correctly assigned to their sample of origin, as discussed in the next section.

Mixed Stock Analysis and Individual Assignment

Mixed Stock Analysis vs. Individual Assignment

Distinguishing among the five morphologically similar subpopulations (fall, winter, late fall, Butte Creek, and Mill and Deer Creek springs) of chinook salmon in the Central Valley is important in fisheries management and conservation, particularly because some stocks are protected and others are not. Population genetics has been applied to this problem, in several different contexts, involving adult and juvenile phases of the life cycle. Run identification is made possible by the baseline survey of microsatellite DNA variation in population samples from the Central Valley (Banks and others 2000). Two population genetic methods are used to distinguish among the different spawning runs: mixed stock analysis (MSA) and individual assignment to population of origin. MSA is a population-based method that has been widely used to estimate the relative contributions of salmon stocks to random samples of adults taken in mixed ocean harvests (Milner and others 1985; Utter and Ryman 1993). In the Central Valley, MSA can be applied to mixtures of chinook salmon juveniles from different spawning populations, which co-mingle in the Sacramento-San Joaquin Delta during emigration from the freshwater habitat. Individual assignment, on the other hand, estimates the most likely population of origin for an individual, based on the odds that its genotype belongs to one rather than to another subpopulation (Paetkau and others 1994; Banks and Eichert 2000). Individual assignment is useful when adults are collected for hatchery propagation or when the presence of protected runs must be ascertained in small samples from fish salvage operations at Delta pumping facilities. Actually, as we shall illustrate, a combination of the two methods is needed to analyze mixtures in the Delta and the ocean fishery.

The Central Valley chinook baseline can be used in computer simulations to illustrate the two methods and to demonstrate their relative merits and effectiveness. The baseline data are randomly permuted to produce 200 individuals from each of the five populations: winter, spring from Mill and Deer creeks, spring from Butte Creek, fall and late fall. Each individual has been genotyped for seven of the 10 markers studied by Banks and others (2000). This creates a mixed stock of 1,000 individuals of known population descent, with which to evaluate the characteristics and performance of each method. MSA uses the Statistical Package for Analysis of Mixture (SPAM, version 3.2, available at <http://www.cf.adfg.state.ak.us/geninfo/research/genetics/soft->

ware/spamPage.htm). Individual assignment is performed following procedures described by Banks and Eichert (2000). Statistical power of assignment is then assessed through population simulations (Banks and others forthcoming). Results of both MSA and individual assignment are presented in Table 1. MSA accurately estimates the contributions from all runs; the actual contribution of each subpopulation, 0.2, lies within two standard errors of the estimated contribution. On the other hand, although 99.7% of simulated winter-run individuals are correctly assigned, only 60% to 80% of non-winter individuals are correctly assigned. The poorer assignment of non-winter fish is attributable to the smaller genetic distances separating the non-winter runs from one another. MSA is better at identifying the contributions of all runs because it uses not only the information present in the baseline but also the information in the mixed population sample. Individual assignment, like MSA, uses the baseline information but has only the limited information from the single individual being assigned.

Although the five subpopulations contribute equally to our example mixture, they are likely to contribute very unequally to most samples from natural populations. The accuracy of individual assignment based strictly on the likelihood of genotypes in baseline populations is affected by the relative contribution from source populations. If genotype A is relatively common in run 1 but quite rare in run 2, individuals with genotype A will be assigned to run 1 in the absence of information on the relative abundance of the two runs. However, if run 2 is 1000 times more abundant than run 1, then the likelihood that genotype A belongs to run 2 increases. Prior information on the relative abundance of runs can be used to correct the individual assignment, using Bayesian statistical methods (Shoemaker and others 1999). We shall show that MSA can provide estimates of relative run abundance that are, in turn, used to adjust the assignment.

Individual assignment for spring, fall, and late-fall populations could be improved with additional markers that increase the genetic distance among these runs. New microsatellite markers have been developed for spring-run characterization (Greig and Banks forthcoming), and additional markers for Pacific salmon are being developed by West Coast laboratories at an increasing rate. A program for evaluating the power of alternate sets of markers through re-sampling simulations (WHICHLOCI, Banks and others forthcoming) now facilitates the choice of markers needed to reach a given level of accuracy and precision of individual assignment. The cost of assigning individuals to non-winter runs will be greater, of course, than the cost of assigning winter run individuals, because more markers will be required.

Table 1 Results for assigning components of a mixed stock to population origin using mixed stock analysis and individual assignment^a

Mixed Stock Analysis			
Population	Expected	Estimate	Standard Error
Winter	0.2000	0.2009	0.0126
SP-MD	0.2000	0.2185	0.0122
SP-B	0.2000	0.1899	0.0122
Fall	0.2000	0.1874	0.0093
Late fall	0.2000	0.2033	0.0122
Individual Assignment			
Population	% Correct	Standard Deviation	
Winter	99.7226	0.508	
SP-MD	77.5115	4.0626	
SP-B	90.4935	2.9192	
Fall	69.7285	4.5995	
Late fall	80.0215	4.0677	

^a A mixed stock was composed of 200 individuals from each of five populations created through permutation of baseline populations. The mean, standard deviation, and standard error estimated from 1,000 bootstrap samples.

Avoiding Hybridization in the Winter-run Supplementation Program

In 1991, the U.S. Fish and Wildlife Service initiated a hatchery supplementation program aimed at helping to prevent the Sacramento River winter chinook salmon from going extinct. Research on the genetic effect of the program is described in the next section. Here, we consider a problem that became apparent in 1995, namely, how to distinguish winter run from non-winter run in selecting broodstock for the hatchery supplementation program.

In 1995, 38 of 85 fish collected by the USFWS for the winter-run supplementation program failed to mature in the hatchery. These non-maturing fish appeared to have phenotypic and genotypic affinities with spring chinook. A re-investigation of 140 winter-run brood stock that had been used for winter-run supplementation from 1991 to 1995 revealed strong, non-random associations (called gametic-phase or linkage disequilibria or LD) of allelic combinations at pairs of microsatellite loci. Typically, adults from naturally spawning populations show random associations of allelic combinations at pairs of loci, because mating of Pacific salmon occurs randomly with respect to genetic

markers (Figure 3). One significant cause of LD in samples from salmon populations, particularly hatchery populations, is admixture of non-interbreeding populations (Waples and Smouse 1991). Mixture was already evident from the spring-run affinities of non-maturing brood fish captured in 1995. The implication of finding significant levels of LD in the spawning fish was that spring run had been hybridized with winter run in the supplementation program and that possibly all samples of winter-run had actually been mixtures of two or more distinct runs.

By identifying and removing individuals with multiple, pairwise allelic combinations typical of spring run, it was possible to divide the mixture into winter and spring components, each of which is in linkage equilibrium. A multifactorial analysis of individual genotypes confirms the separation based on analysis of LD (Figure 4). Nineteen of the 140 winter brood fish clearly cluster with 37 of 38 non-maturing 1995 brood fish (one of the non-maturing fish clusters with the true winter-run fish). The remaining 121 “true” winters show only 2% of loci-pairs with significant gametic-phase disequilibria when 5% are expected by chance (Figure 4). The winter-run baseline population now comprises these “true” winters plus samples of carcasses obtained from the Sacramento River, which were similarly purged of a few, admixed non-winters.

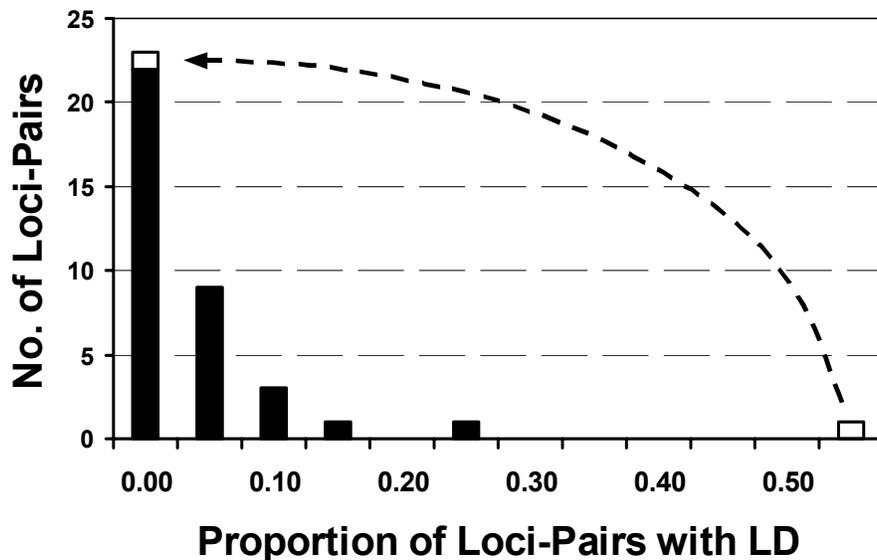


Figure 3 The proportion of loci-pairs with significant associations (linkage disequilibrium or LD) in 36 samples of non-winter chinook salmon from the Central Valley (black bars). The extremely high proportion of significant associations in winter chinook captured for a hatchery supplementation program (white bar) is greatly reduced after likely non-winter fish are removed from the sample (dotted arrow).

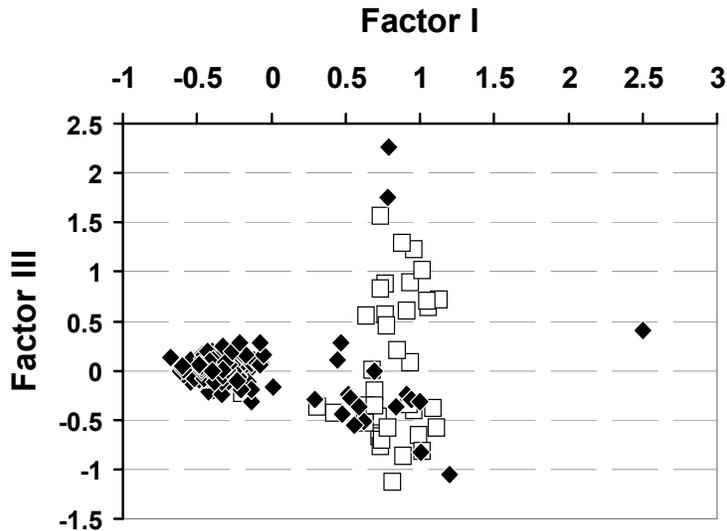


Figure 4 Genetic clustering of chinook salmon captured for hatchery-propagation of the winter run. Scores of each fish on the first and third factors derived from factorial correspondence analysis of genotypes at 13 loci are plotted. Black diamonds denote the 140, putative winter run spawned from 1991 through 1995. White boxes denote adults captured in 1995 that did not mature and that clustered closely with spring-run populations (not shown). Note that 19 of the putative winter run adults cluster with the non-maturing, spring-run fish, while one of the non-maturing fish clusters with the true winter run.

The discovery of unwitting winter-spring hybridization in 1995, together with the observation in the same year that hatchery-spawned fish were returning to Battle Creek rather than the Sacramento River (where they had been released as fry), caused the USFWS to temporarily halt the supplementation program. The program resumed in 1998, after construction of the Livingston Stone Fish Culture Facility on the Sacramento River solved the imprinting problem and development of sufficient microsatellite markers and baseline data permitted accurate assignment of brood stock. A “rapid response” program was implemented in 1998 to genotype potential brood stock caught at the fish traps at the Keswick and Red Bluff diversion dams on the Sacramento River, as well as fish returning to the Coleman National Fish Hatchery on Battle Creek. A caudal fin clip is taken from each trapped fish and sent to the Bodega Marine Laboratory for analysis of seven microsatellite markers. Simulation results suggest that 99.1% (s.d. = 0.91%) of true winter run are correctly identified when the criterion for assignment is 10:1 or greater odds that a given genotype belongs to the winter run. More importantly, the percentage of non-winter run incorrectly assigned to winter run under this criterion is 0.02% (s.d. = 0.16%). Thus, a threshold of 10:1 or greater odds provides ample protection against incorporating non-winter run adults into the hatchery supplementa-

tion program for winter run. We typed 356 fish from the winter spawning runs of 1998 to 2000, of which 240 were assigned to the winter run (Table 2). From 1997 to 2000, we continued to monitor fish returning to the Coleman National Fish Hatchery; out of 357 examined, 108 were winters, most of which were relocated to spawning habitat in the Sacramento River.

Table 2 Numbers of chinook adults caught at the Keswick Dam (Sacramento River) and at the Coleman National Fish Hatchery (Battle Creek) subsequently genotyped and assigned to winter run

Year	<i>Keswick Dam (Sacramento River)</i>		<i>Coleman National Fish Hatchery (Battle Creek)</i>	
	<i>Number genotyped</i>	<i>Number winter run</i>	<i>Number genotyped</i>	<i>Number winter run</i>
1997	---	---	116	89
1998	152	107	117	15
1999	42	24	70	0
2000	162	109	54	4

Juvenile Emigration and Delta Salvage

We have applied both MSA and individual assignment methods to juvenile chinook emigrating from California's Central Valley. Though peak times of emigration for the different subpopulations differ, all five populations potentially intermix in the Sacramento-San Joaquin Delta (Fisher 1994). Understanding the timing of winter-run emigration and their occurrence at the State Water Project (SWP) and the Central Valley Project (CVP) is essential to evaluating the effects of these water-pumping facilities on the endangered Sacramento River winter-run chinook salmon. More than 5,000 samples were collected and genotyped over five consecutive seasons (1995–2000) at two large water pumping facilities in the Sacramento-San Joaquin Delta. In this application, in contrast to the selection of hatchery brood stock, we use an assignment criterion of even or better odds, rather than 10:1 odds, that a given genotype belongs to the winter run. The aim of this criterion is to protect all winter run at the expense of also protecting some non-winter run fish incorrectly assigned by the inclusive criterion.

The contributions of various spawning populations to the mixture of juveniles in the Delta are expected to be unequal and variable with the season. Winter run contributes a large number of samples early in the season and fewer samples later, when fall run dominates fish salvage. However, as mentioned above, the relative abundance of the various subpopulations can have a sub-

stantial effect on individual assignment. To correct for this, we use MSA to estimate the relative abundance of the runs among juveniles of similar size caught around the same time as each individual whose genotype alone suggests winter-run provenance. In other words, MSA establishes the prior probability for the runs and, using a Bayesian statistical approach, serves to correct the individual population assignment for unequal relative frequencies of subpopulation (Dean and others forthcoming). In practice, the assignment of relatively few individuals is affected by this correction (Figure 5). Having thus identified which emigrating juveniles are winter run, we see that the results do not accord with the growth model predicting the relationship of juvenile size and provenance. Winter juveniles are caught at similar sizes throughout the season of emigration, in contrast to the growth curves that presently define the subpopulations for purposes of determining take of protected winter run (Figure 5). The growth curves clearly overestimate the losses of winter-run in the Delta. These results further suggest the hypothesis that the winter run does not use the lower Delta as rearing habitat.

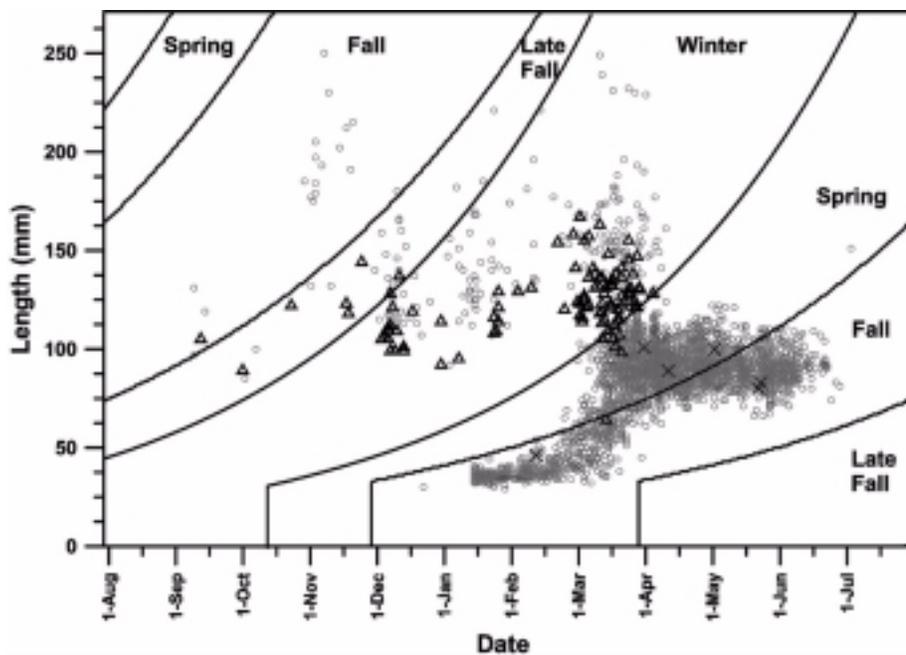


Figure 5 Size and date of salvage for 4,045 chinook juveniles genotyped between 1995 and 1999. Those individuals with greater than even odds of being assigned to the winter run, adjusted for the abundance of all runs at the time of sampling, are indicated with triangles. Six individuals, whose assignments to winter were overturned by adjustment for relative run-abundance, are indicated with an "X." All other genotyped samples are indicated with small open circles. Curved lines represent the confidence limits around the expected growth curves for each of the named runs.

Ocean Catch

Another area where the use of genetic stock identification can help protect threatened stocks is in the monitoring of ocean catches. A recent study considers data from an experimental fishery conducted for seven days (April 15–21, 1997) between Lopez and Magu points in southern California (Banks and others forthcoming). As above, both MSA and individual assignment were applied in this study, as was the Bayesian correction of individual assignment for the actual abundance of contributing stocks. Three data sources were used, microsatellites, allozymes and coded-wire tag recoveries, and all indicated a surprisingly large harvest of the endangered winter run in this short fishery (about 2%). Precise identification of protected subpopulations within watersheds, such as winter run from the Central Valley, could lead to more refined fishery management. For example, it should be possible to determine the specific conditions and/or locations that minimize the harvest of protected runs, so that a more targeted fishery on non-threatened stocks could be sustained. Real-time genetic monitoring could be used to verify run composition of harvest, and effort could be re-directed as necessary to ensure maximum harvest of chosen runs. Such use of population genetics for adaptive fisheries management could facilitate sustainable salmon harvests even in areas where threatened stocks exist.

Genetic Impact of Supplementation

Ryman-Laikre Models

Having plummeted from annual runs of nearly 100,000 fish in the late 1960s to less than 200 fish in 1991, the winter chinook was protected under both California and federal endangered species laws in the early 1990s. A hatchery supplementation program was initiated with broodstock captured from the Sacramento River and taken to the Coleman National Fish Hatchery on Battle Creek for maturation and spawning. Progeny were tagged internally with coded-wire tags, marked externally by clipping of adipose fins, and released into the Sacramento River as juveniles (smolts). Hedrick and others (1995, 2000a, 2000b) have used a demographic population genetics model (Ryman and Laikre 1991) to evaluate the potential genetic effect of this hatchery supplementation program from 1991 through 1995. One danger of hatchery supplementation is that it could dilute the gene pool by flooding the natural population with the offspring of a few individuals. However, this dilution need not occur.

The effect of hatchery supplementation on genetic diversity is mediated through effects on the effective size (N_e) of the natural population. N_e is the size of a mathematically ideal population that has rates of genetic drift and

inbreeding equivalent to those in the actual population under study. In the mathematically ideal population, there are equal numbers of both sexes, adults mate at random, and variance in number of offspring per adult is binomial or Poisson. The number of adults N in the ideal population is, by definition, equal to the effective size, and the ratio of $N_e:N = 1.0$. In actual populations, the sexes may not be in equal numbers, mating may not be at random, or the variance in offspring number may be larger than binomial or Poisson.

For a hatchery-supplemented population, N_e depends on the effective sizes of the hatchery and wild components of the population and on the relative proportion of hatchery origin fish (after Ryman and Laikre 1991):

$$N_e = \frac{N_{eh} \times N_{ew}}{x^2 N_{ew} + y^2 N_{eh}}$$

N_{eh} and N_{ew} are the effective sizes of the hatchery and wild components of the population, respectively, while x and y are their relative contributions to the total ($x + y = 1.0$). For each year, we calculate N_{eh} from data on the number of progeny contributed by each male and female brood fish to the release of juveniles. The $N_e:N$ ratio for the naturally spawning population is assumed to have a lower bound of 0.10 (Bartley and others 1992) and an upper bound of 0.33 (R.S. Waples, personal communication, see Notes). These ratios are multiplied by the run-size estimate in any year to obtain N_e before capture of adults (that is, what the effective size would have been without supplementation). The N_{ew} after capture of adults for supplementation discounts N_e by the number of adults taken to the hatchery. Estimates of the Ryman-Laikre model parameters from 1991 through 1995 for the winter-run supplementation program are given in Table 3. There are four important points to note:

1. The supplementation program likely had little, or perhaps a slightly positive effect on winter-run effective population size in all years. N_e with supplementation is higher than N_e without supplementation in all years, if $N_e:N = 0.1$; N_e with supplementation is higher than without in three of five years at $N_e:N = 0.33$ (Table 3).
2. The proportion of fish contributed by the hatchery, x , tends to be high in years when the run size was low (1994), and low when the run size was high (1992, 1995). Estimates of x are based on numbers of females, their egg production, and the survival of these progeny from egg to smolt stages. For hatchery stocks, the egg to smolt survival is esti-

mated to be 28.5%, about twice as high as estimates for egg to smolt survival in the wild, 14.7% (Hedrick and others 2000). Of course, this boost in early survival is precisely what makes hatchery supplementation such an attractive recovery option in the first place.

3. The genetic effect of supplementation depends critically on x , unless run size is very small. For example, if x in 1995 had been 10% higher, the effect would have been negative, at $N_e/N = 0.33$, rather than positive. On the other hand, in years of low run size, the hatchery program increases effective population size over a broad range of parameter combinations.
4. Ratios of effective to actual numbers of captive broodstock, $N_{eh}:N_{hr}$ ranged from 0.47 to 0.8, much higher than the $N_e:N$ ratio assumed for the naturally spawning population (0.1 to 0.33). This boost in $N_e:N$ ratio of the hatchery component is what counterbalances the dilution of natural genetic diversity that seemingly ought to occur in a simple view of supplementation.

Table 3 Effect of hatchery supplementation on the effective size of Sacramento River winter chinook salmon, 1991-1995

<i>Parameter</i>	1991	1992	1993	1994	1995
Naturally spawning run size	191	1180	341	189	1361
No. taken captive (N_h)	23	29	18	29	47
No. of breeding parents ($N_f + N_m$)	15	26	12	26	42
Hatchery effective size (N_{eh})	7.02	19.07	7.74	23.2	29.2
(95% confidence interval)	(3.58, 12.22)	(12.67, 26.68)	(3.20, 13.34)	(15.9, 30.8)	(21.3, 37.8)
N_{eh}/N_h ratio	0.468	0.733	0.645	0.8	0.62
Relative contribution from hatchery (x)	0.159	0.061	0.130	0.407	0.083
N_e without hatchery (lower & upper bounds)	19.1 – 63.7	118 – 393.3	34.1 – 113.7	18.9 – 63.0	136.1 – 453.7
N_{ew} (lower & upper bounds)	16.8 – 56.0	115.1 – 383.6	32.3 – 107.7	16.0 – 53.3	131.4 – 438
N_e with hatchery (lower & upper bounds)	21.9 – 61.6	127.3 – 401.0	39 – 108.6	34.3 – 72.8	150.7 – 463.6

Since N_{eh} is based on adult contributions at release rather than at return and spawning, the above calculations are predictions of N_e . By typing microsatellite DNA markers (Banks and others 1999, 2000) on all returning, adipose fin-clipped adults, we were able to assign 93 fish from the 1994 year class to family (Hedrick and others 2000b). We found that the contributions at release of each fish spawned in the hatchery remained approximately the same at return (Table 4) and that the N_{eh} calculated for spawning adults was within the predicted 95% confidence intervals (Hedrick and others forthcoming).

As illustrated in this example, higher survival and higher $N_e:N$ ratios of hatchery offspring, combined with contributions that are inversely proportional to the wild stock size, can increase variance effective size and conserve more of the natural biodiversity than would have been conserved in the absence of supplementation. Hatchery enhancement does not necessarily constitute a threat to genetic resources; indeed, hatchery supplementation can help to retain biodiversity that would otherwise be lost from threatened and endangered populations without intervention. However, we agree with Waples and Do (1994) that supplementation programs are likely to succeed only when the initial environmental causes of population decline are ameliorated.

Table 4 The proportions of progeny released and returning from the different female and male parents of the 1994 brood year

<i>Female</i>	<i>Releases</i>	<i>Returns</i>	<i>Male</i>	<i>Releases</i>	<i>Returns</i>
3	0.080	0.108	B	0.102	0.097
4	0.070	0.054	C	0.073	0.097
5	0.058	0.075	D	0.107	0.172
6	0.054	0.065	E	0.139	0.086
7	0.056	0.032	F	0.120	0.161
8	0.053	0.022	G	0.128	0.065
9	0.054	0.054	H	0.102	0.108
11	0.054	0.075	I	0.147	0.172
12	0.062	0.032	J	0.070	0.032
13	0.092	0.086	K	0.029	0.011
14	0.032	0.022			
15	0.079	0.108			
16	0.066	0.108			
17	0.064	0.075			
18	0.071	0.043			
19	0.057	0.043			
Total	43,346	93	Total	43,346	93

Domestication Selection?

Concern is often expressed about genetic changes in supplemented populations resulting from artificial or domestication selection for survival in the hatchery environment or from shielding of adults or hatchery-reared progeny from natural selection (for example, Waples 1999). While this is undoubtedly true for production hatchery stocks of fall chinook salmon in the Central Valley, conservation hatcheries get brood stock continually from the wild and do not typically use hatchery-reared progeny to propagate the next generation. In this case, the efficiency of selection on a single pass through a hatchery is likely to be low, especially if differential survival among families is minimized.

Equivalence in the relative proportions of winter-run families at spawning, release, and return suggests low additive genetic variance for survival in the hatchery or at sea. Moreover, data on the relative numbers of naturally spawned and hatchery fish returning to the Sacramento River, though subject to large uncertainty (Botsford and Brittnacher 1998), suggest the hatchery contribution is not consistently less at return than at release. For 1995 through 1998, the proportions of hatchery-origin winter run, at return compared to release (three years before), are 6.1% vs. 6.1%, 20.1% vs. 16.1%, and 25.0% vs. 41.7% (addendum to USFWS ESA Section 10 Permit Supplement, dated February 20, 1998). These data suggest the relative survival of hatchery and wild fish in the wild is not grossly different, given the large uncertainty in the escapement estimates. In this one example, at least, we see little evidence for selection as the result of a single pass through a supplementation hatchery. The long-term risk to diversity from over-propagating a few adults appears to far outweigh the risk from artificial selection, at least in the winter-run propagation program. This need not be the finding in other programs, however. The important point is that data on family proportions at spawning, release, and adult stages allow evaluation of the relative strengths of selection and random drift and should be required for supplementation programs.

Hybridization in Production Hatcheries

Hybridization in the Coleman National Fish Hatchery Fall Stock

Analyses of linkage disequilibrium in samples of fall and late-fall chinook stocks propagated or heavily influenced by hatcheries show higher levels of LD than typically observed in naturally spawning stocks of chinook salmon (Figure 6). The median proportion of pairwise combinations of loci showing significant LD is 0.069 for hatchery stocks and 0.025 for naturally spawning adult chinook populations. A likely explanation for this slight elevation of LD in production hatchery stocks is recent admixture and hybridization between

fall and spring or between fall and late-fall stocks in the hatchery programs for fall and late-fall chinook. Because of the high genetic similarity of these stocks, however, information from many more loci will likely be needed to test this hypothesis. New microsatellite loci being developed for the diagnosis of spring chinook may help resolve the causes of LD in production hatchery stocks.

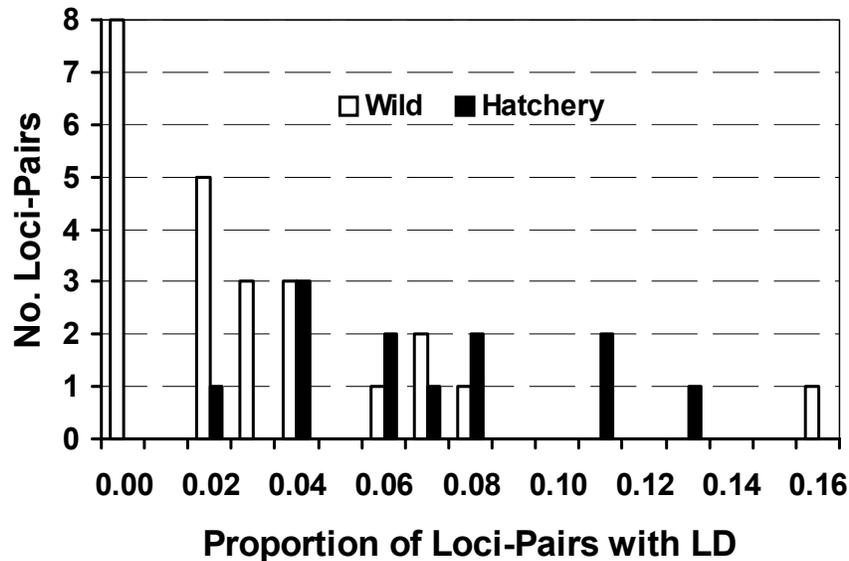


Figure 6 The proportion of loci-pairs with significant linkage disequilibrium in non-winter chinook stocks of the Central Valley. Hatchery populations (black bars) appear to have higher levels of linkage disequilibrium than naturally spawning populations (white bars). Hatchery populations include hatchery stocks as well as populations likely to be heavily affected by hatchery operations, such as late-fall in the Sacramento River. The wild population with significant LD at about one-sixth of the loci-pairs is a sample of spring run from Butte Creek that may have been contaminated with a few fall-run fish.

Hybridization of Fall-run and Spring-run in the Feather River Hatchery?

Hybridization of fall and spring run is thought to have occurred in the Feather River Hatchery, based on returns of tagged fall progeny during the spring-run spawning season and vice versa. Our analyses of samples from hatchery and naturally spawning chinook populations in the Feather River do not support this hypothesis, however. First, none of these populations shows significant linkage disequilibrium, unlike the winter and fall chinook stocks discussed above. Lack of LD suggests either that hybridization of fall with spring runs, such as those observed in Mill, Deer, and Butte creeks, has not occurred or that it has not occurred recently. Several generations of random mating fol-

lowing some past hybridization event could have reduced initial LD to non-detectable levels. Second, chinook in the Feather River cluster with the fall-run lineage in the Central Valley (Figure 7), not with the spring chinook lineages observed in Mill, Deer, and Butte creeks. This proximity of Feather River chinook to the fall-run lineage is observed when samples, whose origin is marked “unknown” by DFG collectors, are pooled after testing for and failing to find any significant heterogeneity among these samples. Still, few of the “unknown” samples can be included in the homogeneous pool of fall samples, so some slight but statistically significant genetic differentiation does exist between many of these unknown samples and fall chinook populations. The nature of this differentiation is still under investigation, but it seems not to be the result of hybridization. Finally, under the hypothesis of past hybridization followed by random mating, one might expect to see Feather River populations occupying a genetically intermediate position between fall and spring runs. Yet, there is no consistent tendency for Feather River “unknown” samples to have frequencies intermediate to fall and spring frequencies.

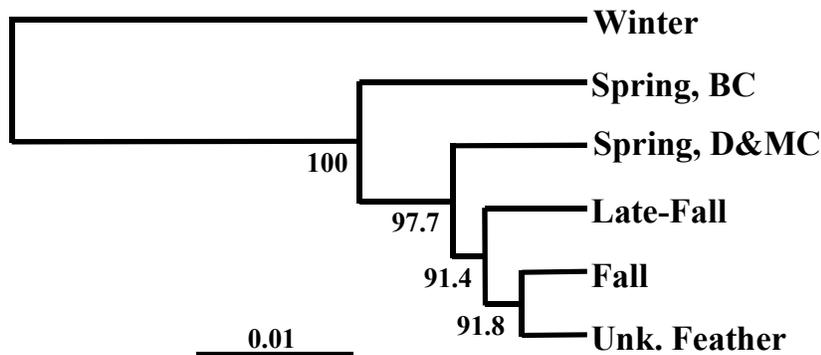


Figure 7 Clustering of Central Valley chinook samples by similarity at seven microsatellite loci shows chinook of unknown (spring?) race in the Feather River to be most closely related with fall chinook

Parentage and Kinship

One of the exciting new areas in population genetics is the application of highly polymorphic microsatellite DNA markers to questions of parentage and kinship in natural populations (O’Reilly and others 1998; Goodnight and Queller 1999; Bentzen and others 2000). These methods and markers are equally applicable to hatchery populations, in which the parents or potential parents are often known, as in the case of the winter-run hatchery supplementation program. In this case, the parents of any given progeny can be identi-

fied by simple matching algorithms; WHICHPARENT, a program facilitating such matching of progeny and parents, is available at <http://www-bml.ucdavis.edu/imc/Software.html>.

More difficult is ascertaining kinship when parents are unknown. In the course of our survey of variation in the Central Valley, for example, we had several samples of the threatened spring run that comprised only juveniles. In the past, population geneticists advised against using such samples because the presence of full- or half-sibs could bias allele-frequency estimates (Allendorf and Phelps 1981). Indeed, these samples showed significant departures from single locus and pairwise linkage equilibrium, compared to samples from naturally spawning adult populations. We investigated kinship in these spring-run chinook juvenile samples and attempted to estimate the allele frequencies of the adult spawning population from which they were derived (Banks and others 2000). This was done by first identifying groups of individuals showing significant odds of being full-sibs. Of the 206 individuals in these samples with sufficient genotypic information, 114 were involved in pairwise comparisons for which the hypothesis of a full-sib relationship was significantly more likely ($P < 0.01$) than the hypothesis that they were unrelated. Next, we determined the mating type or combination of parental genotypes at each locus with the maximum likelihood of producing the array of genotypes in each full-sib group. We then replaced these 114 individuals with 86 inferred parents. After adjustment of juvenile samples for kinship, the proportions of single- and multiple-locus genotypes within each conformed to random mating expectations. This procedure allowed us to use the information gained from juvenile samples in our Central Valley baseline data set.

These procedures for adjusting estimates of allele frequencies for kinship should be generally applicable to salmon molecular ecological studies. This is an active area of research, and several laboratories, including ours, are presently refining statistical approaches that will accurately recover parental genotypes from juvenile samples.

Conclusions

Population genetic analysis of highly polymorphic microsatellite DNA markers confirms the existence of genetically diverse subpopulations of chinook salmon in the Central Valley. These subpopulations correspond to the traditional seasonal runs, winter, spring, fall, and late-fall, though two distinct lineages of spring run have been identified, one in Mill and Deer creeks, the other in Butte Creek. The availability of a high quality genetic database for Central Valley chinook populations now enables identification of the run-composition of mixtures, which can occur at all stages of the life-cycle, using the traditional method of Mixed Stock Analysis (MSA). Moreover, the high

level of diversity among runs at microsatellite DNA markers enables the assignment of individuals to run with an unprecedented degree of accuracy and precision. Individual identification is useful in determining the presence of winter run at all phases of the life cycle. Confirming the run-origin of putative winter chinook brood stock is essential for the hatchery supplementation program. Identifying protected runs in the fish salvage operations at the CVP and SWP in the Delta and in ocean harvests are other important application of microsatellite DNA markers. Thus, the development and application of microsatellite DNA markers has significantly advanced knowledge of winter-run biology as well as conservation efforts. Extension of the methods developed for winter-run identification to threatened spring-run populations should now be straightforward.

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Notes

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Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California

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Abstract

Chinook salmon (*Oncorhynchus tshawytscha*) formerly were highly abundant and widely distributed in virtually all the major streams of California's Central Valley drainage—encompassing the Sacramento River basin in the north and San Joaquin River basin in the south. We used information from historical narratives and ethnographic accounts, fishery records and locations of in-stream natural barriers to determine the historical distributional limits and, secondarily, to describe at least qualitatively the abundances of chinook salmon within the major salmon-producing Central Valley watersheds. Individual synopses are given for each of the larger streams that historically supported or currently support salmon runs.

In the concluding section, we compare the historical distributional limits of chinook salmon in Central Valley streams with present-day distributions to estimate the reduction of in-stream salmon habitat that has resulted from human activities—namely, primarily the construction of dams and other barriers and dewatering of stream reaches. We estimated that at least 1,057 mi (or 48%) of the stream lengths historically available to salmon have been lost from the original total of 2,183 mi in the Central Valley drainage. We included in these assessments all lengths of stream that were occupied by salmon, whether for spawning and holding or only as migration corridors. In considering only spawning and holding habitat (in other words, excluding migration corridors in the lower rivers), the proportionate reduction of the historical habitat range was far more than 48% and probably exceeded 72% because most of the former spawning and holding habitat was located in upstream reaches that are now inaccessible for salmon. Individual stream assessments revealed substantial differences among streams in the extent of salmon habitat lost. Some streams experienced little or no reduction (for example, Bear River, Mill Creek) while others were entirely eliminated from salmon production (for example, McCloud, Upper Sacramento, and Upper San Joaquin rivers.)

The river cañons, where the old bars were located, were romantic places previous to being disturbed and torn up by the gold-digger. The water was as clear as crystal, and above each ripple or rapid place was a long, deep pool, with water blue as turquoise, swarming with fish. Salmon at that time ran up all the streams as far as they could get, until some perpendicular barrier which they could not leap prevented further progress. (Angel 1882, p 402)

Introduction

The broad expanse of the Central Valley region of California once encompassed numerous salmon-producing streams that drained the Sierra Nevada and Cascade mountains on the east and north and, to a lesser degree, the lower-elevation Coast Range on the west. The large areal extent of the Sierra Nevada and Cascades watersheds, coupled with regular, heavy snowfalls in those regions, provided year-round streamflows for a number of large rivers which supported substantial—in some cases prodigious—runs of chinook salmon (*Oncorhynchus tshawytscha*). No less than 26 main Central Valley tributaries supported at least one annual chinook salmon run, with at least 23 of those streams supporting two or more runs each year.

In the Sacramento River basin, constituting the northern half of the Central Valley system (covering about 24,000 square miles; Jacobs and others 1993), most Coast Range streams historically supported regular salmon runs; however, those “westside” streams generally had streamflows limited in volume and seasonal availability due to the lesser amount of snowfall west of the valley, and their salmon runs were correspondingly limited by the duration of the rainy season. Some westside streams, such as Cache and Putah creeks, did not connect with the Sacramento River at all during dry years, and salmon runs only entered them opportunistically as hydrologic conditions allowed. In the San Joaquin River basin, composing much of the southern half of the Central Valley system (covering approximately 13,540 square miles; Jacobs and others 1993), a number of major streams such as the Merced, Tuolumne and upper San Joaquin rivers sustained very large salmon populations, while other streams with less regular streamflows (for example, Calaveras, Chowchilla and Fresno rivers) had intermittent salmon runs in years when rainfall provided sufficient flows. However, all of the westside San Joaquin basin streams, flowing from the Coast Range, were highly intermittent (Elliott 1882) and none are known to have supported salmon runs or any other anadromous fishes to any appreciable degree.

The great abundance of chinook salmon of the Central Valley was noted early in the history of colonization of the region by Euro-American people. The pioneer John Marsh, for example, wrote in 1844: “The magnificent valley through which flows the rivers San Joaquin and Sacramento is 500 miles long It is

intersected laterally by many smaller rivers, abounding in salmon” (Elliott 1882, p 44). However, following the California Gold Rush of 1849, the massive influx of fortune seekers and settlers altered the salmon spawning rivers with such rapidity and so drastically that the historic distributions and abundances of anadromous fish can be determined only by inference from scattered records, ethnographic information, and analysis of the natural features of the streams. Probably the only species for which adequate information exists to develop a reasonably complete picture is the chinook salmon – the most abundant and most heavily used of the Central Valley anadromous fishes.

In this report, we consolidate historical and current information on the distribution of chinook salmon in the major streams of the Central Valley drainage to provide a comprehensive assessment of the extent to which salmon figured historically in the regional landscape. This paper is based and expands on an earlier work (Yoshiyama and others 1996) to include additional historical information as well as more recent data on chinook salmon abundances. Hereafter, references to “salmon” pertain to chinook salmon.

The Four Runs of Central Valley Chinook Salmon

Four seasonal runs of chinook salmon occur in the Central Valley system – or more precisely, in the Sacramento River drainage – with each run defined by a combination of adult migration timing, spawning period, and juvenile residency and smolt migration periods (Fisher 1994). The runs are named after the season of adult upstream migration – winter, spring, fall and late-fall. The presence of four runs in the Sacramento River lends it the uncommon distinction of having some numbers of adult salmon in its waters throughout the year (Stone 1883a; Rutter 1904; Healey 1991; Vogel and Marine 1991). The fall and late-fall runs spawn soon after entering the natal streams, while the spring and winter runs typically “hold” in their streams for up to several months before spawning (Rutter 1904; Reynolds and others 1993). Formerly, the runs also could be differentiated to various degrees on the basis of their typical spawning habitats – spring-fed headwaters for the winter run, the higher-elevation streams for the spring run, mainstem rivers for the late-fall run, and lower-elevation rivers and tributaries for the fall run (CFC 1900a, 1900b; Rutter 1904; Fisher 1994). Different runs often occurred in the same stream – temporarily staggered but broadly overlapping (Vogel and Marine 1991; Fisher 1994), and with each run utilizing the appropriate seasonal streamflow regime to which it had evolved. On the average, the spring-run and winter-run fish generally were smaller-bodied than the other Central Valley chinook salmon, and late-fall run fish were the largest (Stone 1874; F. W. Fisher unpublished data).

Before the (US) American settlement of California, most major tributaries of the Sacramento and San Joaquin rivers probably had both fall and spring runs of chinook salmon. The large streams that lacked either adequate summer flows or holding habitat to support spring-run salmon, which migrate upstream during the spring and hold over the summer in pools, had at least a fall run and in some cases perhaps a late-fall run. The fall run undoubtedly existed in all Central Valley streams that had adequate flows during the fall months, even if the streams were intermittent during other parts of the year. Generally, it appears that fall-run fish historically spawned in the valley floor and lower foothill reaches (Rutter 1904)—below 500 to 1,000 ft elevation, depending on location—and probably were limited in their upstream migration by their egg-laden and deteriorated physical condition.

The spring run, in contrast, ascended to higher-elevation reaches—judging from spawning distributions observed in recent years and the reports of early fishery workers (Stone 1874; Rutter 1904). The California Fish Commission noted, “It is a fact well known to the fish culturists that the winter and spring run of salmon, during the high, cold waters, go to the extreme headwaters of the rivers if no obstructions prevent, into the highest mountains” (CFC 1890, p 33). Spring-run salmon, entering the streams while in pre-reproductive and peak physical condition well before the spawning season, were understandably better able to penetrate the far upper reaches of the spawning streams than were fall-run fish. Their characteristic life-history timing and other adaptive features enabled spring-run salmon to use high spring-time flows to gain access to the upper stream reaches—the demanding ascent facilitated by high fat reserves, undeveloped (and less weighty) gonads, and a generally smaller body size. The spring run, in fact, was generally required to use higher-elevation habitats—the only biologically suitable places—given its life-history timing. Spring-run fish needed to ascend to high enough elevations for over-summering to avoid the excessive summer and early-fall temperatures of the valley floor and foothills—at least to about 1,500 ft elevation in the Sacramento drainage and most likely correspondingly higher in the more southerly San Joaquin drainage¹. If the spring-run fish spawned in early fall, they needed to ascend even higher—at least to about 2,500 to 3,000 ft in the Sacramento drainage—to be within the temperature range (35 to 58 °F) required for successful egg incubation. Spring-run fish that spawned later in the season did not have to ascend quite so high because ambient temperatures would have started to drop as autumn progressed—but presumably there were constraints on how long they could delay spawning, set by decreasing stream-

1. English units of measurement for distances and elevations are used in this paper for ease of comparison with information quoted from earlier published work. Some locations are given by “river miles” (rm)—the distance from the mouth of the stream under discussion to the point of interest.

flows (before the onset of the fall rains), ripening of eggs, and deteriorating body condition.

The spring run probably was originally most abundant in the San Joaquin system, ascending and occupying the higher-elevation streams fed by snowmelt where they over-summered until the fall spawning season (Fry 1961). The heavy snowpack of the southern Sierra Nevada was a crucial feature in providing sufficient spring and early summer streamflows, which were the highest flows of the year (F. W. Fisher unpublished data). The more rain-driven Sacramento system was generally less suitable for the spring run due to lesser amounts of snowmelt and proportionately lower flows during the spring and early summer, but the spring run nonetheless was widely distributed and abundant in that system (Campbell and Moyle 1991). Some notable populations in the Sacramento drainage occurred in Cascades streams where cold-water springs provided adequate summer flows (for example, Upper Sacramento and McCloud rivers, Mill Creek). These coldwater springs emanated from the porous lava formations around Mount Shasta and Mount Lassen and were ultimately derived from snowmelt from around those peaks and also from glacial melt on Mount Shasta.

The winter run—unique to the Central Valley (Healey 1991)—originally existed in the upper Sacramento River system (Little Sacramento, Pit, McCloud and Fall rivers) and in nearby Battle Creek. There is no evidence that winter runs naturally occurred in any of the other major drainages before the era of watershed development for hydroelectric and irrigation projects. Like the spring run, the winter run typically ascended far up the drainages to the headwaters (CFC 1890). All streams in which populations of winter-run chinook salmon were known to exist were fed by cool, constant springs that provided the flows and low temperatures required for spawning, incubation, and rearing during the summer season (Slater 1963)—when most streams typically had low flows and elevated temperatures. The unusual life-history timing of the winter run, requiring cold summer flows, would argue against such a run occurring in other than the upper Sacramento system and Battle Creek, apparently the only areas where summer flow and water temperature requirements were met. A possible exception was the Big Meadows area (now Lake Almanor) on the North Fork Feather River where extensive cold-water springs provided year-round flows with “temperature[s] not higher than sixty degrees Fahrenheit” (CFC 1884, p 16), which theoretically might have been suitable for the winter run; however, we have seen no historical records or suggestions of winter-run salmon occurring in that drainage. A similar environmental constraint may apply to some extent to the late-fall run, of which the juveniles remain in freshwater at least over the summer and therefore require coldwater flows (Vogel and Marine 1991; Fisher 1994)—whether from springs or from late snowmelt. The late-fall run probably spawned originally in the mainstem Sacramento River and major tributary reaches now blocked

by Shasta Dam (Fisher 1994) and perhaps in the upper mainstem reaches of other Sacramento Valley streams such as the American River (Clark 1929). There are indications that a late-fall run possibly occurred also in the San Joaquin River, upstream of its major tributaries at the southern end of that drainage (Hatton and Clark 1942; Van Cleve 1945; Fisher 1994).

Distributional Survey: General Background and Methods

As summarized by Clark (1929), makeshift barriers were built across Sierra Nevada streams as early as the Gold Rush period when mining activities significantly impacted salmon populations in a number of ways—for example, by stream diversions, blockages, and filling of streambeds with debris. Hydropower projects appeared in the 1890s and early 1900s, although most of the large irrigation and power dams were constructed after 1910 (F. W. Fisher unpublished data). The early hydropower dams of the early 1900s were numerous, however, and collectively they eliminated the major portion of spawning and holding habitat for spring-run salmon well before the completion of the major dams in later decades.

The early distributional limits of salmon populations within the Sierra Nevada and some Cascade drainages are poorly known, if at all, because of the paucity of accurate scientific or historical records pre-dating the heavy exploitation of populations and the destruction or degradation of stream habitats. It was not until after the late 1920s that reliable scientific surveys of salmon distributions in Central Valley drainages were conducted. Reports by Clark (1929) and Hatton (1940) give information on the accessibility of various streams to salmon and they identify the human-made barriers present at those times. They provide a valuable “mid-term” view of what salmon distributions were like in the first half of the 20th century after major environmental alterations had occurred and salmon populations were significantly depleted compared to earlier times. However, the survival of the runs was not yet imperiled to the extent it is presently. Those reports also give limited qualitative information on salmon abundance.

Fry (1961) provided the earliest comprehensive synopsis of chinook stock abundances in Central Valley streams, covering the period 1940–1959. Quantitative data were given by Fry (1961) for both spring and fall runs, but the fall-run estimates also included the winter and late-fall runs for the streams where those other runs occurred. Since then, fairly regular surveys of spawning runs in the various streams have been conducted by the California Department of Fish and Game and periodically summarized in the Department’s “Administrative Reports.”

In the following section we synthesize the earlier information with that available from more recent sources, with the aim of providing comprehensive descriptions for the major salmon-supporting streams of the Central Valley. For each of the major streams (excepting some tributaries in the upper Sacramento River system, for which little data exist) that are known to have had self-sustaining chinook salmon populations, we provide a narrative including their probable “original” distributions and later “mid-term” 1928-1940 distributions as indicated by published literature and unpublished documents. The probable original distributions were determined by considering the presence of obvious natural barriers to upstream salmon migration together with historical information (for example, accounts of gold miners and early settlers) and they apply to the salmon populations up to the period of intensive gold mining, around 1850–1890, when massive environmental degradation by hydraulic mining activities occurred. We also drew from ethnographic studies of Native American people. Much information on the material culture of the native peoples of California had been obtained by ethnographers who interviewed elder Native Americans of various tribal groups during the early part of the 20th century. That information pertains to the life-experiences and traditions of the native informants during the period of their youth and early adulthood and to the mid-life periods of their parents and grandparents from whom they received information and instruction-i.e., spanning essentially the middle and latter parts of the 19th century (Beals 1933; Aginsky 1943; Gayton 1948a). Generally, we quoted the original statements of earlier observers (both Native Americans and immigrants) on salmon and steelhead as fully as seemed informative so that readers may assess for themselves the meaning and credibility of those statements. The known or inferred historical upstream limits of salmon in Central Valley streams are compiled in Table 1.

Table 1 Historical upstream limits of chinook salmon in the California Central Valley drainage ^a

<i>Stream</i>	<i>Upstream distributional limit ^b</i>
Sacramento River Basin	
Pit River	Mouth of Fall River
Fall River	Source springs near Dana, about nine miles above mouth
McCloud River	Lower McCloud Falls
Upper (Little) Sacramento River	Vicinity of Box Canyon Dam (Mt. Shasta City) and Lake Siskiyou (that is, Box Canyon Reservoir)
Cow Creek	
North Fork (Little Cow)	Falls near Ditty Wells fire station
South Fork	Wagoner Canyon
Battle Creek	
North Fork	Falls three miles above Volta Powerhouse
Digger Creek	Vicinity of Manton, possibly higher
South Fork	Falls near Highway 36 crossing
Antelope Creek	Up North and South forks to present Ponderosa Way crossings
Mill Creek	Morgan Hot Spring
Deer Creek	Lower Deer Creek Falls
Big Chico Creek	Higgins Hole, about one mile above present Ponderosa Way crossing
Butte Creek	Centerville Head Dam (DeSabra)
Feather River	
West Branch	Vicinity of Stirling City
North Fork	Six miles above Lake Almanor, three miles up Hamilton Branch, and to Indian Falls on East Branch of North Fork
Middle Fork	Bald Rock Falls
South Fork	Upper limit of Lake Oroville (six miles above former mouth of South Fork)
Yuba River	
North Fork	Mouth of Salmon Creek, near present Sierra City
Middle Fork	Falls about one miles above juncture with North Fork
South Fork	Falls 0.5 mi below Humbug Creek
Bear River	Waterfall at vicinity of Camp Far West Reservoir

^a Upper stream limits pertain to the farthest migrating seasonal run—meaning, either the spring run in most streams or the winter run where it occurred with the spring run, or the fall and late-fall runs in streams where spring and winter runs were absent.

^b Sources are given in the text.

Table 1 Historical upstream limits of chinook salmon in the California Central Valley drainage ^a (Continued)

<i>Stream</i>	<i>Upstream distributional limit ^b</i>
American River	
North Fork	Mumford Bar
Middle Fork	Mouth of Rubicon River
South Fork	Waterfall near Eagle Rock
Clear Creek	French Gulch, above Whiskeytown Dam
Cottonwood Creek	
North Fork	Five miles above Ono
Middle Fork	Eight miles into Beegum Creek
South Fork	Maple Gulch
Stony Creek	Juncture of Little Stony Creek, five miles below Stonyford
Cache Creek	Vicinity of Capay Dam
Putah Creek	Vicinity of Monticello
San Joaquin River Basin and Sacramento-San Joaquin Delta	
Cosumnes River	Falls 0.5 mi below Latrobe Highway Bridge
Mokelumne River	Bald Rock Falls, seven miles upstream of Electra
Calaveras River	At least to site of New Hogan Dam
Stanislaus River	
North Fork	Makays Point, eight miles above juncture with Middle Fork
Middle Fork	Near Spring Gap Powerhouse, two miles below Beardsley Reservoir
South Fork	Presumably not used by salmon
Tuolumne River	
Mainstem	Preston Falls
North Fork	One mile above mouth
Middle and South forks	Presumably not used by salmon
Merced River	
Mainstem	Vicinity of El Portal
North Fork	Not used by salmon
South Fork	Peach Tree Bar
Upper San Joaquin River	Midway (3 mi) up length of Mammoth Pool Reservoir
Kings River	Mouth of North Fork
^a Upper stream limits pertain to the farthest migrating seasonal run—meaning, either the spring run in most streams or the winter run where it occurred with the spring run, or the fall and late-fall runs in streams where spring and winter runs were absent.	
^b Sources are given in the text.	

For the mid-term salmon distributions, we relied heavily on the papers of Clark (1929) and Hatton (1940) and retained much of their original wording to faithfully represent the situation they reported at those times. We also give more recent and current (1990s) salmon spawning distributions based on government agency reports, published papers, and interviews with agency biologists². The stream accounts are presented starting with the southernmost Sierra streams and proceeding northward. We also include accounts for several streams on the west side of the Sacramento Valley which are known to have had chinook salmon runs. They are representative of other small west-side or upper Sacramento Valley streams that formerly sustained salmon stocks, if only periodically, but lost them because of extensive stream diversions and placement of man-made barriers. More detailed physical descriptions of Central Valley salmon streams, factors limiting their salmon production, and management recommendations are given in Reynolds and others (1993) and USFWS (1995).

For each stream account, we attempted to identify which seasonal salmon runs were historically present, given the available information. Remember that the lack of historical documentation for certain runs in some watersheds does not necessarily mean that those runs were absent from those watersheds in past times. The late-fall run, for example, was not even recognized as a distinct run until the late-1960s after seasonal salmon counts were initiated at Red Bluff Diversion Dam on the mainstem Sacramento River. The presence of the late-fall run in several Sacramento River tributaries during recent decades (Reynolds and others 1993) might argue for its historical occurrence in some of those streams, assuming that streamflow conditions during the time of year when late-fall salmon were present were not substantially altered after the emplacement of dams and diversion projects. We also provide information on historical salmon abundances in individual streams where possible. While usually highly incomplete or anecdotal, the early statements and estimates on salmon abundances nonetheless indicate those watersheds which historically supported substantial, or in some cases enormous, salmon runs and also demonstrate that chinook salmon existed at viable population levels in streams through much of the Central Valley drainage. We have drawn particularly from Fry (1961) for earlier quantitative data.

We mention steelhead trout in several stream accounts, particularly where information on salmon is lacking. The intent is to show that certain stream reaches were accessible to at least steelhead and, hence, may have been reached also by chinook salmon – particularly spring-run fish, which typically

2. Agency abbreviations are as follows: California Department of Fish and Game (DFG); California State Board of Fish Commissioners (CFC); Federal Energy Regulatory Commission (FERC); United States Commission for Fish and Fisheries or U.S. Fish Commission (USFC); United States Fish and Wildlife Service (USFWS).

migrated far upstream. However, the correspondence between the occurrence of steelhead and spring-run salmon in stream reaches was by no means complete. Steelhead aggressively ascend even fairly small tributary streams, in contrast to chinook salmon which generally use the mainstems and major forks of streams (E.R. Gerstung, personal observation). The migration of steelhead during the peak of the rainy season (January-March) aided their ascent into the small tributaries. Steelhead also are able to surmount somewhat higher waterfalls—perhaps up to about 15 ft high—while chinook salmon in California appear to be stopped by falls greater than 10 to 12 ft high (E.R. Gerstung, personal observation), depending on the abruptness of the drop. Furthermore, steelhead do not require as much gravel for spawning. For example, steelhead formerly used streams in the upper Sacramento River drainage (near Shasta Reservoir) that had small patches of gravel interspersed among boulder substrate, which salmon generally shunned (E.R. Gerstung, personal observation). Yet, in terms of ascending the main stream reaches, it may be reasonably assumed that where steelhead were, spring-run salmon often were not far behind. Using the advantage of high spring flows, the salmon could have surmounted obstacles and reached upstream areas not much lower than the upper limits attained by steelhead in some streams.

Non-game fishes such as hardhead (*Mylopharodon conocephalus*), Sacramento pikeminnow (*Ptychocheilus grandis*) and Sacramento sucker (*Catostomus occidentalis*) also provide hints about salmon distribution. Those species are typical of valley floor and low- to mid-elevation foothill streams (Moyle 1976), and their recorded presence in stream reaches that are not blocked by obvious natural barriers is a good indication that anadromous salmonids likewise were able to ascend at least as far, and possibly even farther upstream. The presence of non-game native fish populations above obvious natural barriers in some streams suggests that at least some of the barriers were formed after the initial dispersal of those species into the upper watersheds.

Distributional Synopses of Salmon Streams

Kings River (Fresno County). Spring and fall runs of chinook salmon are known to have occurred at least periodically in the Kings River, the southernmost Central Valley stream that supported salmon. In the past, the Kings River flowed into the northeast part of Tulare Lake, and its waters occasionally ran into the San Joaquin River during wet periods when water levels became high enough in Tulare Lake to overflow and connect the two drainages (Carson 1852; Ferguson 1914). Streamflows would have been greatest during the spring snowmelt period, so it is most likely that the spring run was the predominant run to occur there. Spring-run salmon would have had to ascend to high enough elevations (probably >1,500 ft) to avoid excessive summer water temperatures, going above the area presently covered by Pine Flat Reservoir. The

mainstem upstream of Pine Flat Reservoir is of low gradient (E.R. Gerstung, personal observation) and free of obstructions for some distance (P. Bartholomew, personal communication), so salmon probably were able to ascend about 10 to 12 mi beyond the present upper extent of the reservoir. The bulk of salmon migration in the Kings River probably ascended no farther than the confluence of the North Fork (Woodhull and Dill 1942), which we take as the upper limit. There is an undocumented note of "a few salmon" having occurred much farther upstream at Cedar Grove (28 mi above present-day Pine Flat Reservoir) in the past—"before Pine Flat Dam was constructed" (DFG unpublished notes). However, it is not clear if salmon actually could have reached that far, due to the presence of extensive rapids below around the area of Boyden Cave (3,300 ft elev.) and below Cedar Grove. The North Fork Kings River is very steep shortly above its mouth, and salmon most likely did not enter it to any significant distance (P. Bartholomew, personal communication, see "Notes").

Native American groups had several fishing camps on the mainstem Kings River downstream of Mill Flat Creek, including one used by the Choinimni people (a tribelet of the Northern Foothills Yokuts) at the junction of Mill Creek (about two miles below the present site of Pine Flat Dam). There, the "spring salmon run" was harvested and dried for later use (Gayton 1948b). Gayton (1946, p 256) wrote:

On the lower Kings River, the Choinimni (Y) [Y denoting Yokuts] and probably other tribes within the area of the spring salmon run (about May) held a simple river-side ritual at their principal fishing sites. The local chief ate the first salmon speared, after cooking it and praying to Salmon for a plentiful supply. Then others partook of a salmon feast, and the season, so to say, was officially open.

The existence of a well-established salmon ritual among the native people seems to indicate that salmon runs in the Kings River were not uncommon, even if they did not occur every year (for example, in years of low precipitation). Furthermore, in regard to inter-tribelet relations among the Northern Foothills Yokuts, Gayton (1948b, p 143) stated: "While the Choinimni felt the north bank of Kings River to be theirs, ... the Gashowa were welcome to occupy their fish camp ... during the spring salmon run. These neighbors remained there while the fish dried, which they then took home to store." This statement indicates that there was a fairly regular granting of salmon-fishing privileges between some native groups around the Kings River.

The Tachi Yokuts, located on the Central Valley floor around the north shore of Tulare Lake and the lower reaches of the Kings River (Gayton 1948a; Cook 1955, 1960), also caught salmon as well as other fishes. The Spanish Lieutenant José Mariá Estudillo observed Tachi tribesmen catching fish by means of hand

nets from the Kings River on 2 November 1819: “This they did before my very eyes, with great agility, diving quickly and staying under the water so long that I prayed After having caught sufficient large fish, salmon and others very palatable ...” (translation by Gayton 1936, p 78). Given the date, those salmon were undoubtedly of the fall run. Steelhead also appear to have entered the Kings River drainage, at least to some extent. The pioneer Thomas Jefferson Mayfield, who was raised amongst the Choinimni people during the 1850s, recollected that “There were many pools of water in Sycamore creek, and in them we caught trout and speared a fish we called a steel head” (Latta 1929, p 15). Mayfield evidently was referring to the present Sycamore Creek which enters the Kings River above Trimmer (compare his description with map 2 of Gayton 1948a), at the upper part of Pine Flat Reservoir. Mayfield also stated that “Trout and other large fish were speared with a gig almost like a modern salmon gig” (Latta 1977, p 509). The ethnographer Frank Latta, a noted authority on the Yokuts nationality, added: “Many of the fish obtained in this manner were known as steelheads. They are a large fish resembling both salmon and trout. The meat of these, as well as others, was dried and smoked in large quantities” (Latta 1977, p 511).

Drawing on testimony from a Native American informant, Gayton (1948a) reported that “Salmon (*da'tu*) were well known and greatly depended upon” by the Chunut people (a subgroup of the Southern Valley Yokuts) who dwelt on the eastern shore of Tulare Lake—essentially the downstream terminus of the Kings River. A second Chunut informant interviewed by Latta (1977, p 722) similarly attested to the presence of salmon, and evidently steelhead, in the lake:

There were lots of fish in Tulare Lake. The one we liked best was a-pis, a bit [sic] lake trout. They were real big fish, as big as any salmon, and good meat Sometimes the steelheads came in the lake too; so did the salmon. We called the steelheads tah-wah-aht and the salmon ki-uh-khot. We dried lots of fish. When it was dried and smoked, the salmon was the best.

The common “lake trout” of Tulare Lake was not a salmonid, but most likely the Sacramento pikeminnow. State Fish Commissioner B.B. Redding described it as “a fine large white-fleshed fish, about 2 feet 6 inches long, ... It looks to me to be a carp, and of finer flavor than any I ate in Europe” (USFC 1876b, p 480). It is evident, however, that both salmon and steelhead entered Tulare Lake at least on occasion, where they were taken by Chunut fishers. It seems unlikely that the Chunut traveled out of their territory to the Kings River to obtain salmon, nor have we found any indication in the ethnographic literature that they did so. There would have been little reason for the Chunut to make regular fishing excursions to areas away from Tulare Lake, given that the lake contained an abundance and variety of high-quality fish resources (Gayton 1948a; Latta 1977), and in fact it was the Kings River Choinimni peo-

ple (and perhaps others) who made seasonal trips downriver to Tulare Lake for fishing (Latta 1929; Gayton 1948b).

Furthermore, an early newspaper article mentioned the probable occurrence of salmon in Tulare Lake and its environs:

The abundance of fish of all kinds in these waters is absolutely astonishing. ...Pike, perch, bass, salmon trout [probably steelhead or perhaps salmon grilse], eels [lampreys], suckers, and many other kinds, ... are caught with the greatest of ease, and we have no doubt that the lordly salmon himself frequents the lakes in his proper season (San Francisco Picayune, 15 November 1851; reprinted in Heizer 1976, p 59).

Diversions from the Kings River and other streams for agricultural irrigation occurred from the early years of American settlement and farming in the San Joaquin Valley. The reduced streamflows undoubtedly diminished the frequency of salmon runs—and perhaps extinguished them altogether—for a period spanning the late-19th to early-20th centuries. The California Fish and Game Commission reported that after a channel was dredged out between the Kings and San Joaquin rivers in about 1911, salmon began appearing in the Kings River—“a few” in the spring of 1911, a “very considerable run” in 1912, which ascended to Trimmer Springs (river mile [rm] 125) near the upper end of present-day Pine Flat Reservoir, and another “very considerable run” in June 1914 (Ferguson 1914). Several small chinook salmon were caught by a DFG biologist in the fall of 1942 near the town of Piedra on the mainstem Kings River (about two miles downstream of the mouth of Mill Creek; W. Dill, personal communication, see “Notes”); those fish were notable in that they were precociously mature males—in other words, running milt (W. Dill, personal communication, see “Notes”). A single, approximately five-inch chinook salmon (with “very enlarged testes”) was later captured in September 1946 in the mainstem “about eight miles above the junction of the North Fork Kings River” (W. Dill DFG letter). Moyle (1970) later collected juvenile chinook salmon (about four inches total length) in April 1970 from Mill Creek, just above its mouth. Salmon that spawned in Mill Creek likely ascended the stream at least several miles to the vicinity of Wonder Valley (P. Bartholomew, personal communication, see “Notes”). Salmon runs in the Kings River were observed to occur more frequently after the construction of the Kings River Bypass in 1927, with “especially noticeable runs” in 1927, 1938, and 1940 (Woodhull and Dill 1942).

The Kings River salmon run was probably bolstered by, or perhaps even periodically reestablished from, the San Joaquin River population, particularly after series of dry years during which the run would have progressively diminished. After 1946, the termination of most natural streamflows down the channel of the San Joaquin River, except during exceptionally wet years,

resulted in the extirpation of salmon runs in both the Kings and upper San Joaquin rivers.

San Joaquin River (Fresno County). Spring and fall runs of salmon formerly existed in the major San Joaquin River tributaries and in the upper San Joaquin River (Clark 1943; Fry 1961), and there also may have been a late-fall run present in the mainstem. However, all salmon runs in the San Joaquin River above the confluence of the Merced River were extirpated by the late-1940s.

The Spanish explorers and missionaries of Old California, probing the inner San Francisco Bay and Sacramento-San Joaquin Delta region, encountered evidence of salmon. In early April 1776, an expedition led by Captain Juan Bautista de Anza observed salmon (evidently spring-run) being harvested by the native people near present-day Antioch at the mouth of the San Joaquin River. De Anza wrote:

We have noted that the fish most abundant at present from the mouth of the bay to here are the salmon. They are very red in color, and are tender, and none of those we have seen is less than five quarters long [about 40 inches; based on Latta 1977, p 64]. ... At the village which we passed there were so many that it seems impossible that its residents could eat them, ... (Bolton 1930a, p 146).

Father Pedro Font, diarist for that party, further noted that on April 2:

The soldiers purchased four fish somewhat more than a vara long [one Spanish vara equals about 33 inches; Cutter 1957, p 34] and about a third of a vara wide. At first we did not recognize it, but on opening it, and especially when we ate it, we saw that it was salmon, tenderer, fatter, and more savory than that which we ate at the mission of Carmelo [Carmel],... Bolton 1930b, p 377).

Spanish exploration did not fully encompass the San Joaquin Valley until October 1806, when a party led by Ensign Gabriel Moraga traversed the eastern side of the San Joaquin River. Records of the expedition do not mention actual observations of salmon, but Father Pedro Muñoz noted that “Beaver abound and also salmon, according to what was told us by the Indians native to this country” (Diary of Father Pedro Muñoz, translation by Cook 1960, p 248). Moraga’s expedition discovered and named the three major tributaries of the San Joaquin River—the River of Our Lady of Guadalupe (Stanislaus River), the River of Our Lady of Sorrows (Tuolumne River), and the River of Our Lady of Mercy (Merced River) (Cutter 1950; Cook 1960)—and those three streams now remain the southernmost streams supporting chinook salmon in North America.

On a later expedition in 1810, Father José Viader recorded that on October 20 at the village of Cholvones (or Pescadero) on Old River (the West Branch of the lower San Joaquin River), "...we rested here and passed time well with fresh salmon and wild grapes"; and, on October 23, "Indians ...from the village of Cuyens, came out to meet us, bearing as a gift three very big, red, salmon" (Report of Father José Viader, translation by Cook 1960, p 259, 260). Cuyens (or Guyens) was located just downstream of the Stanislaus River mouth (Cook 1955; Bennyhoff 1977). The dates given in that report indicate that the salmon were of the fall run, which is perhaps the earliest explicit record of fall-run salmon for the San Joaquin River basin.

There are virtually no historical references to salmon occurring on the western side of the San Joaquin Valley, where the streams were seasonally prone to dry out. One enigmatic exception is the diary entry for 26 August 1810 by Father José Viader, when the expedition passed the area of San Luis Creek, just east of Pacheco Creek: "We stopped at the foot of the range along a creek which had no more water than a few scattered pools. In just one of these we caught forty fish including six trout or little salmon" (Cook 1960, p 259). Conceivably, those latter six fish might have been steelhead.

An American traveler, John Woodhouse Audubon, provided an early testimony of fall-run salmon in the San Joaquin River basin which he observed sometime after mid-November 1849 in a reach several days travel above the confluence of the Stanislaus River:

The water is beautifully clear now, and is full of fine-looking fish; the large salmon of these rivers is a very sharky-looking fellow and may be fine eating; but as yet we have not been fortunate enough to get one, though several have been shot by Hudson and Simson as they lay in the shallows (Audubon 1906, p 185).

Likewise, the naturalist John Muir, while boating on the San Joaquin River just above the confluence of the Tuolumne river, observed on 18 November 1877 that "Salmon in great numbers are making their way up the river for the first time this season, low water having prevented their earlier appearance" (Muir 1938, p 244)—further attesting to a numerous fall salmon run. Muir found on that day a "salmon trout" carcass—possibly a steelhead—"new killed and dressed and laid out on the bank for me by fish hawks" (Muir 1938, p 243). Livingston Stone of the US Fish Commission stated, "...in regard to this [San Joaquin] river that it is much warmer than the Sacramento, but is frequented somewhat by salmon, especially in the fall, which are killed in considerable quantities on some of its tributaries" (Stone 1874, p 176). The California Fish Commission noted: "This [San Joaquin River] is a very good stream for the Fall run of salmon, the ascent being not very steep, and the cur-

rent, especially the first seventy-five miles, not being very strong" (CFC 1884, p 15).

While the uppermost distribution of salmon in the San Joaquin River in earlier years is not known with certainty, the US Fish Commission (USFC 1876a, p xxviii) noted that salmon went up "...to the headwaters of the San Joaquin, about two hundred and fifty miles." The California Fish and Game Commission reported:

These [spring-run] salmon ascend the river during May, June and the first part of July. In the foot hills near Friants they congregate in the large pools and remain until such time in the fall as the temperature is right for them to spawn, then they ascend the river into the gorge of the San Joaquin River where they spawn in the fall. This is the result of our observations and data gathered from the residents and deputies who have lived in that vicinity for years (CFGC 1921a, p 21).

It was reported that the spring run historically ascended the river past the present site of Kerckhoff Power House to spawning grounds in the higher reaches (CFGC 1921b). A natural barrier shortly upstream of Willow Creek near present-day Redinger Lake may have posed an obstruction to salmon (E. Vestal, personal communication, see "Notes"). However, there is evidence that salmon traveled considerably farther upstream at least to the vicinity of present-day Mammoth Pool Reservoir (about 3,300 ft elev.). The oral history of Native American residents in the region includes references to salmon occurring there (P. Bartholomew, personal communication, see "Notes" based on interviews with Native American informants). Lee (1998, p 87), drawing from family reminiscences, stated that salmon ascended to "their old spawning grounds upriver from *Cha:tiniu* [Logan Meadow, adjacent to Mammoth Pool Reservoir]...[where] our ancestors speared salmon only a few hundred yards from the meadow where they lived." Hence, we take the point about three miles up the length of Mammoth Pool Reservoir as the (minimal) upstream historical limit of salmon.

Based on the absence of natural barriers, it may be inferred that salmon probably entered two small tributaries of the upper San Joaquin River near Miller-ton Reservoir – Fine Gold Creek, perhaps "as far upstream [about six miles] as opposite Hildreth Mtn," and Cottonwood Creek probably at least two miles (E. Vestal unpublished notes and personal communication, see "Notes"). Also, salmon evidently entered two larger, intermittent tributaries farther downstream on the valley floor – the Chowchilla and Fresno rivers – which probably had only occasional runs during the wet years. The Fresno River arises "far back in the Sierra" and long ago was described as "carrying an immense body of water down toward the plains" (Elliott 1882, p 20), so the occasional past occurrence of salmon would not be surprising. In passing ref-

erence to those streams, B.B. Redding of the California Fish Commission wrote to US Fish Commissioner Spencer Baird in April 1875:

Formerly there was considerable work done in the catching of salmon in the San Joaquin, but of late years it has been abandoned, ...I suppose that the fish are still going up the San Joaquin to spawn, but, if taken at all, are only now taken by Indians on the Merced, the Chowchilla, the Fresno, and the other branches of the San Joaquin, and I have no doubt they continue to do so (USFC 1876b, p 479).

As recently as the 1980s, a few salmon—presumably strays from other streams—have been observed by anglers in the Chowchilla and Fresno rivers during years of high streamflows (R. Kelly, personal communication, see “Notes”). Because of the uncertainty of how far salmon formerly ascended the intermittent or small tributaries of the upper San Joaquin River, we exclude them from our tabulation of stream lengths historically used by salmon. Hence, our assessment of the distributional limits of salmon in the upper San Joaquin River drainage is conservative.

Native people of the Northern Foothill Yokuts groups, including the Chukchansi from Coarse Gold Creek and the Fresno River, traveled to and fished for salmon in the San Joaquin River near the area of Friant (Gayton 1948b). According to Gayton’s (1948b, p 165) ethnographic account, the salmon were watched for “when the Pleiades were on the western horizon at dusk,” and a first salmon ritual for the spring run was held by several different Yokuts groups when the first salmon of the season was caught. Large quantities of salmon were dried for storage: “They were put in a sack [skin?] and packed home with a tumpline. A man carried about two hundred pounds of fish” (Gayton 1948b, p 185). The zoologist-ethnographer C. Hart Merriam recorded in his field notes for 30 October 1903: “...a few Pit-kah’-te and Kosh’-o Indians [Yokuts groups] were fishing on a stretch of the river from Pullasky [later named Friant] upstream for a mile or so. They were spearing salmon and drying them for winter use” (Heizer 1967, Part III, p 416). Given the date, those salmon undoubtedly were the fall run. The ethnographer Frank Latta (1977, p 511) noted: “We are assured that along the San Joaquin River, many tons of salmon were taken during the annual ‘run’ and that the bushes and banks about the villages and camps were red with drying fish.”

The areas farther up the upper San Joaquin River, above the Yokuts, were occupied by Western Mono groups. The “Northfork Mono” people (or Nüm), who lived on the “North Fork” San Joaquin River (also called Northfork Creek or Willow Creek), Whiskey Creek and nearby areas, caught “Steel-head trout (*Salmo rivularis*), rainbow trout, and the Sacramento salmon” which “were eaten with acorn mush” Gifford (1932, p 21). Fishing for salmon was done primarily in the mainstem upper San Joaquin River, rather than in the small trib-

utaries. Lee (1998, p 89) identified the crossing at *Samhau* (just above present-day Redinger Lake) and *Pakapanit* (north of Italian Bar Road) as the preferred fishing spots in the old days, and he also noted that his grandfather and great-grandfather “speared salmon, suckers and trout” at “Pasagi, near *Chu:wani*” (on Ross Creek). Excursions also were made “to the river where Kerckhoff Dam is, to fish for salmon” (Lee 1998, p 87). We have found no references which indicate how far up Willow Creek salmon ascended, if at all, so we presently do not include it as a former salmon stream. The Northfork Mono people were said to have held first salmon rites (Aginsky 1943).

As early as 1884, the California Fish Commission noted that the salmon runs had been detrimentally affected because of “dams on the headwaters of the Stanislaus, Tuolumne, San Joaquin, and the upper Sacramento Rivers ...a great drawback to the salmon interest, as the spawning grounds are, for the most part, above the dams” (CFC 1884, p 15). On the upper San Joaquin River, the construction and operation of Kerckhoff Dam (about 1920) for power generation permanently blocked the spring-run salmon from spawning areas upstream and seasonally dried up about 14 mi of stream below the dam, where pools formerly provided over-summering habitat for the salmon (CFGC 1921b). Later in that decade, Clark (1929) reported that the salmon spawning beds were located in the stretch between the mouth of Fine Gold Creek and Kerckhoff Dam and in the small tributary streams within that area, covering a stream length of about 36 mi; a few scattered beds also occurred below the town of Friant. At the time of Clark’s (1929) writing, there were four dams on this river that impeded the upstream migration of salmon: the “Delta weir” (in a slough on the west side of the river, 14 mi southeast of Los Banos); Stevenson’s weir (on the main river east of Delta weir); Mendota weir (1.5 mi from the town of Mendota); and the impassable Kerckhoff Dam, 35 mi above Friant. The first three dams were irrigation diversion projects. Friant Dam had not yet been constructed. In addition to the barriers themselves, reduced streamflows due to irrigation diversions impeded and disoriented uncounted numbers of migrating salmon which went astray in the dead-end drainage canals on the valley floor, where they abortively spawned in the mud (Clark 1930).

Hatton (1940, p 358) considered the upper San Joaquin River in 1939 to possess the “most suitable spawning beds of any stream in the San Joaquin system,” and “even in the dry year of 1939, most of the suitable areas were adequately covered with water and the water level was satisfactorily constant.” The spawning beds in the San Joaquin River were located along the 26 mi from Lane’s Bridge up to the Kerckhoff Power House, all of which were accessible, and the “best and most frequently used areas” were between Lane’s Bridge and Friant. The stream just above Friant, where it entered a canyon, was viewed as generally unsuitable, comprising mainly bedrock, “long, deep pools” and “short stretches of turbulent water” (Hatton 1940, but see

CFGC 1921a and above). The planned Friant Dam would cut off an estimated 16 mi of stream where spawning occurred, representing about 36% of the spawning beds, but at that time Hatton considered the spawning beds below Friant Dam to be "so underpopulated that even after the completion of the dam more than adequate areas will still be available, if water flows are adequate." The expected negative impact of Friant Dam was not so much the elimination of spawning areas above the dam as the diversion of water from the stream channel downstream. However, quoting Hatton (1940, p 359), it was "hoped that seepage from the dam and returned irrigation water will provide sufficient flow to make spawning possible." Evidently, the deleterious consequences of vestigial streamflows and polluted irrigation drainage on salmon were not yet fully appreciated at that time.

Hatton (1940) reported that the stretch of the San Joaquin River where spawning occurred was "singularly free of obstructions and diversions," but there were obstructions farther downstream. The lowermost barrier below the spawning beds was the "sack dam" of the Poso Irrigation District, "several miles below Firebaugh" (near Mendota). He stated: "In the average water year this dam destroys any possibility of a fall run up the San Joaquin. The complete diversion of water leaves the stream bed practically dry between that point and the mouth of the Merced River" (Hatton 1940, p 359). The sand bags constituting this dam were left in place until they were washed out by the winter floods. The only other obstruction below the spawning beds was the Mendota weir, which was equipped with a "satisfactory fishway"; however, there were eight unscreened diversions above the dam which Hatton viewed as "a serious menace to the downstream migrants."

The numbers of salmon that at one time existed in the San Joaquin River were, by some accounts, tremendous. Clark (1929, p 31) stated that, "Fifty or sixty years ago, the salmon in the San Joaquin were very numerous and came in great hordes." Indeed, the early residents of Millerton on the banks of the San Joaquin were kept awake by the migrating spring-run salmon (Vandor 1919; CSHA 1929), because "their leaping over the sandbars created a noise comparable to a large waterfall" (NCHRSP 1940, p 13). The historian Vandor (1919, p 106) wrote:

The San Joaquin was a stream of pure icy water, and clear as a crystal where not muddied by mining. Salmon ascended to the spawning grounds by the myriads, and, when the run was on, the fish were hunted with spear, pitchfork, shovel, even with shotgun and revolver. Salmon appeared in such shoals that as late as July, 1870, it was recorded that restful sleep was disturbed because 'myriads of them can be heard nightly splashing over the sand bars in the river opposite town as they make their way up.'

The site of Millerton is now covered by Millerton Reservoir. In reference to the fall-run salmon (and perhaps steelhead), one correspondent wrote to State Fish Commissioner B.B. Redding: "...in the fall the salmon and salmon-trout find their way up here in large quantities. Last fall I helped to spear quite a number, as that is about the only way of fishing in this part of the county; but below the San Joaquin bridge I understand they were trapped in a wire corral by ranchers and fed to hogs; they were so plentiful" (USFC 1876b, p 480).

The former spring salmon run of the San Joaquin River has been described as "one of the largest chinook salmon runs anywhere on the Pacific Coast" and numbering "possibly in the range of 200,000 to 500,000 spawners annually" (DFG 1990). During a reconnaissance in late-July 1853 in the vicinity of Fort Miller (just upstream of Millerton), Blake (1857, p 20) observed, in reference to spring-run salmon: "During our stay at this camp we purchased fresh salmon of the Indians, who catch them in the river. It is probable, however, that they are not abundant, as the mining operations along the upper part of the stream and its tributaries sometimes load the water with impurities." While Blake's conjecture regarding the spring-run salmon evidently was not accurate at the time, it foreshadowed events to come.

By the end of the 19th century, the California Fish Commission observed:

Formerly there was a considerable run of salmon in the San Joaquin River, but as a result of mining and the diverting of water for irrigation, the run has decreased until now [1897-1898] it is confined to a short period in the fall. This fall run does not seek the extreme headwaters to spawn as formerly, and while a few enter the Stanislaus and Merced rivers, the majority seem to prefer the San Joaquin proper. ...Why the spring run does not go up this stream [San Joaquin River] instead of preferring the Sacramento, while some of the fall run continue up this river...remains unresolved. That the condition described is well recognized by the net-fishermen is proved by the fact that none of them are to be found above Jersey Island in the spring, while a number of boats are used above that point in the fall (CFC 1900a, p 24).

The Fish Commission of that time apparently did not fully realize that it was the spring run, rather than the fall run, that had formerly ascended to the headwaters and, hence, had been more drastically affected by the mining and the water diversions, although previous state fish commissioners were well aware of the detrimental impact of dams which had cut off the upper spawning grounds in the San Joaquin basin tributaries (for example, CFC 1884, p 15). Later, Clark (1929, p 31) reported that a "very good run" of salmon was seen at Mendota in 1916-1917 and a "fairly good" one for 1920, but thereafter the runs declined so that by 1928 "very few" fish were seen and the salmon of the San Joaquin River seemed to be "fast decreasing." By then there was essen-

tially only a spring run, the water being too low to support any appreciable fall run (Clark 1929).

The decline of the salmon resource of the upper San Joaquin River was, of course, noted by the river inhabitants. Particularly affected were Native Americans who depended upon the runs for sustenance. In the words of a Yokuts man named Pahmit (William Wilson) in 1933:

Long time 'go lots salmon in San Joaquin River. My people – maybe two to three thousand come Coo-you-illik catch salmon – catch more salmon can haul in hundred freight wagons. Dry 'em – carry 'em home. ...[Since 1909] no salmon in river. White man make dam at old Indian rancheria Käh-wäh-chu – stop fish – now Indian got no fish. Go river – water there, but no fish. White man got no fish. White man got no money. Injun got no fish – Injun got no money – everybody broke. That's bad business (F. Latta unpublished field notes).

Coo-you-illik (“Sulphur Water”) was a Dumna Yokuts village at the later site of Fort Miller (Latta 1977). The salmon were also well remembered by non-Native Americans in later decades: “The salmon fishing in the San Joaquin River was out of this world. It was one of the finest spawning rivers for salmon....There were hundreds and hundreds.... The salmon looked like silver torpedoes coming up the river” (Anthony Imperatrice interview, 11 February 1988; in Rose 1992, p 119).

In spite of the general decline of salmon in the upper San Joaquin River due to increasingly inhospitable environmental conditions, particularly for the fall run, a substantial spring run and even a remnant fall run managed to persist for a time. Hatton (1940, p 359) reported that the fall run occurred in “some years...making a hazardous and circuitous journey through a series of natural sloughs and irrigation laterals [canals], beginning near the mouth of the Merced [River] and miraculously entering the [San Joaquin] river through the main canal above Mendota Weir.” Clark (1943) stated that in 1942, the upper San Joaquin River had “a fair-sized spring run of king [chinook] salmon for many years” and a fall run that had “been greatly reduced.”

Fry (1961) also reported that during the 1940s before the construction of Friant Dam, the San Joaquin River had “an excellent spring run and a small fall run” and that its spring run was probably “the most important” one in the Central Valley. The spring run amounted to 30,000 or more fish in each of three years of that decade and a minimum of 56,000 spawners which passed Mendota weir in 1945 (DFG 1946; Fry 1961), with an annual value of “almost one million dollars” (Hallock and Van Woert 1959, p 246). In 1946, the sport fishery in the San Joaquin Valley took an estimated 25,000 salmon produced by the upper San Joaquin River, with perhaps another 1,000 caught in the ocean

sport fishery (DFG 1955 unpublished document). In addition, the commercial harvest (averaged for the period 1946–1952) accounted for another 714,000 pounds of salmon that originated from the San Joaquin River (DFG 1955 unpublished document). However, both the spring and fall salmon runs were extirpated from the upper San Joaquin River above the confluence with the Merced River as a direct result of the completion of Friant Dam (320 ft high) in 1942 and its associated water distribution canals (namely, Madera and Friant-Kern canals) by 1949 (Skinner 1958). Friant Dam itself cut off at least a third of the former spawning areas, but more importantly, the Friant Project essentially eliminated river flows below the dam, causing about 60 miles of river below “Sack Dam” to completely dry up (Skinner 1958; Hallock and Van Woert 1959; Fry 1961). During the relatively dry winter of 1946–1947, the US Bureau of Reclamation allowed no more than 15,000 acre-feet of water to be released from Friant Dam for the spring run, and only 6,000 salmon were counted passing Mendota weir in 1947 (DFG 1948). The last substantial spring-run spawning cohort (numbering >1,900 fish) occurred in 1948 (Warner 1991). While not attributing the collapse of the Sacramento-San Joaquin River spring-salmon fishery solely to Friant Dam, Skinner (1958) noted the “striking coincidence” that in the 1916–1949 (pre-Friant) period, the spring-run catch averaged 664,979 pounds (31% of the total Sacramento-San Joaquin River commercial catch) and in 1950–1957 (post-Friant) it averaged 67,677 pounds (6% of the total catch)—a 90% reduction in absolute poundage. Skinner (1958) further chronicled the telling correlation between events in the development of the Friant Project, their effects on year-classes of fish, and the rapid deflation of the spring in-river fishery—the latter falling from a high catch of 2,290,000 pounds in 1946 to a low of 14,900 pounds in 1953. “Last-ditch” efforts by DFG biologists to preserve the last cohorts of the upper San Joaquin River spring-run salmon in 1948, 1949, and 1950 were foiled by insufficient streamflows and excessive poaching, thereby resulting in the extinction of the run (DFG 1950; Warner 1991).

Since the closure of Friant Dam, polluted irrigation drainage during much of the year has comprised essentially all of the water flowing down the course of the San Joaquin River along the valley floor until it is joined by the first major tributary, the Merced River (San Joaquin Valley Drainage Program 1990). In only very wet years in recent decades have a few salmon occasionally ascended the San Joaquin River below Friant Dam, the latest record being that of a single 30-inch male (possibly spring-run) caught by an angler on 1 July 1969 below Friant Dam (Moyle 1970).

The former San Joaquin River salmon runs were the most southerly, regularly occurring large populations of chinook salmon in North America, and they possibly were distinctly adapted to the demanding environmental regime of the southern Central Valley. The California Fish Commission regarded the

migration of the fall salmon run during the seasonally hot portion of the year as extraordinary:

Large numbers pass up the San Joaquin River for the purpose of spawning in July and August, swimming for one hundred and fifty miles through the hottest valley in the State, where the temperature of the air at noon is rarely less than eighty degrees, and often as high as one hundred and five degrees Fahrenheit, and where the average temperature of the river at the bottom is seventy-nine degrees and at the surface eighty degrees (CFC 1875, p 10; USFC 1876b, p xxv).

The Commissioners noted that during August-September of 1875-1877, the average monthly water temperatures for the San Joaquin River where two bridges of the Central Pacific Railroad crossed (at 37°50'N, 121°22'W and 36°52'N, 119°54'W) were within 72.1 to 80.7 °F (considering both surface and bottom water) and maximal temperatures were 82 to 84 °F (CFC 1877). The high temperature tolerance of the San Joaquin River fall-run salmon inspired interest in introducing those salmon into the warm rivers of the eastern and southern United States (CFC 1875, 1877; USFC 1876a, 1876b). Quoting the California Fish Commission (CFC 1875, p 10):

Their passage to their spawning grounds at this season of the year, at so high a temperature of both air and water, would indicate that they will thrive in all the rivers of the Southern States, whose waters take their rise in mountainous or hilly regions, and in a few years, without doubt, the San Joaquin Salmon will be transplanted to all of those States.

Perhaps it was this hardiness of the fall-run fish that enabled them to persist through years of depleted streamflows, “miraculously” negotiating the sloughs and irrigation ditches from about the mouth of the Merced River up the San Joaquin River drainage as mentioned by Hatton (1940, p 359). Yet, nothing is known of the physiological and genetic basis of the seemingly remarkable temperature tolerances of San Joaquin River fall-run salmon because that population was driven to extinction decades ago. It is not known to what degree the remaining fall-run populations in the major tributaries of the San Joaquin River possess the temperature tolerances and genetic characteristics of the original San Joaquin River fall run. Because of extreme fluctuations in year-to-year run sizes in recent times and the probable loss of genetic variation during population bottlenecks, it is likely that present-day fall-run salmon of the San Joaquin tributaries are genetically different from their forebears, or at least from the former San Joaquin River fall run. Similarly, the spring-run fish of the San Joaquin River perhaps also were physiologically and genetically distinctive due to their extreme southerly habitation. After completion of Friant Dam, spring-run fish began to use areas below the dam (Clark 1943). Approximately 5,000 spring-run fish were observed over-sum-

mering in pools below the dam during May through October 1942, where water temperatures had reached 72 °F by July. The fish remained in “good condition” through the summer, and large numbers were observed spawning in riffles below the dam during October and November (Clark 1943, p 90). A temperature of 80 °F has been regarded as the upper thermal limit for San Joaquin River spring-run fish, above which most of them would have died (DFG 1955 unpublished document), although much lower temperatures (40 to 60 °F) are necessary for successful incubation of the relatively temperature-sensitive eggs (Seymour 1956; Beacham and Murray 1990).

In addition to the spring and fall salmon runs, there were indications that a late-fall run possibly occurred in the San Joaquin River (Van Cleve 1945). In 1941, a run apparently of appreciable size entered the river, starting about 1 December and continuing through at least 10 December (Hatton and Clark 1942). The authors concluded that “a run of several thousand fish may enter the upper San Joaquin River during the winter months, in addition to the spring run during March, April and May” (Hatton and Clark 1942, p 123). This December run has been viewed as a possible late-fall run (Fisher 1994) because peak migration of late-fall-run fish characteristically occurs in December, at least in the Sacramento River system. A likely alternative, however, is that the migration observed by Hatton and Clark was simply the fall run, having been delayed by unfavorable conditions that evidently typified the river in the early fall months. Clark (1943) in fact stated that a “late-fall run of salmon occurs after this sand dam [the Sack Dam near Firebaugh] is washed or taken out in late November,” indicating that the fall run was usually blocked from ascending past that point any earlier. Furthermore, spawning of Central Valley fall-run stocks tend to occur progressively later in the season in the more southerly located streams, at least at the present time (F. W. Fisher unpublished data), and the spawning migration period is known to include December in the San Joaquin basin tributaries (Hatton and Clark 1942; T. Ford, personal communication, see “Notes”). Nevertheless, a distinct late-fall run (*sensu* Fisher 1994; Yoshiyama and others 1998) may have actually existed in earlier times in the San Joaquin River. Historical environmental conditions in the mainstem reach of the San Joaquin River just above the valley floor were apparently suitable for supporting late-fall-run fish, which require cool water flows during the summer juvenile-rearing period. To wit, Blake (1857, p 20) noted of the San Joaquin River (near Fort Miller) in late July 1853:

The river was not at its highest stage at the time of our visit; but a large body of water was flowing in the channel, and it was evident that a considerable quantity of snow remained in the mountains at the sources of the river. A diurnal rise and fall of the water was constantly observed, and is, without doubt, produced by the melting of the snow during the day. The water was remarkably pure and clear, and very cold; its temperature seldom rising above 64° Fahrenheit while that of the air varied from 99° to 104° in the shade.

Merced River (Merced County). Both spring and fall salmon runs, and evidently steelhead, historically occurred in the Merced River, but only the fall run has survived and is now the southernmost native chinook salmon run in existence (Reynolds and others 1993). According to a gold miner's account, Native Americans were observed harvesting salmon in the spring of 1852 at Merced Falls, where their "rancheria" (village) was located (Collins 1949). Another gold miner noted, during the first half of November 1849, "At the River Merced we saw some Indians, ...These Indians were fishing for salmon, at which business they are very expert and successful" (Woods 1851, p 83)—in obvious reference to the fall run. Boating down the lower Merced River below Hopeton on 10 November 1877, John Muir observed, "Fish abundant in deep pools—salmon, trout, and suckers" (Muir 1938, p 241). Based on the date, the salmon he saw undoubtedly were fall-run salmon and the "trout" may have been steelhead. Spring-run salmon were also reported from the vicinity of "Horse Shoe Bend" (now covered by Exchequer Reservoir), near Coulterville (Mariposa Gazette, 24 June 1882 and 25 June 1887; J.B. Snyder, personal communication, see "Notes"). Oral history obtained from local residents (Snyder unpublished memorandum, 9 May 1993) indicates that salmon occurred in the mainstem Merced River in the area between Bagby and Briceburg near the branching of the North Fork. There is a 20-foot waterfall below Briceburg (Stanley and Holbek 1984), but it probably was not steep enough to have posed a substantial obstacle to salmon (see below). Another gold miner's journal (Perlot 1985) indicates that salmon were caught in abundance on the mainstem Merced River some unspecified distance above the confluence of the South Fork—possibly approaching the vicinity of El Portal (about 2,000 ft elev.). The section of river above El Portal is of high gradient and would have presented a rigorous challenge to migrating fish; thus, it is not clear if substantial numbers of salmon, if any, were able to ascend beyond that point.

There has been disagreement on whether any salmon reached Yosemite Valley. Dr. Lafayette Bunnell, writing of his service with the Mariposa Battalion which discovered the Yosemite Valley in 1851, noted:

Below the cañon of the Yosemite, young salmon were once abundant. The Indians used to catch fish in weirs made of brush and stones; but during the extensive mining operations on the Merced and other rivers, the salmon seemed to have almost abandoned their favorite haunts, for the mud-covered spawn would not hatch. Large salmon were speared by the Indians in all the rivers,... (Bunnell 1990, p 165).

Shebley (1927, p 169) later stated: "At that time [1892] ...the steelhead and salmon ascended the Merced River to Wawona [South Fork] and into Yosemite Valley [on the mainstem] as far as the rapids below the Vernal-Nevada Falls," and there "were a few low dams in the river, but they were not high enough to prevent the steelhead and salmon passing them during the

spring floods." However, Shebley provided no evidence to support his statement, which was later discounted (Snyder 1993 unpublished memorandum). The absence of any clear reference to salmon in the early historical accounts of the Yosemite Valley (for example, Muir 1902, 1938, 1961, 1988; Hutchings 1990), and the present lack of archaeological and ethnographic evidence showing that native peoples subsisted on salmon in the higher elevation parts of the drainage (Snyder 1993 unpublished memorandum) seem to argue against the past occurrence of salmon there, at least in significant numbers. Snyder (unpublished 1993 memorandum), noted that there are no references to salmon in the native folklore of the Yosemite region, nor to terms related to the procedures of salmon fishing as there are in the cultural milieu of native inhabitants of the lower elevations. The paucity of suitable spawning gravels in Yosemite Valley (E.R. Gerstung, personal observation) also would indicate that few, if any, salmon ascended that far, although the presence of "speckled trout" (rainbow trout, *Oncorhynchus mykiss*) in Yosemite Valley was noted in some early accounts (Caton 1869; Lawrence 1884; Hutchings 1990). Yet, California Fish Commissioner B.B. Redding had noted even earlier, in 1875:

A few years since, they [salmon] spawned near the Yosemite Valley. A dam built for mining purposes, some four or five years since, prevented them from reaching this spawning ground. Last year the dam was removed and the fish have again free access to the headwaters of the Merced, but whether they have returned to their former spawning grounds on this river ...I have not learned (USFC 1876b, p 481).

It appears, therefore, that salmon at one time and in unknown numbers may have approached the vicinity of Yosemite Valley, even if they did not enter the valley proper. However, for the present, the area around El Portal or just downstream of it may be the best estimate of the historical upstream limit of salmon in the mainstem Merced River, unless supporting evidence for Shebley's (1927) statement that they ascended farther upstream can be found. Even the vicinity of El Portal may be higher than where most of the salmon historically ascended, considering the lack of archaeological evidence of salmon-fishing technology or salmon remains in excavations near El Portal (J. Snyder, personal communication, see "Notes").

Salmon most likely ascended the South Fork Merced River at least to Peach Tree Bar, about seven miles above the confluence with the mainstem, where a waterfall presents the first significant obstruction (P. Bartholomew, personal communication, see "Notes"). Hardheads are limited in their upstream distribution by the waterfall, and Sacramento suckers occur even farther upstream to the vicinity of Wawona (Toffoli 1965; P. Bartholomew, personal communication, see "Notes"). Salmon commonly spawn in the same reaches frequented by those species (Moyle 1976; E.R. Gerstung, personal observation), so they undoubtedly also reached Peach Tree Bar, if not further. It is possible

that salmon surmounted the waterfall and ranged above Peach Tree Bar, but there is no confirmatory historical information available; if they did so, their upstream limit would have been a 20-foot waterfall located near the mouth of Iron Creek, about four miles below Wawona (E.R. Gerstung, personal observation). The North Fork Merced River is a relatively low watershed (about 1,300 ft elev. at the lower end), but there are substantial falls located about one mile above the mouth (T. Ford, personal communication, see "Notes"; E. Vestal unpublished notes) which would have prevented further penetration into the drainage by salmon. Rutter (1908) also mentioned "a 12-foot fall" that separated the North Fork from the "main Merced River." This perhaps was the cascade mentioned by the gold miner J.N. Perlot which "had at all times been an insurmountable obstacle for the fish," thus accounting for his observations that the North Fork "contained no kind of fish whatsoever, not the least white-bait, not the smallest gudgeon" (Perlot 1985, p 282).

As early as 1852, a temporary barrier was erected by fishermen about ten miles below Merced Falls which blocked the spring-run salmon from their upstream spawning areas (Collins 1949). In the following decades, a succession of dams was built at Merced Falls and at locations upstream up to the Yosemite National Park boundary – including the 120-foot high Benton Mills Dam at Bagby (built in 1859) and a later (1900) dam at Kittredge, four miles below Bagby (Snyder 1993 unpublished memorandum). Those dams had already impeded the upstream migration of salmon by the 1920s, but it was the construction of Exchequer Dam that permanently barred the salmon from their former spawning grounds (CFGF 1921b). Clark (1929) stated that the existent spawning beds were on "occasional gravel bars" located between the river mouth and Exchequer Dam, with "about 12 miles" of streambed available. These are in the lower river and therefore pertain to fall-run fish. As of 1928, there were three obstructions to migrating salmon: Crocker Huffman irrigation diversion dam near Snelling; Merced Falls about three miles upriver, where there was a natural fall and the 20-foot Merced Falls Dam with a defunct fishway; and Exchequer Dam, 20 mi above Merced Falls. A decade later, Hatton (1940) considered the spawning areas to occur between "a point half a mile downstream from a line due south of Balico" and Exchequer Dam. Of this 42.2-mi stretch, only 24.1 mi was accessible to salmon due to obstructions; there were four beaver dams, passable under "usual water conditions," and four impassable rock dams lacking fishways and allowing only "seepage" to pass downstream. Above these rock dams was the Merced Falls Dam, equipped with a fishway but inaccessible to the salmon because of the downstream obstructions and low water flows. Presently, natural spawning by fall-run fish principally occurs in the stretch above Highway 59 to the Crocker-Huffman diversion dam, the upstream limit of salmon migration (Reynolds and others 1993). The Merced River Hatchery (operated by DFG) is located by this dam. Fall-run spawners ascending to this point are captured at the dam's fish ladder, for use as hatchery broodstock.

Clark (1929, p 31) reported both spring and fall salmon runs present in the Merced River and mentioned recollections by early residents of "great quantities of fish coming up the river to spawn in the summer and fall...so numerous that it looked as if one could walk across the stream on their backs." An early newspaper account (Mariposa Gazette, 26 August 1882, J.B. Snyder, personal communication, see "Notes") reported "...the water in the Merced river has become so hot that it has caused all the salmon to die. Tons upon tons of dead fish are daily drifting down the river, which is creating a terrible stench, and the like was never known before." Judging from the date, the reference was to spring-run salmon; fall-run salmon would not have entered the tributaries so early, assuming they behaved similarly to the Sacramento River fall run. By 1928, the runs were greatly depleted, with only several hundred fish reported in the Merced River during the fall (before 12 November) of that year (Clark 1929, p 31). According to Clark (1929, p 32), very low flow conditions due to irrigation diversions during the spring, summer and early fall had "just about killed off the spring and summer runs" (the "summer" run evidently was the latter part of the spring run or perhaps an early fraction of the fall run), and only fish arriving in late fall after the rains were able to enter the river. These fish were probably a late-running component of the fall run, rather than a true late-fall run (*sensu* Fisher 1994) because there was no explicit mention by Clark (1929) of early residents referring to salmon runs in December or later that would have been more characteristic of the late-fall run. Clark also referred to late fall as including November in his account for the Mokelumne River, which is a somewhat earlier run time than is characteristic of most late-fall-run fish. Even in recent years when drought conditions and extensive irrigation diversions reduced streamflows to very low levels, the salmon did not spawn in the Merced River "until after the first week of November when water temperatures [had] become tolerable" (Reynolds and others 1993, p VII.96).

Fry (1961) considered the Merced River to be "a marginal salmon stream" due to the removal of water by irrigation diversions, and he stated that there was "a poor fall run and poor spring run." Run-size estimates for the fall run were 4,000 fish for 1954 and <500 fish for every other year during the period 1953–1959 (Fry 1961). No numerical estimates were available for the spring run at that time. After 1970, fall-run spawning escapements increased to an annual average of 5,800 fish, reaching 23,000 spawners in 1985, due to increased streamflows released by the Merced Irrigation District and operation of the Merced River Hatchery (Reynolds and others 1993). As in other San Joaquin basin tributaries, spawning escapements in the Merced River, including returns to the Merced River Hatchery, dropped to "seriously low levels" during the early 1990s – numbering <100 fish in 1990 and <200 in 1991 (DFG 1996 unpublished data). The fall run increased from about 1,000 to 2,000 spawners in 1992–1993 to 4,000 to 6,000 spawners in 1996–1998 (DFG 1996 unpublished data), perhaps auguring a partial recovery of the stock. The Merced River

Hatchery, operated since 1971 by DFG, has received a major fraction of the spawning run in this stream, accounting for 5% to 39% of the annual runs during the 1980s, 19% to 67% in 1990–1994, and 17% to 30% in 1995–1998 (DFG unpublished data). Late-fall-run salmon are said to occur occasionally (Reynolds and others 1993), but the spring run no longer exists in the Merced River.

Tuolumne River (Stanislaus and Tuolumne counties). At least spring and fall salmon runs historically used the Tuolumne River. Clavey Falls (10 to 15 ft high), at the confluence of the Clavey River, may have obstructed the salmon at certain flows, but spring-run salmon in some numbers undoubtedly ascended the mainstem a considerable distance. The spring-run salmon were most likely stopped by the formidable Preston Falls four miles above Early Intake Dam near the boundary of Yosemite National Park (about 50 mi upstream of present New Don Pedro Dam), which is the upstream limit of native fish distribution (DFG unpublished data). Sacramento suckers (*Catostomus occidentalis*), riffle sculpins (*Cottus gulosus*) and California roach (*Lavinia symmetricus*) were observed during stream surveys between Early Intake and Preston Falls (DFG unpublished data; P. B. Moyle unpublished data), and spring-run salmon probably formerly occurred throughout that reach as well. If they were present in the Tuolumne drainage, steelhead probably ascended several miles into Cherry Creek, a tributary to the mainstem about one mile below Early Intake, and perhaps spring-run salmon also entered that stream. Steep sections of stream in the Clavey River and the South and Middle forks of the Tuolumne shortly above their mouths most likely obstructed the salmon (T. Ford, personal communication, see “Notes”), although Sacramento pikeminnow are found within the first mile of the Clavey River and suckers and roach occur up to 10 to 15 miles upstream (EA Engineering, Science and Technology 1990). In the lower South Fork, a large waterfall (25 to 30 ft high, Stanley and Holbek 1984) probably prevented further access up that fork. The North Fork, with a 12-foot waterfall about one mile above the mouth, likewise offered limited access. Probably few, if any, salmon entered those upper reaches of the Tuolumne drainage (T. Ford, personal communication, see “Notes”). The waterfalls just below present Hetch Hetchy Dam on the mainstem, about ten miles above Preston Falls, evidently stopped all fish that might have ascended that far, and John Muir wrote that the river was barren of fish above the falls (Muir 1902). There are no indications that salmon ever reached Hetch Hetchy Valley, or Poopenaut Valley farther downstream (Snyder 1993 unpublished memorandum). Just as with the Merced River, there is no archaeological or ethnographic evidence indicating that salmon were part of the subsistence economics of the native inhabitants of the higher elevations along the upper Tuolumne River (Snyder 1993 unpublished memorandum).

The first written record of salmon in the Tuolumne River is that of the Frémont Expedition of 1845–1846. Frémont’s (1848, p 18) journal entry for 4 Feb-

ruary 1846 reads: "Salmon was first obtained on the 4th February in the Towal-um-né river, which, according to the Indians, is the most southerly stream in the valley in which this fish is found." It is not clear whether Frémont's party caught the salmon or obtained them from the local native inhabitants, but in any case, it is likely that the fish were early arrivals of the spring run. Although the bulk of the spring-run salmon migration occurs during April through June, at least in the Sacramento drainage (Fisher 1994), spring-run fish have occasionally appeared in their spawning streams in early February, as in Butte Creek during 1995 (F. W. Fisher unpublished data), and sometime during February in the American River (in 1946) (Gerstung 1971 unpublished report). The occurrence of salmon in the Tuolumne River in those early years was also noted by John Marsh, who had arrived in California in the mid-1830s. Quoting Marsh, Edwin Bryant wrote, "...the river of the Towalomes; it is about the size of the Stanislaus, which it greatly resembles,...and it particularly abounds with salmon" (Bryant 1849, p 277). Furthermore, in his memoirs of the Gold Rush, the entrepreneur Samuel Ward recollected enjoying "a plentiful fish supper" of fresh salmon, caught by rifle shot in the lower Tuolumne River at Dickensons Ferry (located roughly halfway between the river mouth and the Sierra foothills (Collins 1949, p 104). That occasion was "late in the autumn [1851], just after winter's first premonitory showers" (Collins 1949, p 100) – coincident with the timing of the fall run. A later historical account also noted of the local native people: "Every spring, when the salmon were running up the river, enough were caught and dried to last nearly all the year"; "The waters of the Tuolumne, Stanislaus, Merced and San Joaquin generally furnish them with good fishing. They spear the salmon with spears made of some kind of tough wood,..." (Elliott 1882, p 162, 166).

Significant blockage of salmon runs in the Tuolumne River began in the 1870s when various dams and irrigation diversion projects were constructed, although dams and water diversions associated with mining had been present as early as 1852 (Snyder 1993 unpublished memorandum) and undoubtedly had some effect. Wheaton Dam, built in 1871 at the site of present-day La Grange Dam, may have blocked the salmon to some degree (T. Ford, personal communication, see "Notes"). By 1884, the Tuolumne and Stanislaus rivers were "dammed in such a way to prevent the fish from ascending" (CFC 1884, p 16). La Grange Dam, a 120-foot-high engineering marvel when completed in 1894, permanently cut off the former spring-run spawning areas. In 1896, the California Fish Commission stated, "The number of salmon that enter this stream [Tuolumne River] to spawn is small, and after its waters are taken out for irrigating purposes, will probably decrease," and the proposed fish ladder for La Grange Dam was viewed by the Fish Commission to be "not warranted, and would be of little or no benefit to the people or the fish" (CFC 1896, p 18). However, mining and other activities that degraded the river habitat undoubtedly also affected the salmon runs even before the early period of dam construction on the Tuolumne River. John Muir recorded in his journal in

November, 1877: "Passed the mouth of the Tuolumne.... It is not wide but has a rapid current. The waters are brown with mining mud. Above the confluence the San Joaquin is clear..." (Muir 1838, p 244).

Clark (1929) stated that the spawning grounds in 1928 extended from the town of Waterford to La Grange, over 20 miles of "good gravel river." At the time, there were two dams of major significance: La Grange Dam and Don Pedro Dam (built in 1923) 13 miles upriver; the latter was 300 ft high and formed a large irrigation reservoir (Clark 1929). Hatton (1940) later stated that the spawning beds in the Tuolumne River lay between a point 2.2 miles below the Waterford railroad bridge and the La Grange Power House. As of 1939, the Modesto Weir (a low structure) had no water diversion and was passable to salmon because the flash boards were removed "several weeks in advance of the fall run" (Hatton 1940). The rest of the Tuolumne River was clear of obstructions up to the impassable La Grange Dam. Spawning now occurs in the approximately 20-mile stretch from the town of Waterford (rm 31) upstream to La Grange Dam (EA Engineering, Science and Technology 1992). La Grange Dam remains a complete barrier to salmon and thus defines the present upstream limit of their spawning distribution (Reynolds and others 1993). The total area of spawning gravel presently considered available to salmon in the lower Tuolumne River (below La Grange Dam) is 2.9 million square feet (EA Engineering, Science and Technology 1992).

The California Fish Commission (CFC 1886, p 20) noted of the Tuolumne River: "[it] at one time was one of the best salmon streams in the State; Salmon have not ascended the stream for some years." Clark (1929) also reported that salmon generally were "scarce" in the Tuolumne River; at that time, both spring and fall runs still occurred at low levels, but the spring run was inconsequential, amounting "to almost nothing," and the fall run comprised "some fish" (Clark 1929, p 32). Clark noted, however, that "a good run" (evidently the fall run) had been reported in 1925 which "surpassed anything that had appeared in several years." Two decades later, only "a bare remnant of a spring run" was reported to exist during 1944-1946 (DFG 1946).

Only the fall run presently occurs in appreciable numbers in the Tuolumne River. In the past, fall-run spawning escapements in the Tuolumne River during some years were larger than in any other Central Valley streams except for the mainstem Sacramento River, reaching as high as 122,000 spawners in 1940 and 130,000 in 1944 (DFG 1946; Fry 1961). In fact, over the past half-century the Tuolumne River has supported one of the largest natural populations of salmon in the Central Valley tributaries (DFG unpublished data; USFWS 1995). Tuolumne River fall-run salmon at times comprised up to 12% of the total fall-run spawning escapement for the Central Valley (Reynolds and others 1993), but run sizes during the early 1990s fell to extremely low levels—specifically, fewer than about 130 spawners in each of the years 1990-1992 and

about 400 to 500 fish in 1993 and 1994 (DFG 1996 unpublished data). The fall run recently rebounded to at least 3,600 to 5,500 spawners in 1996–1997 and 7,900 spawners in 1998 (DFG unpublished data). The fall run historically has been a naturally sustained population because there is no hatchery on the Tuolumne River, unlike most other major salmon streams in the Central Valley (Reynolds and others 1993). However, increasing numbers of hatchery-derived spawners have ascended the Tuolumne River in recent years, mainly due to large releases of hatchery juveniles (from Merced River Hatchery) for study purposes into this stream and elsewhere in the San Joaquin River basin and Sacramento-San Joaquin Delta (DFG unpublished data; FERC 1999).

It has been stated that “a small population” of late-fall-run fish exists in the Tuolumne River (Reynolds and others 1993), but the existence of such a run appears to be based mainly on the occurrence of juveniles in the river during the summer and on observations of occasional spawning in later months (January through March) than is typical for fall-run fish (T. Ford, personal communication, see “Notes”). However, hydrological conditions in the Tuolumne River during the past few decades have not been conducive to the maintenance of a late-fall run – notably the lack of consistent, cool streamflows during the summer to support the juveniles (Reynolds and others 1993). It is possible that the infrequent observations of fish with late-fall-run timing characteristics have been strays from the Sacramento River system and their progeny. Late-emerging or slow-growing fry produced by fall-run fish, perhaps of hatchery origin, also could account for some of the juveniles observed over-summering in the river.

Stanislaus River (Stanislaus, Calaveras counties). Both spring and fall runs historically occurred in the Stanislaus River. The forty-niner Alfred Doten wrote in his journal for 4 November 1850: “At sunset we crossed the Stanislaw river and camped on the opposite side – Beautiful river – forded it at a shallow place where the natives were shooting and spearing salmon” (Clark 1973, p 59) – obviously the fall run. Another gold miner, Howard C. Gardiner, made note of salmon in the Stanislaus River at Knights Ferry, in mid-December 1848 (the exact date unknown, but probably soon after December 19): “...we reached the ferry...the others went over, leaving me to dicker with an Indian for the purchase of a salmon which we had seen him capture a few minutes previous. The native soon came with the fish which must have weighed twenty-five pounds.... I bought the salmon for eight dollars...” (Morgan 1970, p 109). The approximate date is consistent with the peak migration period of the late-fall run, but also with the end of the fall run (Fisher 1994). The California Department of Fish and Game reported that besides the spring salmon run, “lesser runs occurred in fall and winter due to the natural, unaltered regime of the river” (DFG 1972, p 2–3), but the later-running fish were most likely late-fall-run salmon or perhaps a segment of the fall run.

Steelhead evidently also were seen by the gold miners, as attested by Alfred Doten:

The Salmon Trout of the mountain streams is a most beautiful and delicious fish, and not to be beaten for good eating by any other freshwater fish; at least I used to think so when I was a gold digger. They generally weigh from two to four pounds, and are abundant in most of the upper streams and rivers of the Sierra Nevada (Clark 1973, p 311).

The native Central Sierra Miwok people, located near the Tuolumne and Stanislaus rivers, were said to have “fished in the Le Grange [sic] and Knights Ferry Area for two kinds of salmon: The summer salmon which were small and also called ‘red salmon,’ and winter salmon or ‘dog salmon’ which were larger, ‘they were all the big ones’” (Theodoratus 1976, p 486) – the two kinds apparently corresponding to spring-run (summer or red) and fall-run (winter or dog) salmon. In an interview conducted in 1975, an elder (90+ years old) Miwok informant stated that the “red salmon” (spring run) were speared in the Stanislaus River above a bridge near Knights Ferry, and some numbers also were taken at “Burns Ferry” (now covered by Tulloch Reservoir) and farther upstream at a “dam” near Columbia (perhaps at a mining diversion) (Theodoratus 1976). The “winter salmon” (fall-run) fishing spots were at Knights Ferry and, when the water was high, at “Wild Cat Canyon.” Other Miwok and non-Indian informants reported that salmon were taken below the “old Camp Nine bridge” (near the town of Stanislaus), “under the bridge at Parrotts Ferry” and “in the Melones area...in the early 1900s” (Theodoratus 1976, p 487; Maniery 1983). The latter two sites are now covered by upper New Melones Reservoir. According to one Miwok informant, his father caught salmon in six-foot long basketry fish traps: “...he use[d] to haul fish out of the canyon with ten of his mules up from Camp Nine [Stanislaus] to Tablerock Mountain up to Murphys...to sell the salmon for 50¢ a piece” – some of which “weighed up to twenty-five pounds or so” (Theodoratus 1976, p 398). The large size of those fish suggests they were of the fall run. Salmon also were taken near Duck Bar (4.5 mi below Stanislaus, now inundated), where a long-time Miwok resident named Indian Walker caught them in fish traps to sell to the white community (Cassidy and others 1981). Barrett and Gifford (1933, p 189) reported that “salmon were caught in the late spring” – in obvious reference to the spring run.

Spring-run and perhaps some fall-run salmon probably went considerable distances up the forks because there were few natural obstacles (W. Loudermilk, personal communication, see “Notes”). Before the filling of New Melones Reservoir, there were no natural barriers to salmon in the reach from Old Melones Reservoir upstream to the mouth of the Middle Fork Stanislaus River (which was a popular rafting reach; E.R. Gerstung, personal observation), or on the Middle Fork from its mouth up to Sand Bar Flat located just below the

Spring Gap Powerhouse (E. Vestal, personal communication, see "Notes"). One ethnographic account stated, "On the Stanislaus river, salmon (*kosimo*) went as far as Baker's bridge where there is a waterfall" (Barrett and Gifford 1933, p 189). Baker's Bridge was located near Spring Gap Powerhouse on the Middle Fork, about two miles below present-day Beardsley Reservoir, according to an old-time rancher in that area (personal communication to E.R. Gerstung, see "Notes"). That same location was designated as "Baker's Crossing" on an old US Geological Survey map, drawn in 1901 by Thomas R. Hanna (Map of Stanislaus Forest Reserve, Alpine Count Library Archives, Markleyville). Apparently, there were no impassable natural obstacles on the Middle Fork to just above present-day Beardsley Reservoir (3,400 ft elev.) (E. Vestal, personal communication, see "Notes"), although the increasingly steep gradient up to that point may have deterred most salmon.

In the North Fork Stanislaus River, suckers and hardhead occurred in the first several miles up to the confluence of Griswold Creek (Northern California Power Authority 1993 unpublished report), so salmon undoubtedly would have ascended at least to that point. The North Fork was probably accessible to salmon as far as McKay's Point (about eight miles above the confluence with the Middle Fork), where the gradient steepens and which we take as the practical upstream limit. Presumably few, if any, salmon passed that point and they probably were blocked five miles farther upstream by a 15-foot waterfall above Board's Crossing. The South Fork Stanislaus River is a small drainage and is unlikely to have supported more than a few, if any, salmon because of the paucity of habitat. We have seen no suggestions of salmon having occurred in the South Fork, and for the present we do not include it as a former salmon stream.

Damming and diversion of water on the Stanislaus River, for both mining and irrigation, began soon after the Gold Rush. The earliest "permanent" dam on the river was the original Tulloch Dam, constructed in 1858 just downstream of the present Tulloch Dam (Tudor-Goodenough Engineers 1959). The original Tulloch Dam was a relatively low structure and evidently had an opening at one end (photograph in Tudor-Goodenough Engineers 1959), and its impact on the salmon runs, therefore, may not necessarily have been significant. Clark (1929) stated that the salmon spawning beds were distributed over ten miles of stream, from the marshlands above Oakdale to Knight's Ferry. Dams on the river by that time included 20-foot Goodwin Dam (completed in 1913) 18 mi above Oakdale, which had a fishway and was at times negotiable to salmon, and the 210-ft impassable Melones Dam (completed in 1926) above the town of Melones. The spawning beds in 1939 were reported by Hatton (1940) to extend from Riverbank Bridge to the Malone Power House, although of this 32.7-mile distance, the 9.3 miles between Goodwin Dam and the Power House was "only rarely accessible to salmon." Hatton (1940, p 355) stated that the fishway over Goodwin Dam was "seldom passable" and that the fluctuat-

ing water level caused by hydroelectric operations above Goodwin Dam and the “almost complete diversion of water at the dam” made it “very nearly an impassable barrier.” Fry (1961) also mentioned the blockage of migration by Goodwin Dam, the operation of which also caused low and warm flows downstream during the summer and “violent” water fluctuations (due to power-generation releases) during the fall and winter. Presently, the salmon do not ascend the Stanislaus River farther than Goodwin Dam, which regulates streamflows from Tulloch Reservoir and diverts water for irrigation and power generation (Reynolds and others 1993). Much of the spawning occurs on the extensive gravel beds in the 23-mile stretch from Riverbank upstream to Knights Ferry, which are essentially on the valley floor (T. Ford, personal communication, see “Notes”). Upstream of Knights Ferry, where the river flows through a canyon, spawning is concentrated at Two Mile Bar (about one mile above Knights Ferry) but also occurs in scattered pockets of gravel (T. Ford, personal communication, see “Notes”).

The California Fish Commission reported that while the Stanislaus River had once mirrored the Tuolumne River as a preeminent salmon stream, by 1886 only an occasional salmon was seen “trying to get over one of its numerous dams” (CFC 1886, p 20) Much later, Clark (1929, p 32) reported that the Stanislaus River “has a good spring and fall run of salmon,” but he also stated that their abundance was “about the same as in the Tuolumne” where he had described them to be “scarce.” Given Clark’s contradictory statements, it is not clear how abundant, even qualitatively, the salmon were in the Stanislaus at the time of Clark’s survey (late 1920s). Historically, the spring run was said to have been the primary salmon run in the Stanislaus River, but after the construction of dams which regulated the streamflows (namely, Goodwin Dam and, later, Melones and Tulloch dams), the fall run became predominant (DFG 1972). Fry (1961, p 64) described the Stanislaus River as “a good fall run stream for its size” but it had “almost no remaining spring run.”

The Stanislaus River fall run, in recent historical times, has contributed up to 7% of the total salmon spawning escapement in the Central Valley (Reynolds and others 1993). Annual escapements for the fall run were minimally estimated at 4,000 to 35,000 spawners (average about 11,100) during 1946–1959 (Fry 1961), before the construction of Tulloch Dam (in 1959). In the following 12-year period (1960–1971), the average run size was about 6,000 fish (DFG 1972). Fall-run abundances during the 1970s and 1980s ranged up to 13,600 (average about 4,300) spawners annually (DFG unpublished data). The numbers of spawners returning to the Stanislaus River have been especially low during most of the 1990s—<500 fish annually in 1990–1993, 600 to 800 fish in 1994–1995, and <200 fish in 1996—but there was a modest increase to 1,500 spawners in 1997 and 2,200 spawners in 1998 (DFG unpublished data).

Presently (1999) only the fall run has sustained itself in the Stanislaus River, although small numbers of late-fall-run fish have been reported to occur (Reynolds and others 1993). As in the Tuolumne River, the recent occurrence of late-fall-run salmon in the Stanislaus River could be due to strays from the Sacramento River system.

Calaveras River (Calaveras County). The Calaveras River is a relatively small, low-elevation drainage that receives runoff mainly from rainfall during November through April (Reynolds and others 1993), and its lower reaches historically were dry during part of the year (Carson 1852). This river was probably always marginal for salmon, and it lacks suitable habitat for spring-run fish (E.R. Gerstung, personal observation). Chinook salmon runs reportedly occurred on an "irregular basis" (Reynolds and others 1993), although Clark (1929, p 235) had stated that the Calaveras River was "dry most of the summer and fall and so it has no run of salmon." Yet, the name of the river itself represents, in a way, a salmon legacy. Quoting the historian Sanchez (1932, p 291):

In his diary Moraga says that the river tribes fought against those of the Sierra for possession of the salmon in the stream, and that in one battle many were said to have been killed and left on the field. A great number of skulls, relics of this bloody conflict, were found by Moraga scattered along the creek bed, and for that reason he called it Las Calaveras [The Skulls].

O'Brien (1951, p 33) further elaborated:

Moraga followed them...and there halted in amazement. Skulls and bones littered an acre and more. An Indian of a nearby rancharía explained that the field was an ancient battleground. A long time before, he said, invading warriors swarmed down from the Sierra to drive the tribes of the Sacramento and San Joaquin Valleys from their river fishing preserves...and these skulls and bones were the remains of those who had fallen.

The Calaveras River had, in recent times, an unusual "winter" salmon run which spawned during late-winter and spring, but it is unknown if the run had existed before the dams were built on the river. This run has been referred to as a "winter run," but perhaps it was more like a late-fall run, given that the spawning period was relatively early compared to the Sacramento winter run. The presence of this run was documented for six years within the period 1972-1984 and it numbered 100 to 1,000 fish annually (Reynolds and others 1993). The fish ascended to New Hogan Dam, and they held and spawned in the reach just below the dam (T. Ford, personal communication, see "Notes"). Management of streamflows by the US Army Corps of Engineers entailed high-flow releases from New Hogan Dam interspersed with periods of very low flow, which undoubtedly contributed to the apparent demise of this run since 1987 (T. Ford, personal communication, see "Notes"; USFWS 1995). Bel-

lota Dam, 15 mi below New Hogan Dam, and at least two other diversion dams are known to have blocked upstream salmon migration during periods of low streamflow (Reynolds and others 1993). The run's extirpation may also have been hastened, if not guaranteed, by persistently low streamflows due to the 1987–1992 drought and to irrigation diversions.

It is possible that the existence of salmon—particularly the supposed “winter run”—in this river during recent decades has been mainly the result of suitable conditions created by the dams. Historically, the natural occurrence of salmon there was most likely limited to wet years. Currently, fall-run salmon—perhaps those destined for other San Joaquin River tributaries—occasionally enter the Calaveras River when suitable fall streamflows occur. For example, several hundred fall-run fish were observed during the fall of 1995 at Bellota Dam, where they were temporarily blocked (DFG unpublished data). We have no information on the historical upstream range of salmon in the Calaveras River, so we consider the site of New Hogan Dam (the upper limit in recent times) as a minimal approximation of the historical limit.

Mokelumne River (San Joaquin, Amador counties). The Mokelumne River, in its original state, apparently supported at least fall and spring salmon runs. Some evidence suggests that a late-fall run also occurred at one time. In what is probably the earliest record of salmon in the Mokelumne River, the fur trapper Jedediah Smith, having encamped on “Rock River” (Mokelumne River), wrote in his journal for 22 January 1828: “Several indians came to camp and I gave them some tobacco. They brought with them some fine salmon some of which would weigh 15 or 20 lbs. I bought three of them and one of the men killed a deer...” (Sullivan 1934, p 56). The salmon that would have been present during that part of January in “fine” condition most likely were late-fall-run or perhaps spring-run, although the timing is extraordinarily early for the latter. Smith’s party evidently was on the lower Mokelumne River on the marshy valley floor, for “...although the ground was rolling the horses sank at every step nearly to the nees [sic].” Two decades later, Alfred Doten similarly recorded (for 22 December 1851): “Saw three fine salmon, which were brought from the Moqueleme—they averaged about 20 lbs a piece” (Clark 1973, p 80). That date is consistent with the peak migration time of the late-fall run, and although later-arriving spawners of the fall run cannot be completely discounted, it is more likely that late-fall run fish would have been present in “fine” physical condition. Ethnographic information attests that native Northern Sierra Miwok people on the Mokelumne River in the past had at least a simplified “first-salmon” rite (Aginsky 1943)—suggesting the historical presence of the spring salmon run, given that such rites characteristically were associated with the onset of the spring-run harvest in other Central Valley streams (for example, Gayton 1946 [p 256], 1948b [p 166]; Voegelin 1942, [p 57, 175]) and on the northern California coast (Swezey and Heizer 1977).

Salmon ascended the river at least as far as the vicinity of present-day Pardee Dam (rm 73). Reportedly, a large waterfall (30+ ft high) was present at Arkansas Ferry Crossing, one mile downstream of the Pardee Dam site in a narrow rocky gorge (R. Nuzum, personal communication, see "Notes"), and it may have posed a significant barrier to the fall run. The site of the waterfall was inundated by Camanche Reservoir, and no natural obstructions presently exist between Camanche Reservoir and Pardee Dam (S. Boyd, personal communication, see "Notes"). Spring-run salmon undoubtedly would have ascended past that former waterfall to reach higher elevations where water temperatures were suitable for over-summering. It has been stated that, "An unknown number of chinook salmon" spawned upstream of the Pardee Dam site in earlier times (FERC 1993). Steelhead were believed to have spawned mostly in the reaches above Pardee Dam (Dunham 1961 unpublished report). Because there are no impassable falls between Pardee and the Electra powerhouse 12 mi upstream, spring-run salmon undoubtedly also reached the latter point. Bald Rock Falls (30 ft high), seven miles beyond Electra, is a complete fish barrier (Woodhull 1946). Native fish species such as hardhead and pikeminnow are known to have reached the falls (Woodhull 1946), so Bald Rock Falls can be reasonably taken as a likely upstream limit for both salmon and steelhead.

The California Fish Commission reported in 1884 that the Mokelumne River was the "only stream emptying into the San Joaquin not dammed" (CFC 1884, p 16). Collins (1892, p 163) also asserted: "Salmon do not run into the San Joaquin in large numbers. In the fall, when the fishery is at its best, fishermen go a few miles up the Mokolumne ...[sic]" Yet, the salmon runs into the Mokelumne River already had been largely eradicated by 1877 due to gold mining activities (CFC 1877, p 5). However much the salmon runs subsequently recovered from the habitat degradation of the gold mining era, the runs were believed to have started another decline after the construction of Woodbridge Dam (15 ft high) in 1910, at the town of Woodbridge (rm 39) (Dunham 1961 unpublished report). Fry (1961, p 64) cited Woodbridge Dam as having been "a serious fish block" for many years, as well as providing "often too little water for the passage of salmon," and he mentioned industrial and mining pollution as having been "very serious" at times. As of 1928 the salmon spawning grounds reportedly extended from the river mouth above tidewater for about 15 mi to above Woodbridge Dam (Clark 1929). There was a small fishway at this dam which had very little water flowing down it during summer and fall (Clark 1929). Clark reported that the Mokelumne River at that time had "only a fall run," "usually quite late." He stated that a "considerable run" migrated upriver each year, although not as large as in former years, and that the flashboards in Woodbridge Dam were taken out in late fall (November) to allow passage of the salmon. Although this is possibly an indication of a late-fall run, it seems more likely that the fish for the most part were a late-running fall run, delayed by the lack of water. The true late-fall

run, as currently recognized (Fisher 1994; Yoshiyama and others 1998), probably would not have been present in the Mokelumne River or other tributaries in significant numbers until December at the earliest. However, the earliest historical references to salmon (noted above) seem to indicate that late-fall run salmon actually occurred in the Mokelumne River at least until the mid-19th century.

Despite Clark's (1929) statement to the contrary, spring-run salmon evidently still entered the lower Mokelumne River during the early 1930s. Salmon and other fish were landed in the small fishing port of Lockeford, about nine miles upstream of Woodbridge. Scofield (1954, p 78) reported that in the period 1931-1935, "an average of 2,000 pounds per year of mixed fish were credited to this town" and that "During May, June and July salmon predominated." The salmon in that season almost certainly would have been spring-run fish. Scofield (1954, p 78) also reported "only the record of 3,800 pounds of salmon in August and September of 1931" associated with the town of Acampo three miles north of Lodi on the east side of the Mokelumne River. If the fall run in this river usually ran late, as Clark (1929) stated for that historical period, then perhaps those salmon recorded in August-September at Acampo were a component of the spring run that had been blocked from ascending farther upstream, presumably by Woodbridge Dam.

The construction of Pardee Dam in 1928 presented an insurmountable obstacle, cutting off the upper spawning areas (Dunham 1961 unpublished report). Hatton (1940) stated that spawning beds on the Mokelumne River occurred in the 22.5 mi between Lockeford Bridge and Pardee Dam. At that time (1939), the irrigation dam at Woodbridge had a fishway but was impassable at times due to "fluctuating water levels," and Hatton was of the opinion that probably most of the migrating spawners did not ascend to the spawning beds until the dam's weir boards were removed, usually "around the first week in November."

Fall-run salmon are now stopped at the lower end of Camanche Reservoir, about nine miles below Pardee Dam. They spawn in the reach from Camanche Dam (rm 64) downstream to Elliott Road (rm 54) (J. Nelson, personal communication, see "Notes"), and 95% of the suitable spawning habitat is within 3.5 miles of Camanche Dam (Reynolds and others 1993). Before the completion of Camanche Reservoir (1964), the fall run also spawned upstream from Camanche Dam to the canyon about three miles below Pardee Dam (Reynolds and others 1993). The Mokelumne River Hatchery, operated by DFG, was built in 1965 as mitigation specifically for that spawning stock component (Reynolds and others 1993; J. Nelson, personal communication, see "Notes").

Fry (1961) reported that counts of fall-run spawners passing Woodbridge Dam ranged from <500 (in two separate years) to 7,000 fish during the period

1945–1958, and there were partial counts of 12,000 fish each in 1941 and 1942 (DFG 1944; Fry 1961). Fry also stated that the spring run appeared to be “practically extinct.” During the period 1940–1990, total annual run sizes ranged between 100 and 15,900 fish (Reynolds and others 1993); the runs averaged 3,300 spawners during 1940–1963 (before impoundment of Camanche Reservoir) and 3,200 spawners during 1964–1990 (post-impoundment) (Reynolds and others 1993). More recent annual run-size estimates for the fall run have been 400 to 3,200 (average about 1,800) total spawners during 1990–1994, increasing to 5,400 to 7,800 fish in 1995–1996 and perhaps 16,700 fish in 1997 (DFG unpublished data). The latter DFG estimate for 1997 may be inflated; a lower escapement of about 10,180 spawners was reported by the East Bay Municipal Utility District (J. Miyamoto, personal communication, see “Notes”). Hatchery returns have composed 14% to 69% of the fall run during the 1990s. Estimated numbers of natural spawners during this period ranged from 180 (in 1991) to 10,160 fish (in 1997), averaging 2,500 fish (DFG unpublished data).

Cosumnes River (El Dorado County). The Cosumnes River, a branch of the Mokelumne River, historically has been an intermittent stream and therefore offered limited access to salmon. Yet, the river derives its name from the Cosumne triblet of the Valley Yokuts – the “People of the Salmon Place” in the language of the neighboring Miwok people (Latta 1977, p 99) – or, alternatively, from Southern-Central Miwok words for salmon (*kos'-sum*, *kos'-sum-mi*) (Powers 1877, p 347; Bennyhoff 1977, p 101). Latta (1977, p 100) noted that the Cosumne village of “*Musu* (moo-soo, probably a variant of *Cosu* and meaning Salmon Place) was...located two miles northeast of present Bruceville” – about nine miles above the mouth of the Cosumnes River.

Only a fall salmon run is definitely known to have occurred in this river. Hallock and Van Woert (1959) reported that the Cosumnes River had a “notoriously late” fall run, probably due to insufficient streamflows until well into the fall rainy season. There is no indication that a spring run ever existed here (J. Nelson, personal communication, see “Notes”) and the atypical streamflow regime and low elevation of the drainage make it unlikely that there was one. There is a 30-foot falls a half mile below Latrobe Highway Bridge which has been viewed as a barrier, and which we take as the historical upstream limit. However, salmon probably did not usually reach that far upriver because of the limited time available for migration in this stream, and most likely only a few fish ascended past Michigan Bar (rm 31). If any fish were able to surmount that obstacle, they undoubtedly were stopped by a second waterfall (50 ft high) 8.5 mi farther upstream at the Highway 49 crossing.

Clark (1929) reported the presence of “a considerable run” (fall run), which he stated to be equal in abundance to that in the Mokelumne River. At that time the spawning grounds extended from the river mouth above tidewater to the

irrigation diversion dam near the town of Sloughhouse, which was a barrier to the salmon. In 1939, the spawning grounds on the Cosumnes River extended along the 15.2 mi stretch from Sloughhouse Bridge up to the falls below Latrobe Highway Bridge (Hatton 1940). Hatton (1940) reported that the best spawning areas were between the Sloughhouse and Bridgehouse bridges; just above Bridgehouse the river passed through a canyon where bedrock largely replaced the gravel beds. At that time (1939), the 18-foot high Bridgehouse Dam was the only permanent dam on the river, having two “apparently satisfactory fishways” but an unscreened diversion. The lower end of the stream was dry during the months when irrigation diversions were taken, but in late fall “a run of undetermined size” took place (Hatton 1940). The fall run presently spawns in the reach from downstream of the Highway 16 crossing (Bridgehouse Bridge) up to the falls below Latrobe Road (J. Nelson, personal communication, see “Notes”). Additional spawning habitat occurs downstream of the Highway 16 crossing to Sloughhouse Bridge, but below that point the substrate is largely sand and unsuitable for spawning (E.R. Gerstung, personal observation). The sole dam in the river—Granlees Diversion Dam (located one mile upstream of the Highway 16 crossing)—presently may pose an obstacle to salmon migration because its fish ladders are sometimes inoperative. The salmon generally cannot ascend the river until late October to November, when adequate flows from rainfall occur (Reynolds and others 1993).

Fry (1961) reported run-size estimates for the fall run of <500 to 5,000 fish for the period 1953–1959. Historically, the run size has averaged about 1,000 fish, but more recent runs, when there was water in the streambed, numbered no more than 100 individuals (Reynolds and others 1993). In many years there has been insufficient streamflow to maintain connection with the San Joaquin River. No salmon have been observed in the Cosumnes River since 1988 (DFG unpublished data).

American River (Sacramento, Placer counties). Spring, fall and possibly late-fall runs of salmon, as well as steelhead, ascended the American River and its branches and were impeded to varying degrees by a number of natural obstacles, at least one which no longer exists. According to a Native American (Nisenan) informant, salmon and steelhead were said to have formerly entered all the small, lower-elevation streams around Auburn (at the juncture of the North and Middle forks) and Colfax (about 16 mi farther up the North Fork) (Wilson 1972). In the North Fork American River, steelhead were observed during DFG surveys in the 1930s at Humbug Bar, above where the North Fork of the North Fork enters (DFG unpublished data); because there are no substantial falls below that point, spring-run salmon no doubt also easily ascended that far. Mumford Bar, about seven miles above Humbug Bar, was one of several salmon fishing spots for the native Nisenan people, at which “salmon [were] taken with bare hands during heavy runs” (Beals 1933, p 347). For the present,

given the lack of more definite information, we take Mumford Bar as the minimal upstream point reached by salmon. However, if the salmon, like steelhead, were able to surmount the waterfall at Mumford Bar, they would have had clear passage about four miles farther upstream to a 10-foot waterfall at Tadpole Creek (2,800 ft elev.), which is too steep for kayakers to boat over (Stanley and Holbek 1984). And if salmon were able to jump that waterfall, their upper limit would have been another seven miles upstream at the 60-foot falls at Royal Gorge (4,000 ft elev.), which likely was the uppermost barrier to steelhead (DFG unpublished data). That uppermost limit would accord with Beals' (1933) general statement that salmon reportedly ranged above the elevational limit of permanent habitation (3,000 to 4,000 ft) of the Nisenan people of the area.

On the Middle Fork American River, falls that had existed before the gold mining era at Murderer's Bar, about three miles above the confluence with the North Fork, obstructed the salmon at least to some degree. The pioneer Myron Angel wrote:

Before the falls at Murderer's Bar was cut down, during spawning time, the salmon would accumulate so thickly in a large pool just below, that they were taken in great numbers by merely attaching large iron hooks to a pole, running it down in the water, and suddenly jerking it up through the mass. And that place was not an exceptional one; it was so at all places where there was any obstruction to free running. During these times, the Indians supplied themselves with fish, which they dried in the sun. (Angel 1882, p 402)

It is likely that the dense aggregations of salmon harvested by the native people below the natural obstacles were more often fall-run fish, impeded by the low fall-season streamflows. The earlier-migrating spring run, ascending mainly during the spring flood flows, would have been able to transcend some of those same obstacles (CFC 1900a, p 25, 1900b, p 13). Spring-run salmon probably were able to ascend the Middle Fork a fair distance due to the absence of natural barriers above Murderer's Bar. In 1938, the spawning area for salmon was reported to extend up the Middle Fork to below the mouth of Volcano Creek (1,300 ft elev.) (Sumner and Smith 1940); salmon likely reached the confluence with the Rubicon River (1,640 ft elev.), which we view as the historical upstream limit. Steelhead were observed in the Rubicon River during the early DFG surveys, but a 15-foot waterfall about four to five miles upstream from the mouth was a likely barrier to them and to any salmon that ascended that far.

In the South Fork American River, a major part of the salmon runs went at least as far as Salmon Falls, and "large quantities" were harvested there in 1850 and 1851 by gold miners and Native Americans (CFC 1875, p 14). As recounted by Special Indian Agent E.A. Stevenson: "...saw them at Salmon

Falls on the American river in the year 1851, and also the Indians taking barrels of these beautiful fish and drying them for winter" (31 December 1853 letter to Superintendent of Indian Affairs T. J. Henley, as cited in Heizer 1993, p 16). The forty-niner Daniel Woods also noted in his journal entry for 4 July 1849, at Salmon Falls: "They [the "Indians"] have brought us in some salmon, one of which weighs twenty-nine pounds. These they spear with great dexterity, and exchange for provisions, or clothing, and ornaments of bright colors" (Woods 1851, p 49). The site of Salmon Falls is now covered by Folsom Reservoir, and there has been disagreement on whether the 20-foot falls originally were a complete barrier to migrating salmon. It seems likely that it was the fall run—egg-laden and migrating during low streamflows—that would have been largely blocked, especially before the major fall rains had swelled the streams (CFC 1900a, p 25). But even the fall run may not have been completely barred by the falls—their dense concentration there and at other places perhaps being bottlenecks where some fraction of the run rested or was stalled until streamflows increased before ascending further. Salmon Falls was blasted sometime near the turn of the century, by one account to create passage for log drives down the river (DFG unpublished notes) and by another to allow the salmon to go farther upstream, but the latter attempt was said to have ended in failure (Cassidy and others 1981). The California Fish Commission reported "the removal of obstructions at Salmon Falls, in the American River" sometime during 1888–1890, for which the State Legislature appropriated \$500 (CFC 1890, p 4). The falls were also later blasted in 1935 by the California Division of Fish and Game "to make them more passable for steelhead trout and salmon" (DFG unpublished notes). However, there is evidence that salmon did in fact ascend the South Fork past Salmon Falls in earlier times, before the attempts to modify the falls. Henry W. Bigler, one of the Mormon workmen at Sutter's Sawmill at Coloma during the fateful winter of 1847–1848, wrote in his diary, "Our grub was mainly unbolted flour, pork, mutton, salmon, peas, tea, coffee and sugar" (Gudde 1962, p 84). Based on a review of that and other documents, Gay (1967, p 138) added: "Beef and beans also formed part of the diet...the pork, mutton and beef was freshly killed on the spot; while the river rewarded anyone who had piscatorial inclinations with a nice catch of salmon." A gold miner's account (Steele 1901, p 275) stated: "In the latter part of August [1852] a band of forty or fifty Indians camped on the opposite bank of the river, spending about two weeks mining and fishing....Here, with long spears, they caught many fine salmon"; the location was "Texas Bar on the south fork of the American River," one-half mile upstream of Chili Bar and "about two miles from Placerville." Also, Voegelin (1942, p 174) reported the following ethnographic information given in 1936 by a 65-year-old Nisenan informant who had lived all her life in the vicinity of Camino (about five miles east of Placerville and due south of present Slab Creek Reservoir on the South Fork): "Salmon obtainable within area, in American River. No salmon caught until certain time in summer; first fish cooked, divided and eaten by all members of community, for 'good luck'." The impli-

cation of the last statement is that those were spring-run salmon which became obtainable as streamflows dropped during the summer; also, there was an annual first salmon ceremony of sorts, indicating that a regular run of salmon in the South Fork American River. Beals (1933, p 347), based upon his ethnographic survey of elder Nisenan informants in 1929, reported that salmon “Ascended S. fork American r. to Strawberry near summit.” However, we view Beals’ statement broadly – that is, that salmon went up to the general area approaching the present town of Strawberry – because it is less specific than other ethnographic references to salmon that we have included. There is a 30-foot waterfall with an incline of 45° (E.R. Gerstung, personal observation) at Eagle Rock, about eight miles downstream of Strawberry, which kayakers portage around (Stanley and Holbek 1984). There are also several steep stretches above Eagle Rock up to Strawberry, and very little suitable habitat (pools and gravel beds), so salmon probably did not ascend past Eagle Rock in significant numbers, if at all. We take the vicinity of Eagle Rock (4,300 ft elev.), therefore, as the most likely upper limit for salmon in the South Fork.

Hydraulic mining during the 1850–1885 period caused the deposition of large quantities of sediments into the American River, as was true for many other Sierra streams. By one estimate, about 257 million cubic yards of gravel, silt, and debris from mining operations were washed into the American River (Gilbert 1917). Again quoting Indian Agent Stevenson (31 December 1853 letter, in Heizer 1993, p 16):

The rivers or tributaries of the Sacramento formerly were clear as crystal and abounded with the finest salmon and other fish.... But the miners have turned the streams from their beds and conveyed the water to the dry diggings and after being used until it is so thick with mud that it will scarcely run it returns to its natural channel and with it the soil from a thousand hills, which has driven almost every kind of fish to seek new places of resort where they can enjoy a purer and more natural element.

According to one gold miner’s account, in the summer of 1851, “Salmon were then caught in the river” at Horseshoe Bar on the North Fork American River about seven miles above the confluence with the South Fork, “and fried salmon was no uncommon dish” (Morgan 1970, p 165). By 1860 a sand bar had formed across the mouth of the American River on the Sacramento River (Reynolds and others 1993). The silting over of the spawning beds in the mainstem and forks due to mining activities nearly exterminated the salmon runs in the American River (Gerstung 1989). Stone (1874, p 176) wrote, “The American Fork was formerly a prolific salmon river, but the mining operations on its banks have rendered it so muddy that the salmon have abandoned it altogether, and none ascend it now.” Similarly, the California Fish Commission reported: “The American is a shallow, muddy stream.... But few fish are found in the lower part of the stream.... This river, prior to placer mining, was

one of the best salmon streams in the State. Of late years no salmon have ascended it" (CFC 1886, p 20).

Somewhat later, the construction of dams that lacked adequate fish passage facilities caused the further diminishment of the runs (Gerstung 1989). The 68-foot high Old Folsom Dam (completed in 1895), 27 mi upstream from the mouth, initially was an impassable barrier to salmon and blocked them from reaching the forks of the American River for about 36 years (Sumner and Smith 1940). A fish ladder was built for Old Folsom Dam in 1919, but Clark (1929) stated that salmon were never known to have passed above it, although steelhead probably did; an effective fish ladder for salmon was later constructed in 1931 (Sumner and Smith 1940). Another potential barrier to salmon was a 16-foot high dam built in 1899 by the North Fork Ditch Company on the North Fork American River near Auburn, a few miles downstream of the confluence with the Middle Fork; a rock chute fishway was provided in 1912, but it allowed difficult passage and few salmon used it (Sumner and Smith 1940). The 140-foot high North Fork Debris Dam (completed in 1939), two miles above the confluence with the Middle Fork, posed yet another impassable barrier and assured the extirpation of the salmon run in the North Fork (Sumner and Smith 1940).

Clark (1929, p 36) stated that the salmon run in the American River had "always been a late-fall migration," although he provided no further details, and also that this river "[had] known great runs." An early gold miner noted salmon migrating up the American River about seven miles east of Sutter's Fort on 1 December 1848, of which "thirty-five splendid salmon" were procured by "well-directed rifle-ball" (Buffum 1959, p 41). Early December coincides with the upriver migration periods of both fall and late-fall runs; however, it is appreciably later than the peak migration presently observed for the Sacramento Valley fall run (September through October) but within the peak migration period for the late-fall run (December) (Fisher 1994). The implication seems to be that a late-fall run occurred in the American River, possibly in substantial numbers. However, it is more likely that the run was a fall run that had a relatively late or extended migration season, combined perhaps with some unknown numbers of true late-fall-run fish. The spring run is known to have entered the American River as early as February, as occurred in 1946 (Gerstung 1971 unpublished report).

Clark (1929) described the 1927-1928 salmon run as "very good" and noted that residents on the river had seen no noticeable decrease in the run size over the previous 20 years, although the run reportedly had been devastated by early mining operations. Spawning occurred from the river mouth to Old Folsom Dam about one mile above the town of Folsom, "a distance of 30 mi of good gravel river." In the 1940s, both the spring and fall runs began to re-establish themselves in the American River above Old Folsom Dam. Counts at

the fishway at Old Folsom Dam showed that the spring run reached a maximum of 1,138 fish in 1944 and the fall run reached 2,246 fish in 1945 (Gerstung 1971 unpublished report). The spring-run count dropped to 42 fish in 1945, 16 in 1946, and three fish in 1947; both the spring and fall runs reportedly were decimated after the fish ladder on Old Folsom Dam was destroyed by flood waters in 1950 (Gerstung 1971 unpublished report). The spring run was finally extirpated during the period of construction of present-day Folsom Dam and Nimbus Dam (the latter completed in 1955) (Gerstung 1971 unpublished report).

Fry (1961, p 64) noted the presence of "a small spring run," at least through 1951, which became mixed with the "much larger fall run" during spawning. Combined run sizes were 6,000 to 39,000 spawners annually during the period 1944–1959, with estimates exceeding 30,000 fish during 1944–1946; these fish comprised mainly the fall run but included "a small but unknown proportion of spring run fish" in the first three years of the period (Fry 1961). During 1944–1955, an estimated average of 26,500 salmon (range 12,000 to 38,652) spawned annually in the mainstem American River below the town of Folsom; about 73% of the spawners used the five-mile stretch between Old Folsom Dam and the present site of Nimbus Dam, and the remainder spawned farther downstream (Gerstung 1971 unpublished report). In recent decades, spawning escapements of the fall run have ranged from about 10,000 to 95,000 fish annually (Gerstung 1989, DFG unpublished data). Spawning escapements were about 10,200 to 75,000 fish (average: 41,000) during 1990–1997, with Nimbus Hatchery accounting for an estimated 9% to 59% of the spawning runs during this period (DFG unpublished data). The fall run formerly spawned not only above the site of Nimbus Dam but above Folsom Dam as well (J. Nelson, personal communication, see "Notes"). Completion of Nimbus Dam is said to have inundated half of the then-existent spawning gravels in the American River (Holmberg 1972). Fall-run salmon presently are limited in their upstream migration by Nimbus Dam and spawn mainly downstream from the dam to just above the Watt Avenue crossing (J. Nelson, personal communication, see "Notes"); the habitat downstream of Watt Avenue presently consists mainly of pools unsuitable for spawning (E.R. Gerstung, personal observation).

Bear River (Placer County). The Bear River, the second largest tributary to the Feather River, historically contained salmon, but evidently only a fall run. The run reportedly was "substantial" (Reynolds and others 1993) but has not occurred in its former numbers for decades (J. Nelson, personal communication, see "Notes"). Adult salmon ascended as far as present day Camp Far West Reservoir, where a waterfall in that vicinity probably barred their further passage. No waterfall exists there now, so it evidently was submerged or built upon during the construction of Camp Far West Reservoir and Dam (J. Hiskox, personal communication, see "Notes"). There are no natural barriers above Camp

Far West Reservoir at least to Rollins Reservoir 24 mi upstream, next to present-day Chicago Park (J. Hiskox, personal communication, see "Notes"). According to one native Nisenan informant who had resided most of her life around Chicago Park, there were no salmon in that area (Voegelin 1942), so the salmon evidently were completely blocked by the waterfall near Camp Far West.

Clark (1929, p 36) stated, erroneously, that the Bear River "has never been known to be a salmon stream," with only an occasional salmon observed there. Clark reported the presence of an impassable dam near the town of Lincoln (which is not on the river but lies about nine miles south of Camp Far West Reservoir). As with other Sierra streams, hydraulic mining activities caused substantial sedimentation problems in the Bear River such that by 1876 its channel had become completely filled (Reynolds and others 1993). According to early historians,

Near Wheatland the river has altered its course for several miles, making a new channel half a mile south of the old bed. The banks of this stream were once twenty-five to thirty feet high. Its channel has been filled up, and the water is so thick and heavy with sediment that in summer there is scarcely any stream at all. From 1866 to 1869, the stream almost ceased to run except on Sundays, the water on other days being used by the miners (Chamberlain and Wells 1879, p 86).

The effect on the salmon runs at that time would have been catastrophic and undoubtedly accounts for the apparent historical scarcity of salmon immediately before Clark's (1929) assessment. Indeed, it was written by early historians:

Bear, Yuba and Feather rivers were full of salmon, and the Indians speared them by the hundred in the clear water. When the river began to be muddy, the fish became scarce. The Indians even then speared them, and although unable to see the fish, they could tell their position with unerring precision by the ripples made in their passage through the water (Chamberlain and Wells 1879, p 15).

The abundance of salmon in the Bear River long ago was also attested in an old newspaper account (Marysville Daily Appeal, 24 July 1889):

J. M. C. Jasper, of Wheatland, says that the generation now growing up in that vicinity are altogether too incredulous, because they wont [sic] believe that thirty years ago he used to stand on the banks of Bear river and with a pitchfork catch salmon weighing thirty pounds and over, to feed to the hogs. Many other old-timers tell the same thing.

And, according to the California Fish Commission, "It is the testimony of all the pioneer miners that every tributary of the Sacramento, at the commencement of mining, was, in the season, filled with this fish, ...A few salmon continued to enter the Feather, Yuba, Bear, and American Rivers until the floods of the Winter of 1860-1, which covered the gravel bottoms of all those streams with mining sediment..." (CFC 1880, p 3). The change in the Bear River was so profound that the Commission would later write, "Bear has lost all claim to the name of river... It never was noted as a fish stream, although a few salmon and perch were taken from its waters in early days" (CFC 1886, p 20).

Within the present decade or so, the fall run has occurred only occasionally, when heavy rains and dam spillage provide adequate flows (Reynolds and others 1993). At those times, the run may number in the "hundreds" (Reynolds and others 1993). The spawning distribution has its upper limit at the South Sutter Irrigation District (SSID) diversion dam, 15 mi above the confluence with the Feather River and 0.5 mi below Camp Far West Reservoir. The spawning areas extend from the SSID dam downstream about six miles to a point near Highway 65, although there are additional spawning gravels extending four to five miles farther downstream to Pleasant Grove Road (J. Nelson, personal communication, see "Notes"). There is no suitable upstream holding habitat for spring-run salmon in the Bear River (J. Nelson, personal communication, see "Notes").

Yuba River (Yuba County). Both spring and fall runs originally occurred in the Yuba River. A pioneer missionary's wife, writing of the Marysville area in 1851, noted:

The rivers abound in excellent salmon, which the Indians spear in great numbers, and dispose of in the towns. They are the finest I ever tasted. Some of them are three and four feet long, and weigh fifty pounds or more. It is amusing to see the Indians spearing them.... Their aim is unerring (Bates 1857, p 156).

In the North Fork Yuba River, salmon were caught by PG&E workers in the Bullards Bar area during the 1898-1911 period of operation of the Yuba Powerhouse Project; the ditch tenders at the diversion dam "would nail two or three salmon on boards, place them body down in the ice-cold ditch stream, and ten hours later the night's dinner would come floating down" to the powerhouse on the valley floor (Coleman 1952, p 139). In later years, the salmon ascended in "considerable numbers" up to Bullards Bar Dam during its period of construction (1921-1924) - "so many salmon congregated and died below it that they had to be burned" (Sumner and Smith 1940, p 8). There are no natural barriers above the Bullards Bar Dam site, so salmon presumably had been able to ascend a considerable distance up the North Fork. There is photographic evidence of steelhead (called "salmon-trout" in early writings)

occurring farther upstream at Downieville at the mouth of the Downie River (DFG file records). In their historical account of Sierra County, Fariss and Smith (1882, p 422) related the following episode from 1849: "While encamped on Jersey flat Jim Crow one day killed with a small crow bar a salmon-trout which weighed fourteen pounds. It was boiled in the camp kettle ... afterwards gold was found in the bottom of the kettle." Jersey Flat (formerly Mur-raysville) was located across the river from Downieville (Fariss and Smith 1882). That incident may have been a reference to salmon because the latest spring-run spawners possibly were present at that date (shortly after October 5). Also, native Central Valley steelhead typically weighed three to eight pounds and rarely exceeded 13 lbs (Eigenmann 1890; Hallock and others 1957, 1961), at least in the present century, although steelhead in coastal streams may reach about 20 lbs (Hubbs 1946; Barnhart 1986). On the other hand, the term "salmon-trout" suggests the fish was distinguished from salmon so it could have been an uncommonly large steelhead, possibly of a now extinct summer run. In fact, there is evidence that "summer" steelhead formerly occurred in parts of the Sacramento River system as late as the 1930s and 1940s (Needham and others 1941; McEwan and Jackson 1996), and a few large steelhead (for example, up to 15.5 lbs) were observed in a DFG study of Sacramento River steelhead during the 1950s (Hallock and others 1961). Referring to the salmon runs in 1850 and 1851, the California Fish Commission (CFC 1875, p 14) stated that "large quantities were taken by the miners and by Indians ... as far up as Downieville on the Yuba," and at other points on the American and Feather rivers. There are no natural obstructions from Downieville upstream to Sierra City, where Salmon Creek enters, so spring-run salmon and steelhead most likely were able to traverse that distance. Deep pools are present throughout the North Fork Yuba River from its mouth up to Sierra City (E.R. Gerstung, personal observation) and would have provided prime holding habitat for spring-run salmon. Spring-run salmon and steelhead probably ascended the higher-gradient reaches up to about two miles above the juncture of Salmon Creek and their absolute upstream limit on the North Fork would have been Loves Falls.

In the Middle Fork Yuba River, there are no significant natural obstructions except for a 10-foot falls in the lower reach, and salmon possibly had access to a considerable portion of the Middle Fork. Both salmon and steelhead were observed in the lower part of the Middle Fork, near where the North Fork joins, during a DFG survey in 1938 (DFG unpublished data). Steelhead were found as far upstream as the mouth of Bloody Run Creek (DFG unpublished data). Whether salmon also reached that far remains conjectural, although it is likely that salmon ascended some unknown distance up the Middle Fork because other native fishes such as pikeminnow have been observed as far upstream as Box Canyon, several miles below Milton Reservoir (R. Cutter, personal communication to E.R. Gerstung, see "Notes"). However, direct information is lacking and it is uncertain if many salmon were able to sur-

mount the 10-foot falls on the lower river; therefore, we conservatively consider the falls 1.5 mi above the mouth as the effective upstream limit of salmon in the Middle Fork. Similarly, little is known of the original distribution of salmon in the South Fork Yuba River—the salmon population was severely depressed and access up the stream long since obstructed by dams by the time the DFG surveys were conducted in the 1930s. There are records of salmon occurring within one to two miles upstream of the mouth of the South Fork Yuba River (DFG unpublished data). A substantial cascade with at least a 12-foot drop, located one-half mile below the juncture of Humbug Creek (CRA 1972; Stanley and Holbek 1984), may have posed a significant obstruction to salmon migration, but it was not necessarily a complete barrier. This cascade, or “step-falls,” is similar in dimensions and conformation to cascades on other streams, which salmon are known to have surmounted (P. Lickwar, personal communication, see “Notes”). However, we presently take that cascade below Humbug Creek as essentially the historical upstream limit of salmon during most years of natural streamflows. Steelhead are known to have ascended the South Fork as far as the juncture of Poorman Creek near the present town of Washington (DFG unpublished data), and perhaps some spring-run salmon historically also reached that point. Among the tributary streams of the lower Yuba River, salmon and steelhead were observed to ascend Dry Creek at least five to six miles in past decades (for example, in the 1960s; E.R. Gerstung, personal observation), and they occasionally still do when streamflows are high. Steelhead also went up Deer Creek a quarter of a mile where they were stopped by impassable falls (E.R. Gerstung, personal observation), but we have no records of salmon in that stream.

The Yuba River, along with the Feather and Bear rivers, sustained some of the most intensive hydraulic mining carried out during the gold mining years (1853–1885) (Kelley 1989; Reynolds and others 1993), and the effects on the salmon runs were undoubtedly severe. The Yuba in its pristine state, in 1849, was described by a forty-niner thusly:

Juba River is a fine stream, deep enough for navigable purposes for a considerable distance up its course to where it widens out at the ford, passing over a broad, level, gravell bed. Its waters in the stream appear of a greenish hue, but when taken into a glass are perfectly colourless, clear, and well-tasted (Kelly 1950, p 50).

With banks rising about fifteen to twenty feet above the original channel at low water, the Yuba River was rapidly degraded by the immense influx of hydraulic mining debris. In March 1860, the Marysville Appeal remarked that the “yellow Yuba...that turgid vehicle of sediment takes a vulgar pride in spreading out its dirty face” (Kelley 1989, p 69). The great flood of 1861–1862 buried much of the “lower” bottomlands along the Yuba under sand deposits averaging two to seven feet deep (Kelley 1989). By 1876 the channel of the

Yuba River reportedly had become completely filled, and what remained of the adjoining agricultural lands was covered with sand and gravel (Kelley 1989; Reynolds and others 1993)—a marked deterioration of the river as salmon habitat. Chamberlain and Wells (1879, p 86) wrote:

At Timbuctoo ravine it is claimed that the Yuba river has been filled with a deposit, eighty feet in depth.... At Marysville, the depth of the deposit is about twenty-two feet. At a point, in front of the city, the river was considerably deeper than at any point above or below; this has been filled up to the regular line of the bottom, the deposit being over thirty feet in thickness. The bottomlands along the Yuba and Bear rivers have been covered to a depth of five to ten feet, extending, in some places, one and one-half miles back from the streams.

It was estimated that during the period 1849–1909, 684 million cubic yards of gravel and debris due to hydraulic mining were washed into the Yuba River system (Gilbert 1917)—more than triple the volume of earth excavated during construction of the Panama Canal. The California Fish Commission described the Yuba River as “a shallow stream, except during the rainy season ... and its water is muddy” due to the mining that was still being carried on along the river (CFC 1886, p 20).

Clark (1929) reported that the salmon spawning grounds extended from the river mouth up to the town of Smartsville, but that very few salmon (evidently spring run) went past that point farther upstream. As of 1928, there was the “Government barrier” dam (Daguerre Point Dam) near the town of Hammond below Smartsville which served to catch sediments washed down the river from mining and dredging operations farther upriver. Although fishways had been provided at this dam, they were destroyed by floods in winter 1927–1928, but in any event few salmon reportedly went farther upriver to spawn (Clark 1929). Daguerre Point Dam (15 ft high), located about 11 mi east of Marysville on the valley floor (at 120 ft elev.), was said to have “almost completely blocked king salmon runs since its construction in 1910” (Sumner and Smith 1940, p 7); but salmon did surmount that dam in occasional years because they were observed in large numbers in the North Fork Yuba River during the early 1920s at Bullards Bar. Before the construction of Daguerre Point Dam, “heavy runs of salmon” reportedly occurred in Dry Creek and Deer Creek upstream of the dam site, but “few, if any,” were present in 1938 (Sumner and Smith 1940, p 8). An even earlier structure, Barrier No. 1 (built in 1904–1905), was 4.5 mi above the later site of Daguerre Point Dam and probably hindered salmon until floods destroyed it in 1907 (Sumner and Smith 1940). Clark (1929) also reported that located on the South Fork Yuba north of Nevada City was Edison Dam, a power project dam that had a “good fish ladder and screens.” There evidently were other dams on the Yuba River which were washed out or damaged during the winter of 1927–1928. Fry (1961, p 63)

later stated that the Yuba River “was seriously handicapped” for many years by a diversion dam (evidently Daguerre Point Dam) which lacked a functional fish ladder and below which there “was often very little water.” Although adequate fish ladders were later provided about 1950–1952 (DFG 1953), the low-water conditions remained as of 1959 (Fry 1961). Construction of Englebright Dam 12.5 mi farther upstream (282 ft elev.) in the late 1930s eliminated much spring-run salmon habitat and “severely reduced the spring run” (DFG 1990). Englebright Dam presently is the upstream limit of salmon distribution. Although most of the salmon spawning habitat occurs in the 7.8 miles of river on the open valley floodplain downstream of Daguerre Point Dam (Reynolds and others 1993), the greater part of the run now generally spawns above Daguerre Point (J. Nelson, personal communication, see “Notes”). The fall run previously spawned in the entire stretch from Englebright Dam downstream to Simpson Lane (Marysville), below which the substrate is too sandy (J. Nelson, personal communication, see “Notes”). The spring run, when the fish were common in the recent past, spawned in the area between Englebright Dam and Highway 20 (J. Nelson, personal communication, see “Notes”).

Salmon originally migrated into the Yuba River in large numbers to spawn. The California Fish Commission reported that in 1850 “the salmon resorted in vast numbers to the Feather, Yuba, American, Mokolumne [sic], and Tuolumne Rivers,” and on the Yuba River as late as 1853 “the miners obtained a large supply of food from this source”; however, by 1876 the salmon no longer entered those streams (CFC 1877, p 5). At the time of Clark’s survey in 1927–1928, a fall run occurred in late fall and there was an occasional, “slight” spring run. Clark (1929, p 37) stated that “very little could be learned” about past salmon abundances in this river, but at that time (1928) the salmon (essentially the fall run) were “holding their own and not decreasing.” By the late 1950s, Fry (1961, p 63) noted that the spring salmon run had “virtually disappeared.” A remnant spring run managed to persist at least up to 1995 in “minimal numbers” (J. Nelson, personal communication, see “Notes”), but the run has been genetically mixed with the fall run due to spatial overlap of their spawning areas, as is the case also in the Feather and American rivers (J. Nelson, personal communication, see “Notes”). Fry (1961) reported fall-run spawning escapements of 1,000 to 10,000 fish during 1953–1959. The assessment by the California Department of Fish and Game (Reynolds and others 1993) was that the Yuba River “historically supported up to 15% of the annual run of fall-run chinook salmon in the Sacramento River system.” Fall-run escapements during the period 1953–1989 ranged within 1,000 to 39,000 fish and averaged 13,050 annually (Reynolds and others 1993). More recently (1990–1997), fall-run estimates have varied from 5,900 to 25,800 spawners annually (DFG unpublished data).

Feather River (Yuba, Butte, Plumas counties). The Feather River, noted by one early traveler in 1843 as “tributary to the Sacramento and still richer in salmon” (Van Sicklen 1945), was renowned as one of the major salmon-producing streams of the Sacramento Valley. California Fish Commissioner R.H. Buckingham wrote in the *Sacramento Bee* (31 December 1885), “In years gone by, some of the fishermen of Sacramento would ascend the Feather river as far as Yuba City, to fish for salmon, which were very plentiful at times, Indians catching as many as two hundred in a single night with spears.” Regarding the native fishing for salmon, an early historical account stated,

The Feather River was partially closed by piles extending nearly to the middle of the stream. These piles were interwoven with brush so as to prevent the passage of the fish. They were thus compelled to pass through the opening, where the Indians on platforms, captured them with their spears in their ascent of the stream (Chamberlain and Wells 1879, p 15).

Salmon originally ascended a considerable distance into the Feather River system, particularly the spring run which spawned in the higher streams and headwaters. They went up the West Branch at least to the site of Stirling City (F. Meyer, personal communication, see “Notes”), and also up along the entire length of the North Fork Feather River through the area now covered by Lake Almanor and into the surrounding tributary streams (>4,200 ft elev.). Early correspondence sent to the DFG state that large numbers of spring-run fish (“in the thousands”) entered the North Fork, most of which were stopped by Salmon Falls (about ten feet high) approximately 2 to 2.5 miles above the town of Seneca (DFG letters no. 1, no. 2). One writer stated, “There was an old indian couple known as Caribou Bill and his wife who used to net them at the Falls, smoking and drying them for use during the winter.... The spring run usually reached the Falls about the first of July” (DFG letter no. 1). A few fish were able to surmount the falls and proceed farther upstream to the area of present Lake Almanor (DFG letter no. 1). Flows from the many springs that fed the Lake Almanor area (formerly “Big Meadows”), together with streamflows from farther up the North Fork, undoubtedly were sufficient for salmon to have ascended through the lakebed area and up the North Fork another six miles or more (J. Nelson, personal communication, see “Notes”). In a newspaper article more than a century ago, a Dr. J.H.C. Bonte wrote of salmon angling: “They are caught with hook and bait now along the Sacramento river above Knight’s Landing, and in the Feather river not far below Lassen’s peak.... Young salmon are frequently caught in Big Meadows, Plumas county, and older ones weighing eight and ten pounds, are also taken though not very often” (*Sacramento Union*, 24 December 1881).

Judging from streamflows that occur in the Hamilton Branch of the North Fork above Lake Almanor, salmon most likely ascended that branch for several miles, possibly to within a very short distance of present-day Mountain

Meadows Reservoir (J. Nelson, personal communication, see "Notes"). Spring-run salmon are also said to have ascended Indian Creek, a tributary of the East Branch of the North Fork (DFG letter no. 2), at least as far as Indian Falls (near the junction of Highways 89 and 70). They concentrated and were harvested there by Native Americans, although the falls were not necessarily their upper limit in that stream (J. Nelson, personal communication, see "Notes"). In reference to two North Fork tributaries, Hanson and others (1940) stated that the quality of spawning habitat was good in Yellow Creek and excellent in Spanish Creek (a tributary of the East Branch of the North Fork), although by that time salmon reportedly were blocked farther downstream by a diversion dam. The previous distribution of salmon in those two streams is unknown, but Yellow Creek probably was used at least to some extent. A substantial waterfall occurs above the mouth of Spanish Creek (R. Flint, personal communication, see "Notes") and possibly barred salmon from ascending any appreciable distance, although DFG correspondence indicates salmon may have entered "Clear Creek" (a tributary of Spanish Creek) for spawning (DFG letter no. 2).

In the Middle Fork Feather River, the salmon were stopped near Bald Rock Dome shortly above Lake Oroville by Bald Rock Falls (18 ft high) and Curtain Falls (30 ft) immediately upstream. Spring-run salmon were observed spawning below Bald Rock Falls in the 1960s before Oroville Dam was built, and sport fishermen often caught large numbers of salmon from the pool below the falls (E.R. Gerstung, personal observation). Testimonies of Native American (Concow Maidu) residents also identify the waterfall below Bald Rock Dome as having "marked the upper limits of salmon migration" which "made it a desirable fishing spot for the Indians" during earlier times (Jewell 1987, p 19). In Fall River, a tributary of the Middle Fork, the 640-foot Feather Falls about one mile above the mouth certainly was a barrier.

The South Fork Feather River, according to Hanson and others (1940), had "much more spawning gravel per mile of stream than either the Middle or North Fork," but at that time nearly all of the streamflow was diverted for irrigation into the Forbestown and Palermo canals. Before the diversion of the stream, spring-run salmon may have ascended to the vicinity of Forbestown, near the present upper limit of the South Fork arm of Lake Oroville.

Clark (1929) reported both spring and fall runs present in the Feather River. The main spawning beds extended for 30 mi from the river mouth up to Oroville. At that time (1928), the spring-run fish evidently still went up all four branches above Oroville, which were all suitable as spawning habitat, up to points where they were blocked by dams. Several dams in the Feather River drainage presented obstacles to salmon in 1928. The Sutter-Butte Dam six miles below Oroville was a five-foot high irrigation diversion dam with a reportedly ineffective fishway and lacking fish screens on the intake ditches,

although the salmon nonetheless surmounted it (Clark 1929). Miocene Dam near the town of Magalia on the West Fork was 12.5 ft high power project with no fishway or fish screens. Stirling City Dam, also on the West Fork, was eight feet high and supplied a powerhouse; it had a fish ladder but Clark stated that salmon never reached this far upriver. On the North Fork was the Great Western Power Company dam equipped with a fish ladder, although water diversions to the powerhouse dried up the river for "a number of miles" when streamflow was low (Clark 1929). Clark was not aware of any barriers to salmon on the Middle Fork Feather River, but he noted that the South Fork had two irrigation diversion dams: Dam No. 1 on Lost Creek, which took "nearly all the water from the South Fork during the summer months," and Dam No. 2 located on the main fork and lacking a fishway.

Clark (1929, p 38) stated: "The runs of salmon, both spring and fall, used to be very heavy in the Feather River previous to the building of obstructions. It is true that the mining operations in the early years may have reduced the amount of fish somewhat, but the building of dams has almost destroyed the spring run." However, the effect of early mining operations on salmon habitat, while not quantifiable, nonetheless was undeniably substantial during their heyday. The California Fish Commission noted that mining sediments which washed into the Feather, Yuba and American rivers during the winter floods of 1860–1861 smothered the spawning grounds of the few salmon returning to those streams up to that time (CFC 1880). John Muir (1938, p 244), referring to the turbidity of the Sacramento River in October 1877, stated, "...the Sacramento is clear above the confluence of the Feather." Somewhat earlier, Stone (1874) noted that poor water quality resulting from intense mining activity was the reason for the absence of salmon from the Feather, Yuba, and American rivers. A decade later, Stone (1883a, p 221) again observed:

...the Feather River, the Yuba, the American Fork, have long ago been completely ruined as spawning grounds, in consequence of the immense deposit of mud in them, caused by the hydraulic mining operations on these rivers. Not a salmon ever enters these streams now. Except possibly at a time of very high water, these streams are so thick with mud that it would kill any fish attempting to ascend them.

A graphic account was given by Chamberlain and Wells (1879, p 85):

A detailed statement of the loss by mining debris it is impossible to make, but its ravages can be seen on every hand. The surface of the country has undergone a change; the streams diverted from their obstructed channels, have been compelled to seek new courses and outlets for their mud-burdened waters. The banks of Feather, Yuba, and Bear rivers, were, formerly, several feet above the ordinary level of the water, and the steamers and sailing vessels were enabled to make easy and convenient landings. The streams were as clear as crystal, at

all seasons of the year, and thousands of salmon and other fishes sported in the rippling waters, their capture being a favorite amusement of both the white man and the native. But now the channels have become choked with sediment, the waters heavy and black with its burden of mud, and the fish been compelled to seek other localities... The bed of the Feather river, from Oroville to the mouth of Yuba river has been raised six or eight feet.

Even two decades later Rutter (1904, p 71) would write: "The water of the upper part of the Sacramento River and the upper tributaries is quite clear, and continues so until the mouth of the Feather River is reached, from which point to the mouth it is very muddy. It is in the muddy water between the mouth of Feather River and Vallejo that the salmon for the markets are taken." An estimated minimum of 40 million cubic yards of mining debris from the lower river and up to 186 million cubic yards from the entire watershed were produced in the Feather River basin during the period of hydraulic mining before 1909 (Gilbert 1917).

Clark (1929, p 38) described the fall salmon run as "large, although not extremely abundant" and having "fallen off in the last few years" and suggested that the populations showed a three- or four-year cycle, based on statements by river residents. Fry (1961) reported run-size estimates for the fall run of 10,000 to 86,000 fish during the period 1940–1959, and about 1,000 to 4,000 fish for the spring run. The fall run spawned mainly in the mainstem, while most of the spring run spawned in the Middle Fork, with a few spring run entering the North Fork, South Fork and West Branch (Fry 1961). Just before the completion of Oroville Dam (in 1967), a small naturally-spawning spring run still existed in the Feather River, but the Oroville project cut off all the original spring-run habitat (Reynolds and others 1993). Currently, the fall run has its upstream limit at Oroville Dam fish barrier, spawning from there downstream to a point about two miles above the Gridley Road crossing (J. Nelson, personal communication, see "Notes"). There is also a hatchery-sustained population of "spring-run" fish that has been genetically mixed with the fall run (Fisher 1994; DFG 1998) and which spawns in the one-half-mile stretch between the fish barrier immediately below Oroville Dam and downstream to Highway 7 (J. Nelson, personal communication, see "Notes"). The hybrid spring-run fish hold over the summer in deep pools within the so-called "low-flow" section of the river between Thermalito Diversion Dam (five miles below Oroville Dam) and the downstream Thermalito Afterbay Outlet (Reynolds and others 1993). They are spawned artificially in the Feather River Hatchery and also spawn naturally in the river during late September to late October (Reynolds and others 1993). The "spring run" thus overlaps temporally as well as spatially with the fall run—which is the cause of the hybridization between the runs. The hybrids consistently enter the hatchery as the early component of the spawning run, but infusion of fall-run genetic material into the hybrid population by artificial hatchery selection

continues to dilute the genetic integrity of the putative (hybrid) spring-run fish (F.W. Fisher unpublished data).

The Feather River Hatchery, located at the town of Oroville, was built by the California Department of Water Resources to mitigate for the loss of upstream spawning habitat of salmon and steelhead due to the building of Oroville Dam (Reynolds and others 1993). The California Department of Fish and Game began operating the hatchery in 1967 (Reynolds and others 1993). The Feather River Hatchery presently is the only source of eggs from "spring-run" chinook salmon in the Central Valley and is viewed as a key component in plans for restoration of spring-run populations (Reynolds and others 1993). Population estimates for the period 1982-1991 indicated an average of 2,800 "spring-run" fish, compared to the average of 1,700 fish before the construction of Oroville Dam (Reynolds and others 1993). The hybrid spring-run stock increased since the early 1980s and numbered >5,000 fish in 1989 (Campbell and Moyle 1991; DFG 1998). More recently (1990-1996), the spring run has ranged between 1,500 and 6,000 fish (average: 3,800; DFG 1998). The increase in numbers is attributed to the consistent supply of cold water to both the hatchery and "low-flow" section of the river (Reynolds and others 1993) but probably also reflects the extension of the seasonal period ("perhaps arbitrarily") in which spawners entering the Feather River Hatchery are defined as spring-run fish (DFG 1998, p VII-6). See Hedgcock and others (this volume) for a discussion of the genetic attributes of Feather River spring run.

Fall-run salmon also increased after completion of the Oroville Dam complex in 1968, averaging 39,100 spawners before the project and 51,400 fish afterwards (Reynolds and others 1993). In addition, anglers are estimated to have harvested 10,000 fish (spring and fall runs combined) each year in the ten-year period before 1993 (Reynolds and others 1993). Fall-run escapements more recently (1991-1997) have averaged 53,600 fish annually (range: 32,200 to 71,800), including both hatchery and natural spawners, compared to an annual average of 51,200 fish (range: 30,500 to 77,800) during the 1980s (DFG unpublished data). The hatchery component of the fall spawning escapements composed 13% to 41% of the annual runs during 1991-1997 (DFG unpublished data). The fall run may be considered to be genetically introgressed by hybridization with the spring run due to hatchery practices (DFG 1998).

The DFG attempted to introduce a late-fall run into the Feather River in the fall of 1970 by planting over one million eyed eggs from Coleman National Fish Hatchery (DFG 1974). The Feather River Hatchery received returning age-3 and age-4 adults for two generations following the plant, during 1973-1978, but this introduced run failed to persist.

Butte Creek (Butte County). Butte Creek, described by John C. Frémont (1848, p 21) as "a beautiful stream of clear water about fifty yards wide, with a bold current

running all the year," historically supported spring and fall salmon runs and evidently a late-fall run (Hallock and Van Woert 1959). The spring run probably ascended at least as far as the present vicinity of Centerville Head Dam near DeSabra, which we consider here as the upstream limit. Pacific Gas & Electric Company employees at one time had reported salmonids migrating past the site to areas upstream (J. Nelson, personal communication, see "Notes"), but it is not known how much farther upstream they went, or whether they were salmon or steelhead. A waterfall (25+ ft high) about one-half to one mile below Centerville Head Dam previously had been viewed as a barrier to salmon migration, but the presence of one salmon carcass above the waterfall during a DFG spawning survey in early 1995 (J. Nelson, personal communication, see "Notes") indicates that some portion of the spring run historically ascended above the waterfall. Steelhead are believed to have ascended as far upstream as Butte Meadows (Flint and Meyer, 1977 unpublished report), but salmon most likely did not reach that far (J. Nelson, personal communication, see "Notes").

Clark (1929, p 38) described Butte Creek has having been known as "a very fine salmon stream" and "a good spawning ground." He stated that there was only a fall run present, "as the water is very low and warm in the summer." At that time (1928) so much water was being diverted from the stream during most of the summer and fall that the fall run was stated by Clark to have been "almost destroyed." However, it appears that Clark did not fully recognize that the flow conditions he observed in the summer and fall, while detrimental to the fall run or to any salmon that might be present in the lower creek, did not preclude the existence of the spring run. Spring-run fish, migrating during the time of high flows, would have been well upstream during the summer-fall period when Clark evidently made his observations. Flint and Meyer (1977 unpublished report) stated that the spring run "historically provided a good fishery in Butte Creek"; they also mentioned the presence of a late-fall run which "migrates up Butte Creek in January and February and spawns immediately after arriving at the spawning beds."

Clark (1929) reported the presence of two duck club weirs and three irrigation dams on the creek, but all were low enough to be surmounted by salmon if there was enough water. Clark specifically mentioned a drainage canal ("833") which carried "considerable water" and in which adult salmon became stranded, to "die in the mud." There were a few spawning beds in the lower creek, but he noted that the few fish that entered the creek spawned in the upper reaches, if they were able to surmount the irrigation dams and ditches. As late as 1958-1960, adult spring-run salmon in Butte Creek were being lost to unscreened irrigation diversions (DFG 1960). In recent years there have been as many as ten diversion dams on Butte Creek above Butte Slough that divert water for various uses (for example, power generation, irrigation, domestic supply) and all impair salmon migration, in some cases by

dewatering sections of the stream (Reynolds and others 1993). However, several dams have been dismantled or are scheduled for removal from Butte Creek to aid in wildlife and fisheries restoration (Sacramento Bee, 5 November 1997). These barriers have affected the upstream migration of the different salmon runs to different degrees because of seasonal variation in streamflows; for example, fall-run fish are most affected, having to migrate when flows are inadequate to allow passage over the barriers.

Hanson and others (1940, p 78) stated that Butte Creek was "a very fine salmon stream in the past" but was no longer suitable for salmon due to extensive mining and hydroelectric development that had occurred in the watershed. Yet, Hallock and Van Woert (1959, p 260) reported the presence of "an early spring run," a fall run, and the "remnants of a late fall run" in Butte Creek during the mid-1950s. In reference to the fall run, they noted that "occasionally considerable numbers of fish" surmounted the numerous diversions on the lower creek to reach the spawning beds (Hallock and Van Woert 1959, p 260). Fry (1961) shortly thereafter noted that Butte Creek had a spring run but "almost no fall run," thus setting it apart from most small streams in the northern Sacramento Valley which had mainly, or only, a fall run. The many removable dams on the creek blocked or reduced flows late into the fall, and the fall run could not surmount them. Fry (1961) reported that the spring run ranged from <500 to 3,000 fish during 1953–1959. During the 1960s, the spring run at times numbered >4,000 fish in Butte Creek (DFG 1998), with smaller numbers of fall-run and late-fall-run fish (Reynolds and others 1993). More recently, estimated spring-run numbers were 100 to 700 fish during the 1990s and rose to 7,500 fish in 1995 and 20,000 fish in 1998 (DFG 1998 unpublished data). The source of the surprisingly numerous spring-run spawners that entered Butte Creek in 1998 is not known, but they presumably were largely due to the strong escapement in 1995. The Butte Creek fall run remains small, numbering "a few fish to as many as 1,000" (Reynolds and others 1993, p VII-42), because of the very low late-summer and fall flows (F.W. Fisher, personal observation). There are also late-fall-run salmon in Butte Creek, but their numbers are unknown (Reynolds and others 1993).

The fall-run salmon generally spawn below the Parrott-Phelan Dam (J. Nelson, personal communication, see "Notes"). The spring-run fish in Butte Creek, unlike spring runs in other streams, presently spawn in the lower part of the creek at relatively low elevation (about 1,000 ft), where they are blocked by the Centerville Head Dam. However, the water there is unusually cold, comparable in temperature to that typically found at about 2,000-foot elevation (F. W. Fisher unpublished data). Although spring-run adults in Butte Creek migrate and spawn at the same times as spring-run fish in other streams, it appears to be a somewhat different "breed" in that the fry emerge in December; some of these fry migrate out immediately while others migrate out in the spring (Reynolds and others 1993), and the remaining fraction

remains in the stream until the following fall (one year after they had been spawned) (F.W. Fisher, personal observation). This is in contrast to the pattern seen in streams where spring-run fish spawn in the colder, high-elevation reaches (Mill and Deer creeks). There the fry do not emerge from the gravel until March, and they remain in the streams over the summer to migrate out in September and October (F. W. Fisher unpublished data). Spring-run adults are present in Butte Creek in early February, March, and April, in contrast to Feather River "spring-run" fish (that is, spring-fall hybrids), which do not enter that river until May or June.

Big Chico Creek (Butte County). Big Chico Creek contains marginally suitable habitat for salmon and probably was opportunistically used in the past. Spring, fall and late-fall runs have occurred in this creek (Reynolds and others 1993). In apparent reference to the fall run, Mrs. Annie Bidwell, wife of the pioneer John Bidwell, noted: "In the fall of the year the first run (being the fish in the streams after the first rains) of salmon were considered the best, as later in the season they had more or less germs in them and were consequently not so good to eat" (Bidwell 1980, p 56).

Fry (1961) gave estimates of 50 fall-run (including late-fall-run) fish in 1957, 1,000 spring-run fish in 1958, and 200 spring-run in 1959. Fry (1961) also reported that a barrier had been removed from the creek in summer 1958, thus providing an additional nine miles of habitat for salmon up to Higgins Hole (a deep pool), above which is another natural barrier (Outdoor California 1958; Travanti 1990). The lower barrier—a 14-foot falls in the Iron Canyon area created by rock-slide debris around the time of the 1906 San Francisco earthquake—blocked upstream access for what had previously been a "sizable" salmon run (Outdoor California 1958). The present distribution of salmon in Big Chico Creek thus is probably not much different from what it had been originally. The spring run has been able to ascend farther upstream during spring flows than is reached by the fall run, and thus is both spatially and temporally isolated from the fall run, as is true in some other streams. The current upper limit of the spring run and steelhead is essentially Higgins Hole, about one-half to one mile above the crossing of Ponderosa Way, although with high enough streamflows the fish can ascend a half mile farther upstream (J. Nelson, personal communication, see "Notes"). The fall run typically spawns below the Iron Canyon Fish Ladder in Bidwell Park, in the lower one-third or one-fourth of the creek (J. Nelson, personal communication, see "Notes").

The average annual run size of the spring-run is believed to have been <500 fish during the 1950s to 1960s and more recently has been considered to be only a remnant (Reynolds and others 1993). Big Chico Creek has been heavily planted with Feather River "spring-run" fish, which evidently had been genetically mixed with fall-run fish. In the last decade or so, very few, if any,

of these hybrid spring-run spawners have returned to the creek (F. W. Fisher unpublished data). During the 1990s, estimated spring-run escapements have ranged from zero to 200 fish, averaging 35 fish (DFG 1998). The Iron Canyon fish ladder was damaged by high flows during the winter of 1994–1995, thereby blocking the spring salmon run in 1995. In that year, about 100 salmon were captured below the obstruction and transported farther upstream and another 100 salmon were observed in the stream (J. Nelson, personal communication, see “Notes”; DFG 1998). A relatively large spring-run escapement (about 400 fish) was observed in 1998 (DFG unpublished data), but the source of these fish is unknown. The fall and late-fall runs in recent times have been highly variable, and the fall run occurs in very low numbers due to lack of water in late summer and fall (Reynolds and others 1993). Intensive pumping of water from lower Big Chico Creek for irrigation takes a heavy toll of young salmon migrating downstream and juveniles that enter the stream for rearing, except during very high streamflow conditions (Reynolds and others 1993; USFWS 1995).

Deer Creek (Tehama County). Both spring- and fall-run salmon occurred in Deer Creek, which is a cold, spring-fed stream. The Yahi branch of the Yana people occupied both the Deer and Mill creek drainages, and for whom salmon and other fishes were an important secondary food source (Johnson 1978). The celebrated Ishi, last of the Yahi, demonstrated to anthropologists the Yahi methods of procuring fish, and he was said to have “used a salmon spear most expertly” (Pope 1918, p 199).

Before the 1940s, the spring-run salmon ascended Deer Creek for about 40 miles from its mouth up to 16-foot-high Lower Deer Creek Falls (Hanson and others 1940), located about one mile below the mouth of Panther Creek. According to Hanson and others (1940), salmon were never known to have passed Lower Deer Creek Falls. Clark (1929, p 39) stated that spawning beds extended from the creek mouth (near the town of Vina) to about ten miles into the foothills, which he described as “a good spawning ground when there is water.” Clark, however, was evidently referring only to the fall run.

Clark (1929) reported the presence of two irrigation diversion dams on the creek: Stanford Vina Dam, about three miles east of Vina, five feet high but with a fish ladder and screens installed on the irrigation ditches, and Deer Creek Irrigation District Dam, eight miles east of Vina. The latter dam had no fish ladder, because it was not considered to be an obstruction to salmon, but it also lacked fish screens at that time (Clark 1929). According to Clark (1929, p 39), there was “a small spring run and quite a large fall run” and salmon previously had been “very numerous in Deer Creek until dams were built which took most of the water from the creek.” Clark furthermore stated that “the spring run has never been successful as the fish come up in the spring and summer and lay in the holes until fall before spawning,” and “The water

becomes too warm for them and they die before they can spawn." Clark may have made this latter statement based on limited observations on fish relatively low in the drainage or during years of low streamflows; spring-run fish are presently known to be capable of over-summering in the pools in Deer Creek (for example, Needham and others 1943; F.W. Fisher, personal observation). Clark stated that the fall run was more successful, when there was "sometimes enough water in late fall," but even the fall run was "very small" at that time (1928) due to irrigation diversions from the creek. Decreased streamflows and consequently high water temperatures in the early summer caused mortalities of up to several hundred late-migrating adult salmon in the years 1945–1947 (Moffett 1949).

As part of the Shasta Fish Salvage Plan (to mitigate for construction of Shasta Dam), a fish ladder was constructed around Lower Deer Creek Falls in 1942–1943 (Needham and others 1943; Moffett 1949). By the end of 1943, salmon were able to ascend about five miles farther upstream to Upper Deer Creek Falls, a "sheer drop" of about 20 feet (Hanson and others 1940), which is the present major upstream barrier. There is, however, a fish ladder at the Upper Falls that is occasionally used by a few salmon (P.B. Moyle, personal observation). Hence, the amount of stream available for over-summer holding and for spawning (particularly for the spring run) has been increased. To compensate for the loss of spawning habitat in the upper Sacramento drainage caused by construction of Shasta and Keswick dams, Sacramento River spring-run salmon were caught at Keswick and transported to Deer Creek during the 1940s to mid-1950s (Needham and others 1943; Moffett 1949; Fry 1961), but those transfers had no noticeable effect on the spring run in Deer Creek (Fry 1961). Deer Creek is currently believed to have sufficient habitat to support "sustainable populations" of 4,000 spring-run and 6,500 fall-run salmon (Reynolds and others 1993). In recent years, most of the flow in the lower ten miles of the creek on the valley floor has been diverted, and in "many years" all of the natural flow from mid-spring to fall is depleted by the three diversion dams and four diversion ditches (Reynolds and others 1993). Although all of the diversion structures have fish screens and fish ladders, inadequate flows sometimes impede or prevent the upstream passage of salmon (Reynolds and others 1993).

The fall run presently still exists, spawning at lower elevations than the spring run and later in the fall, after ambient temperatures have become cooler. The two runs thus are both spatially and temporally isolated for spawning. The center of the present summer-holding and spawning areas for the spring run is the A-line Bridge (at about 2,900 ft elev.), which lies between Lower Deer Creek Falls and the US Forest Service (Potato Patch) Campground farther upstream. The spring run spawns from late August to early October (having held over the summer in the upstream reaches), while the fall run cannot enter

the lower creek to spawn until stream flows increase in late October (F.W. Fisher, personal observation).

Fry (1961) reported spring-run population estimates of <500 to 4,000 fish for 1940–1956 and fall-run estimates of <500 to 12,000 fish for 1947–1959. From the 1960s through 1980s, the number of fall-run spawners in Deer Creek ranged from 60 to 2,000 fish (average: 500), and in the present decade (1990–1997) the run has numbered 70 to 1,200 fish (average: 400 from DFG unpublished data). Estimates for the spring run were 400 to 3,500 fish (average: 2,200) annually during 1950–1979 and 80 to 2,000 fish (average: 660) during 1980–1998 (DFG unpublished data). Although spring-run estimates for most years during the 1990s have been in the low- to mid-hundreds, estimated escapements reached 1,300 in 1995 and 2,000 fish in 1998 (DFG 1998 unpublished data). The spring-run population in Deer Creek is one of only three or four remaining naturally spawning spring-run chinook populations in California that can be considered genetically intact and demographically viable (DFG 1990)—two other such populations within the Central Valley drainage being in nearby Mill and Butte creeks.

Mill Creek (Tehama County). Both spring and fall salmon runs are present in Mill Creek, and occasionally late-fall run fish also occur (Reynolds and others 1993). Stone (1874, p 208) mentioned “Mill-brook, near Tehama, ...a small stream, where the salmon rush up to spawn in great numbers, in October and November. They also come up this brook in April, May, and June.” The presence of a large “summer” (that is, spring) run in 1901 was reported by the US Fish Commission (USFC 1904). The “summer” run in 1902 was blocked by newly constructed racks and the fish all died due to excessively high temperature, while the fall run of that year was small due to low streamflows (USFC 1904). Clark (1929, p 39) later described Mill Creek as “a celebrated salmon stream” that had “some very large runs” and he stated that the spawning beds extended from the US Bureau of Fisheries egg station and hatchery (located about one mile above the creek mouth) for a distance of two miles to Clough Dam. Most habitat for salmon, either for holding or spawning, is currently viewed as extending from the mouth of Little Mill Creek (about 1,500 ft elev.) up to the area around Morgan Hot Spring (about 5,000 ft) (F.W. Fisher, personal observation). Some spring-run salmon in Mill Creek reportedly spawn in stream reaches well in excess of 5,000 ft elevation (Reynolds and others 1993) near the boundary of Lassen National Park—among the highest altitudes known for salmon spawning in North America. All the original upstream habitat suitable for spring-run salmon is still intact, and no major changes have been made on this stream (F.W. Fisher, personal observation).

Mill Creek is spring-fed and generally cold enough to sustain a spring run. However, it is unusual in that there is an elevational temperature inversion. The upper creek is fed by water from Lassen National Park, where there are

many hot springs, but farther downstream the lateral influx from coldwater springs results in cooler temperatures (F.W. Fisher, personal observation). Mill Creek also differs from other streams of the eastside Central Valley drainage in having high silt load and turbidity during the spring snow-melt, the silt originating naturally from volcanic and glacial materials in Lassen Volcanic National Park (Reynolds and others 1993).

Clark (1929) reported three dams on Mill Creek: the Molinas Water Company dam with fish screens on its diversion ditches and "not considered an obstruction"; 16-foot Clough Dam, an irrigation diversion project equipped with fish screens but with a poor fishway, which was seldom passable due to low water; and a third, unnamed seven-foot dam farther upstream with screened diversion ditches. However, these dams were in the lower reaches of the creek, essentially on the valley floor, and they probably posed no real obstruction to spring-run fish during the spring flows. In the early 1990s, there were three dams in the lower eight miles of the creek which diverted most of the natural flow (Reynolds and others 1993). All three dams were equipped with fish screens and the lowermost and uppermost dams had operative fish ladders (Reynolds and others 1993). However, the fish ladder on Clough Dam (the middle, tallest dam) functioned poorly during certain flow conditions (Reynolds and others 1993) and therefore may have impeded upstream migration. Clough Dam was breached by flood flows in January 1997 and since then has not obstructed salmon migration (C. Harvey-Arrison, personal communication, see "Notes").

Clark (1929) noted that salmon abundance in this creek was reflected by the egg takes at the US Bureau of Fisheries egg station, which collected eggs from fall-run fish but not from the spring run. The station operated during 1902-1945, closing down after completion in 1945 of the Coleman National Fish Hatchery on Battle Creek (Reynolds and others 1993). The egg takes peaked during 1904-1906 but were generally high from 1903 to 1918, dropping substantially during the later years 1919-1924. Clark stated that female salmon in this system produced about 5,000 eggs each, thus allowing estimates to be made of female spawner abundance from the total egg takes by the station; he also stated that there were "at least half again the number of males" (in other words, males were 50% or more as abundant as females). Thus, at the peak productivity in 1905 (30 million eggs taken), there were an estimated 9,000 spawners present (including 6,000 females). In 1924, one of the years of lowest egg production, 2.3 million eggs were taken, which translated to 450 female and 675 total spawners in the creek.

Clark (1929, p 41) mentioned the presence of both fall and spring runs, but he described the spring run as "very small and decreasing each year." It is possible, however, that Clark did not realize that spring run fish ascended far upstream and held there over the summer, and he therefore may have under-

estimated their presence. Fry (1961) reported spring-run numbers of <500 to about 3,000 fish during 1947–1959, while the fall run ranged between 1,000 to 16,000 spawners. Fry (1961, p 61) stated that most of the fall run spawned below Clough Dam, while “for all practical purposes the entire spring run goes upstream past the dam.”

In recent decades, the spring-run spawning escapement varied from zero fish, during the severe drought in 1977, to 3,500 fish in 1975 (Reynolds and others 1993; DFG unpublished data), but the trend has been downward from an annual average of 2,000 fish in the 1940s to about 300 in the 1980s (DFG 1990). During 1980–1998, the spring run ranged from about 60 to 840 spawners annually (average: 380) (DFG 1998 unpublished data). Fall-run escapements have been zero to 16,000 spawners since 1952, generally hovering near 1,500 fish (DFG unpublished data). The DFG (1993) reported an average annual fall-run escapement of 2,200 fish for the 38 years of record up to that time. In the present decade (1990s), the fall run has numbered about 600 to 2,100 fish but was absent in some years due to low seasonal streamflows. As in Deer Creek, the spring and fall runs in Mill Creek are separated temporally, the fall run ascending the creek during fall flows after the spring-run fish have finished spawning (F.W. Fisher, personal observation). There is also spatial separation of the spring and fall runs in both Mill and Deer creeks, with spring-run fish spawning well upstream from the fall-run fish and thus further minimizing the possibility of hybridization (DFG 1990). Late-fall run salmon have been occasionally observed spawning in the lower reaches of the creek (Reynolds and others 1993).

Antelope Creek (Tehama County). Both spring and fall runs, and probably a late-fall run, originally occurred in Antelope Creek. Spring-run salmon ascended the creek at least to where the North and South forks join (where several salmon were observed a few years ago by Lassen National Forest biologists), and they probably held there over the summer. The few spring-run fish that now enter the creek ascend the North and South forks about five to six miles to the vicinity of the Ponderosa Way crossings, their probable historical upper limit, beyond which there is little suitable habitat (F.W. Fisher, personal observation).

As in Mill and Deer creeks, the low, late summer and fall streamflows limit the accessibility of the creek to fall-run fish. Until at least 1993 there were two water diversions on Antelope Creek, operated by the Edwards Ranch (50 cfs) and by the Los Molinos Mutual Water Company (70 cfs) (Reynolds and others 1993). During the typical flow-diversion season (1 April to 31 October), operation of both diversions usually dried out the lower reach of the stream (Reynolds and others 1993), thus impeding or preventing the upstream migration of both spring and fall runs.

The spring run formerly numbered 200 to 300 fish annually, with lows down to 50 fish (DFG unpublished data). Reynolds and others (1993) gave an estimated historical spring-run size of 500 fish. No regular escapement estimates have been made recently, but occasional checks indicate that Antelope Creek currently has no more than a remnant spring run which probably is not self-sustaining; for example, two to three individuals at most have been seen through much of the 1990s. However, in 1998 about 150 spring-run fish were observed in Antelope Creek (DFG 1998). The fall run in Antelope Creek generally has been small. During 1953–1984, the fall run numbered 50 to 4,000 fish annually (average: about 470 fish) (Reynolds and others 1993; DFG unpublished data.). Population estimates have not been made in more recent years due to the scarcity of the salmon, and the fall run may be extirpated (Reynolds and others 1993).

Battle Creek (Tehama County). Both spring and fall runs of salmon originally occurred in Battle Creek, and there is evidence that a winter-run was also present. The California Fish Commission noted that, “Salmon enter this stream in large numbers during the months of October and November” (CFC 1896, p 23) and averred, “...there being almost no limit to the number of eggs which can be secured there with proper apparatus” (CFC 1896, p 24). Curiously, Stone (1897, p 218) stated:

This Battle Creek is the most extraordinary and prolific place for collecting salmon eggs yet known, though the eggs are limited to the fall run of salmon, as none worth mentioning of the summer run [the current spring run] of fish ascend Battle Creek. The first salmon make their appearance early in the fall, and before November and during that month they are found in almost incredible numbers in the wide lagoon extending about 2 1/2 miles up the creek from its mouth.

It appears that even at that time fishery biologists had not yet fully explored the upper reaches of the stream where the spring-run salmon over-summered. In April 1902, the US Fish Commission emplaced racks in Battle Creek and observed large numbers of salmon during “late spring and early summer,” thus proving the existence of “a large summer run of fish in the creek” (USFC 1904, p 73). A US Fish Commission Report also noted a “site suitable for a branch hatchery for the summer run of salmon ...on Battle Creek, opposite the mouth of Baldwin Creek” (Smith 1905, p 81) Rutter (1904) then reported capturing in Battle Creek (during October 1898 and early October 1900) recently emerged fry (1.5 inches long) that could only have been of the winter run. In 1939, salmon were observed spawning in Battle Creek during May and June (Needham and others 1941), the typical winter-run spawning time (Slater 1963; Fisher 1994). The North Fork of Battle Creek contains a series of springs near the town of Manton which would have provided coldwater flows required for the summertime spawning and rearing of the winter run, despite

Slater's (1963, p 4) assertion that the winter run would not normally spawn successfully in Battle Creek or in Deer and Mill creeks because of high (>70 °F) summer water temperatures. However, the winter run was largely eliminated after hydroelectric development of the creek in 1910-1911, which cut off the spawning habitat. The formerly large spring run also was significantly reduced by the loss of habitat at that time and it may have been completely eliminated for a period thereafter, as indicated in DFG (1990).

Surveys conducted before the construction of Shasta Dam indicated that the reaches above Coleman National Fish Hatchery could support >1,800 spawning pairs of salmon (Reynolds and others 1993). The North Fork of Battle Creek, especially Eagle Canyon, contains deep, cold pools—ideal summer holding habitat for spring-run salmon (Reynolds and others 1993), and significant areas of spawning gravel have been determined to exist from Coleman Powerhouse on the mainstem up to above the Volta Powerhouse (extending to Macumber Dam) on the North Fork and on the South Fork between South Powerhouse and South Diversion Dam (Reynolds and others 1993). It is likely that much of those areas had been previously used by salmon before blockage of migration and the alteration of the streamflow regime. In the North Fork, salmon have been observed as far as Volta Powerhouse above Manton (T. Healey, personal communication, see "Notes"), but the upper distributional limit would have been a waterfall three miles farther upstream (H. Rectenwald, personal communication, see "Notes"). Hanson and others (1940) reported the presence of a waterfall on the South Fork near the Highway 36 crossing, which evidently was a natural barrier to salmon.

Clark (1929) noted that Battle Creek had a fall run and a "small" spring run. As of 1928, there was a US Bureau of Fisheries egg-collecting station and hatchery (Battle Creek Hatchery) located about 1.5 mi above the creek mouth. The station, first established in September 1895 (CFC 1896), collected eggs from the fall run but allowed the spring run to pass upstream (Hanson and others 1940). Spawning by spring-run fish occurred in the five-mile stretch between the egg station and the upstream dams (Clark 1929). Clark (1929) reported the presence of three power dams and plants: the Coleman plant six miles above the mouth, with an operative fish ladder and screens on the diversion canals; a second dam, 30 ft high and equipped with "a good fish ladder and ditch screens," on the South Fork about 20 mi above the Coleman plant; and the Volta plant on the North Fork. Clark stated that despite the presence of fish ladders, the water was often so low that the dams were impassable to fish.

Presently, natural spawning of salmon in Battle Creek is by far heavily concentrated in the stretch between the creek mouth and the Coleman National Fish Hatchery weir six miles upstream, and instream spawning has been said to be "still significant" (Reynolds and others 1993). The predominant fall-run

salmon are blocked at the hatchery weir, and whatever natural spawning that formerly occurred upstream has been largely eliminated by that blockage and low flows due to hydropower operations of Pacific Gas and Electric Company (PG&E) (Reynolds and others 1993). It is not known how much farther fall-run salmon ascended Battle Creek, and we conservatively assume that they were constrained to the vicinity of the hatchery weir. During recent years when streamflows were adequate, small numbers of spring-run and winter-run salmon have been able to ascend past the weir and spawn in upstream reaches (T. Healey, personal communication, see "Notes"). Spring-run and a few winter-run salmon were observed in the Eagle Canyon area of the North Fork Battle Creek during summer 1995 (T. Healey, personal communication, see "Notes"). As of 1993, there were four unscreened hydropower diversions on the North Fork, three unscreened hydropower diversions on the South Fork, two storage reservoirs and a system of canals and forebays in the drainage, as well as two "significant" agricultural diversions (one unscreened) on the main stem (Reynolds and others 1993). Current negotiations to reconfigure the PG&E hydropower system on Battle Creek, including dismantling several dams, will considerably improve access for salmon to the upper reaches (Sacramento Bee, 4 May 1999).

The records for egg takes (for the fall run) at the US Bureau of Fisheries egg-collecting station indicated peak spawner abundances generally occurring in the period 1896–1907, and the egg takes remained fairly high until 1916, after which there seemed to be an overall decline until 1924 (Clark 1929). Translating the egg takes to numbers of females (assuming 5,000 eggs per female, after Clark [1929]) gives a peak of 10,000 females for 1904 and a low of 200 females for 1924. According to Clark (1929, p 41), the spring run, which was allowed to spawn naturally in the creek, amounted to "almost nothing," and only six or seven spring-run salmon were seen in 1928. The old Battle Creek Hatchery, which took fall-run spawners from the creek, continued to operate through 1945 (Fry 1961). The larger Coleman National Fish Hatchery began operations in 1943 and took small numbers (<1,200) of spring-run fish from Battle Creek in 1943–1946, but during that period Coleman National Fish Hatchery received most of its fish (both spring-run and fall-run) from fish salvage efforts at Keswick Dam and from the Balls Ferry Racks on the mainstem Sacramento River (Moffett 1949, Fry 1961). In 1946, Coleman National Fish Hatchery started taking fall-run fish locally from Battle Creek (Moffett 1949; Fry 1961). (See also Black, this volume, for a thorough review of the history of Battle Creek hatchery operations.)

During the period 1946–1956, the spring run numbered about 2,000 fish in most years (Fry 1961; Campbell and Moyle 1990). By the late 1980s, the spring run in Battle Creek was either extirpated or close to it (Campbell and Moyle 1990). Small numbers of spring-run fish have returned in recent years, ranging from 40 to 100 fish (average: 70) in 1995–1997 (DFG 1998). The escapement for

1998 was about 50 to 100 fish (USFWS 1998 unpublished report). Historical abundance data for the winter run in Battle Creek are almost nonexistent, although Slater (1963) reported that on 22 May 1962, 457 winter-run fish were counted and a population size of 2,687 fish was estimated for the two-mile stretch below Coleman National Fish Hatchery. Small numbers of winter-run fish have been observed in recent years, with about 100 spawners estimated for 1998 (USFWS 1998 unpublished report). Numbers of fall-run spawners in Battle Creek were about 3,000 to 30,000 (average: 15,000) during 1946–1959 (Fry 1961). Annual fall-run escapements during the 1980s and 1990s have ranged between 12,700 and 83,900 fish, with averages of 29,600 (in the 1980s) and 46,400 fish (1990–1997) (DFG unpublished data). Hatchery spawners composed 20% to 73% (average: 51%) of the annual runs during 1980–1997 (DFG unpublished data).

The Coleman National Fish Hatchery also has maintained a late-fall run, but returns of adults have not been consistently strong enough to sustain the run and the hatchery has relied on obtaining late-fall-run spawners from the Keswick fish trap below Keswick Dam on the Sacramento River. During 1995–1997, however, numbers of the late-fall run returning to Coleman National Fish Hatchery were 1,300 to 4,600 fish (average: 3,000) (USFWS 1998 unpublished report).

Mainstem Sacramento River and Upper (Little) Sacramento River (Solano, Yolo, Sacramento, Sutter, Colusa, Glenn, Butte, Tehama, and Shasta counties). The Sacramento River, regarded by Clark (1929, p 34) as “the most important salmon stream in the state” and by Fry (1961, p 59) as “the largest and best salmon stream of the Central Valley,” has the sole distinction among the salmon-producing rivers of western North America of supporting four runs of chinook salmon – spring, fall, late-fall and winter runs.

One of the earliest references to salmon of the Sacramento River was by the fur trapper Colonel J. J. Warner who traveled the Central Valley in 1832: “The banks of the Sacramento river, in its whole course through its valley, were studded with Indian villages, the houses of which, in the spring, during the daytime, were red with the salmon the aborigines were curing” (Chamberlain and Wells 1879, p 12; Gilbert 1879, p 12; Elliott 1882, p 161). John Work, of the Hudson’s Bay Company, reported that his party of fur trappers, while moving down the Sacramento Valley (near Putah Creek) on 16 March 1833, obtained “some fine[?] Salmon” (spring-run, or perhaps winter-run) from the native people (Maloney 1943, p 339). Lieutenant Charles Wilkes, reporting on the United States Exploring Expedition of 1838–1842, later described “a substantially-built fish-weir” – undoubtedly for catching salmon (see Curtis 1924b) – which was observed on 31 August 1841 near the present town of Colusa on the lower mainstem Sacramento River (Wilkes 1845, p 187). Another party of the US Exploring Expedition encountered Native American people (probably

Wintu) farther north in the Sacramento Valley and traded with them for salmon—caught by the natives by means of weirs and long, forked fish spears (Dillon 1975). Perhaps the last published record of the intact native fishery on the Sacramento Valley floor was that of a forty-niner who observed in 1849, near “a very large settlement of Indians” on the lower Sacramento River, “a scrap of beach, on which a vast number of miserable spent salmon of enormous size, split, were hung along on poles to dry in the sun” (Kelly 1950, p 73). Unpublished notes by the pioneer H.C. Bailey also alluded to “Sacramento Valley Indians” taking salmon in the springtime before 1853: “During the salmon run (March and April) they caught them in abundance and some times sturgeon. We could buy a 25 pound salmon for a quart of flour. They were the finest fish I ever tasted.” (Latta 1930–1931).

Salmon fishing as a commercial enterprise on the Sacramento River had been initiated by John A. Sutter near his New Helvetia settlement (present-day Sacramento) by about 1842–1843, if not earlier (Wright 1880; Van Sicklen 1945; Bennyhoff 1977). Another fishing entrepreneur was a Mr. Schwartz, whose fishing operation was located six miles downstream of New Helvetia. Concerning Schwartz’s fishery, the pioneer Edwin Bryant noted in his journal for 26 October 1846:

Mr. Schwartz provided us with a breakfast of fried salmon and some fresh milk.... Near the house was a shed containing some forty or fifty barrels of pickled salmon... The salmon are taken with seines dragged across the channel of the river by Indians in canoes. On the bank of the river the Indians were eating their breakfast, which consisted of a large fresh salmon, roasted in the ashes or embers, and a kettle of atôle, made of acorn-meal. The salmon was four or five feet in length, and when taken out of the fire and cut open, presented a most tempting appearance (Bryant 1849, p 345).

The date of the narrative indicates that the salmon were of the fall run. The lower mainstem Sacramento River later became the center of the bustling commercial salmon fishery carried out by immigrant European and Euro-American fishers drawn to California during the Gold Rush and following period (Clark 1929; Skinner 1962). As noted by a gold-miner, “In 1851...the Sacramento river was full of splendid salmon, equal in flavour to those of the Scottish rivers, though in appearance note quite such a highly finished fish, being rather clumsy about the tail” (Borthwick 1857, p 48).

Unquestionably the spring chinook salmon run, and probably lesser numbers of the winter run, occurred in the Upper (Little) Sacramento River (also called the Destruction River in early accounts). In 1841, a detachment of the US Exploring Expedition reconnoitered the Siskiyou Trail from Oregon to the Sacramento Valley. Traveling southward along the Upper Sacramento River, the party passed downstream of “Soda Springs” and Castle Crags and

observed evidence of the spring run during the latter part of the spawning period (early October) (Poesch 1961; Dillon 1975). Titian Ramsey Peale, a member of that party, recorded in his journal for 6 October 1841:

Passed several old Indian camps, at one there were several new graves, over which were bundles of provisions and near by on a stump a bundle of Salmon... One of our hunters saw several more ["Indians"] on the river below our camp fishing for Salmon, which must have been numerous earlier in the season, as quantities of dead ones now lay along the rocky Shores. We saw the remains of fences and weirs for catching them (Poesch 1961, p 194).

A later historical account of Shasta County noted that the sudden influx of gold miners into the Upper Sacramento River valley in the spring of 1855 drove the native people from their usual haunts (near Castle Crags) and prevented them from obtaining "the salmon they were wont to spear," thus precipitating hostilities (Southern 1942, p 66). Salmon normally present at that time of year would have been either the winter or spring runs (or both). Curtis (1924b, p 87) stated that the Wintu people on the Upper Sacramento River caught (spring-run) salmon in midsummer, "with spears fifteen to twenty feet long, in deep quiet pools"; "In the autumn salmon were speared while spawning in the riffles, and in spring spearing was carried on at night by torchlight..." Furthermore, the winter salmon run was said to have spawned in the headwaters near Mt. Shasta (Stone 1874). Stone (1879, p 234) noted that "in July the summer run [currently termed winter run] are spawning at the headwaters of the McCloud and Little Sacramento; in August and September [the spring run spawn] farther down these rivers..." Scofield (1900, p 68) also reported: "In Hazel Creek, a tributary of the Sacramento near Sims, I found, on November 6, 1897, two sizes of young salmon.... Of the smaller size [average length 2.87 inches] only four were taken....they must have hatched from the egg early in August, and allowing three months for hatching, they were spawned early in May." The timing of those smaller fish is indicative of the winter run. The late-fall run, with its requirement of cool summer flows for fry and juvenile rearing, also possibly entered at least the lower reaches of the Upper Sacramento where such flows existed.

Salmon at one time ascended the Upper Sacramento River in large numbers at least to the falls near the town of Sims, about 31 mi upstream of the site of Shasta Dam. Large numbers of juvenile salmon were observed in the vicinity of Sims during the summer of 1898 by Rutter (1904, p 105), who estimated a probable density of "as many as 10,000 young salmon to the mile in the Upper Sacramento...or between a half and three quarters of a million in all the headwaters of that stream" (see also Rutter 1902). Juveniles were also captured in Hazel Creek, "a favorite spawning stream both for salmon and trout," which joins the Sacramento River near Sims (Rutter 1904). Clark (1929) stated that the falls at Sims stopped most of the salmon, although "a few fish" were able

to surmount them. However, Stone (1874, p 180) reported: "Last July [1871] hundreds of salmon, averaging 15 pounds apiece, were caught in the Little Sacramento with a hook and line, near Frye's Hotel, at Upper Soda Springs," upriver of Sims and just below the town of Dunsmuir. Furthermore, the native Wintu people were said to have fished for salmon (during July) above Sims in the reach from Castle Crag depot (five miles below Dunsmuir) to Shasta Retreat (about one mile above Dunsmuir) (Voegelin 1942). According to one Wintu informant, the salmon fishing activities involved "200 to 300 people" and lasted two to three weeks (Voegelin 1942), indicating that substantial numbers of salmon were able to ascend the falls past Sims. Once over the falls, salmon would have had clear access up to the present site of Mt. Shasta City, and it appears that they were able to ascend almost the entire length of the river to the site of present-day Box Canyon Dam and Lake Siskiyou (also called Box Canyon Reservoir), where several spring-fed streams enter the Upper Sacramento River from the east (Mt. Shasta).

Rutter (1904, p 96) reported netting "nearly 500" juvenile salmon in a single seine haul from a pool at the head of Box Canyon, near Sisson in August 1897, and he stated that it was not uncommon "to catch over a hundred at a time in many of the pools of the headwaters." It is possible that the large numbers of young salmon observed by Rutter were to some extent due to large-scale plantings of salmon fry into the Upper Sacramento from Sisson (Mt. Shasta) Hatchery, a practice started in 1888 when that hatchery was built (CFC 1890; USFC 1892; Shebley 1922), and some numbers of juvenile salmon from Baird egg-collecting station on the McCloud River were transferred to the Upper Sacramento River as early as 1880 and 1881 (Stone 1883b; Green 1887). However, salmon evidently were abundant enough in the remote reaches of the Upper Sacramento River before any hatchery plantings to gain notice in the first report of the California Fish Commission (CFC 1871, p 44): "Salmon are caught by the Indians in the small streams that empty into the Sacramento from the sides of Mount Shasta, at an elevation of more than four thousand feet above the level of the sea; to reach which they must have passed through at least fifty miles of almost continuous rapids." The US Fish Commission (USFC 1876a, p xxviii) likewise stated that the salmon "traverse the Sacramento Valley to the headwaters of the Little Sacramento and the McCloud Rivers, about four hundred miles..." A similar quote was attributed to Dr. David Starr Jordan: "They are known to ascend the Sacramento as far as the base of Mount Shasta, or to its extreme headwaters—about four hundred miles" (CFC 1890, p 59). Jordan's statement (probably made before 1890) antedates any possible results (specifically, returning adults) from regular plantings of young salmon into the Upper Sacramento River from Sisson Hatchery in 1888 and later—given the minimum generation time of three years for chinook salmon.

Stone (1874, p 176) stated that salmon ascended the Upper Sacramento River "in great numbers, and make the clear waters of this stream the principal spawning-ground of the salmon of the Great Sacramento River, with one exception" – the McCloud River. Clark (1929) described the Upper Sacramento River as an "ideal spawning stream" with "wonderful spawning beds" along its entire length; "the salmon were extremely abundant" before construction of the Southern Pacific Railroad through the Sacramento Canyon, but "the run was almost destroyed" by construction work in 1883–1884. Erosion of rocks and sediments into the river blocked and muddied the water, and the railroad workers reportedly blasted areas holding the salmon to catch the fish (Clark 1929). As noted by Shebley (1922, p 64), many fish were used to feed the 9,000 laborers camped along the Sacramento River, but "there was wanton destruction in the way they were killed." Again in 1886, blasting for the railroad along the Upper Sacramento River prevented the salmon from entering that stream very far; "quite a number" attempted the ascent but turned back after a few days and entered the McCloud River instead (Green 1887). Furthermore, a mining tunnel, located just above the confluence with the Pit River, essentially prevented the migration of the fall run when flows were low in August and September during the 1880s. The tunnel's diversion of water from a short stretch of the Upper Sacramento River evidently accounted for the greatly depressed fall run "for a long while past," until the tunnel was closed in 1890 (CFC 1890). In the only quantitative assessment of salmon abundance for this stream, Hanson and others (1940) estimated that the Upper Sacramento River in 1938 had a "potential spawning capacity" of 14,303 redds. This should be viewed as a minimal estimate because the spawning capacity estimates given by Hanson and others (1940) for other streams generally are lower than the run sizes that subsequently have been observed for those streams (F. W. Fisher unpublished data).

On the mainstem Sacramento River on the valley floor, the Anderson-Cottonwood Irrigation District (ACID) diversion dam at Redding was an almost complete barrier to salmon during the irrigation season (April through October) for about ten years (1917–1927) (CFG 1927; Hanson and others 1940). This blockage occurred despite an initial "understanding" during the construction of the dam in 1916–1917 between the California Fish and Game Commission and the Irrigation District's chief engineer "that the dam was not to be raised above a certain level" and "would allow all the salmon to pass the dam and proceed on their way up the McCloud and Pit rivers" (CFG 1921a, p 20). The ACID authorities contended that an open section of the dam was adequate to allow the passage of salmon (CFG 1921c), although McGregor (1922, p 149) noted that "With no little humor, they speak of it as a fishway." It was subsequently determined that salmon did not use that spillway and that very few fish surmounted the dam at any point along it (McGregor 1922). Further testimony regarding the ineffectiveness of the original "fishway" was given by upstream residents who reported that salmon had become

“extremely scarce since the erection of the dam”; as one pioneer fisherman of the area noted, “Why would we journey miles down the river from our homes to fish at the dam if we could get fish up where we belong?” (McGregor 1922, p 153). Clark (1929, p 35) stated that the dam “nearly exterminated the salmon run at that point of the river.” Clark presumably was referring to the winter and spring runs because the dam routinely was dismantled during October; the fall run for the most part had clear access up the river and, therefore, was not significantly affected. After installation of a new fish ladder on the dam, it was reported that “quite a number of salmon” passed over, “but nothing to compare with conditions before the dam was constructed” (Clark 1929, p 35). The ACID dam has continued to pose fish passage problems (Reynolds and others 1993).

The Glenn-Colusa Irrigation District (GCID) diversion facility has been another significant obstacle to salmon, but mainly for downstream-migrating juveniles which are destroyed in large numbers by the pumping operations (Phillips 1931; Reynolds and others 1993). However, by far the greatest factor to affect the salmon runs of the Sacramento River in recent times has been Shasta Dam (completed in 1943). With its closure in November 1942, Shasta Dam barred the salmon entirely from their former spawning grounds in the Upper Sacramento, McCloud and Pit River drainages (DFG 1944), thus removing those areas from salmon production. In addition, about 13 mi of salmon habitat in the mainstem Sacramento River above Shasta and Keswick dams up to the confluence of the Upper Sacramento and Pit rivers were no longer accessible. Operation of the Coleman National Fish Hatchery in Battle Creek was intended to compensate for the habitat loss. Presently, the upstream distribution of salmon in the Sacramento River is delimited by Keswick Dam, a flow-regulating dam nine miles below Shasta Dam. Fall-run salmon spawn in the mainstem Sacramento River where spawning gravels occur from Keswick Dam downstream to below the town of Tehama (Clark 1929; E. R. Gerstung, personal observation) – a distance of about 67 miles. Fall-run spawning escapements in the mainstem Sacramento River averaged 217,100 fish annually during 1952–1959; 136,600 fish in the 1960s; 77,300 in the 1970s; 72,200 in the 1980s; and 48,000 fish from 1990 to 1997 (DFG unpublished data).

McCloud River (Shasta County). The McCloud River, once denoted by the California Fish Commission as “the best salmon-breeding river in the world” (CFC 1890, p 33), originally supported both spring and fall runs of salmon, as well as the winter run (Stone 1874; USFC 1900; Hanson and others 1940; Needham and others 1941). According to native Wintu informants, the spring run was “heavier” than the fall run in both the McCloud and Sacramento rivers, and the average size was “approximately twenty pounds,” with occasional fish weighing as much as 65 and 70 pounds (Du Bois 1935, p 15). The winter run appears to have been the least abundant of the three runs, with small numbers

of spawners reported by various workers (Stone 1874; Scofield 1900; USFC 1900, 1904; Rutter 1904, 1907; Hanson and others 1940). Yet, Stone (1876, p 446) reported that during the egg-collecting season (August and September for the spring run) in 1874 “Young salmon a few inches long were very plentiful” – those evidently being winter-run juveniles. Scofield (1900, p 69) noted that salmon had been observed “spawning in considerable numbers in the [McCloud] river above Baird early in May,” again corresponding to the winter run. The observation of one or two salmon spawning in the McCloud River near the hatchery around 20–24 April 1902 (USFC 1904; Rutter 1907) is indicative of early-spawning winter-run fish or perhaps late spawners of the late-fall run (based on life stage timing given in Vogel and Marine 1991; USFWS 1995). In June 1898, two size groups of young salmon were observed in the McCloud River “in large numbers” (USFC 1899)—one group corresponding in size (three to four inches) to fall-run juveniles and a second group of smaller fish (1.5 inches long) of a size indicative of newly emerged late-fall-run progeny.

Salmon ascended the McCloud River up to the impassable Lower Falls (20 ft high), about six miles above present Lake McCloud (Rutter 1904; Wales 1939; Hanson and others 1940). Hanson and others (1940) reported observations of salmon (evidently winter-run) spawning during May and June, 1939, in the McCloud River between Big Springs and Lower Falls (about 1.5 miles). However, the reach from Big Springs up to Lower Falls was ecologically less suitable than areas downstream for salmon because of relatively low streamflows. Big Springs (rm 49) is the location of two large springs which in the past contributed well over half the minimum streamflow of the McCloud River, and Big Springs thus was somewhat of an “ecological barrier” to salmon (Wales 1939). Ethnographic information similarly indicates that salmon did not ascend in significant numbers past a bend in the river at rm 41, one mile below Lake McCloud; according to a Native American informant, the “salmon got no further, just got there” (Guilford-Kardell and Dotta 1980, p 76). That point was the location of a Wintu village named *Nurumwitipom* (“salmon come back”) or *Nurunwititeke* (“falls back where the salmon turn back”) (Guilford-Kardell and Dotta 1980). The native people, primarily interested in harvesting the salmon in quantity, evidently paid little heed to the presumably small numbers of salmon that ascended past the main fishing sites into the less suitable upper reaches. A few salmon reportedly were observed in Squaw Valley Creek, the largest tributary to the McCloud, in September 1938, and they probably also entered the lower reaches of several other tributary streams (for example, Star City, Claiborne, and Caluchi creeks) (Wales 1939).

Clark (1929, p 43) described the McCloud as “a good spawning stream” from its mouth to the falls near its source. As of 1928 there were no dams or other artificial obstructions on the river except for the racks of the US Fish Commission egg station (Clark 1929). Hanson and others (1940, p 47) estimated that the McCloud River potentially could support 25,097 redds, and they reported

salmon spawning in 1939 near the mouth, at Big Springs, and at “several other places below the Lower Falls.” They also estimated that the lower five miles of Squaw Valley Creek, a tributary entering the McCloud River about 29 mi upstream of the mouth, could support approximately 830 redds (Hanson and others 1940).

After its establishment on the McCloud River in 1872 by the noted fish culturist Livingston Stone, the US Fish Commission egg-collecting station (Baird Station) soon was taking the spawn from almost all of the returning spring-run salmon (Clark 1929). During the early years of its operation (1872–1883), most of the eggs collected were shipped out of California for the main purpose of establishing runs in East Coast rivers, which in almost all attempts were failures (USFC 1892; Clark 1929; Towle 1987). However, production of salmon in the McCloud itself could not be sustained and in 1884 the scarcity of salmon led to the temporary closure of the egg station (Stone 1885a, 1897; Clark 1929).

Clark (1929) presented a tabulation of egg takes by the Baird Station in the years 1872–1924, which illustrated the decline in salmon abundance during the later years compared with earlier years. Aside from the first year operation (1872) in which 50,000 eggs were collected, the egg takes ranged from about 1 million to over 12 million eggs during the period 1873–1883, the first phase of operation before its temporary closure (Clark 1929). Eggs were taken from spring-run fish in that early period, but railroad construction along the Sacramento River during 1883 and 1884 blocked the salmon runs (Stone 1885b), and the paucity of the spring run forced the cessation of egg-collecting operations during 1884–1887 (Stone 1885a). In response to the depleted state of the Sacramento River salmon stocks, Baird Station was reactivated in 1888 for the expressed purpose of “aiding in the maintenance of the salmon fisheries of the Sacramento River” (USFC 1892, p 35). The egg station continued activities until 1935 (Hedgpeth 1941), but taking eggs during some years from the fall run to supplement the temporarily depleted spring run (see CFC 1890, 1907). During that later period of productive operation (mainly 1888–1924), between 1 million and 29.9 million eggs were taken annually, and the peak production (in 1903) was from about 5,600 females (Clark 1929). After 1907, the egg takes showed a fairly steady decline down to about 1 million to 1.5 million eggs per year (Clark 1929). By 1924 there were “only about 260 fish at the racks” which produced 1.2 million eggs (Clark 1929, p 43), and in 1935 only 5,200 eggs were collected, “probably from a single female” (Hedgpeth 1941, p 145).

Stone (1876, p 446) had estimated that in 1874, the first year in which a weir was set across the McCloud River for capturing the salmon, “Tens of thousands, not to say hundreds of thousands, which would perhaps be nearer the truth” passed upstream before the weir was finished, and “thousands more”

were blocked after its completion. Stone (1897, p 213) noted that in 1878, there was “an immense gathering of salmon in the McCloud.” He averred:

I have never seen anything like it anywhere, not even on the tributaries of the Columbia. On the afternoon of the 15th of August there was a space in the river below the rack about 50 feet wide and 80 feet long, where, if a person could have balanced himself, he could actually have walked anywhere on the backs of the salmon, they were so thick” (Stone 1880, p 749).

Stone (1880, p 763) also stated that during the 40 days before 5 October 1878, the egg-collecting crew “caught and examined, one by one, nearly 200,000 salmon” – all of which were of the spring run, as eggs were taken from only that run (in other words, “the first or August run”) at Baird Station during the period before 1888 (CFC 1890, p 17; USFC 1892, p xxxv). After the hiatus in the mid-1880s, the salmon (both spring and fall runs) returned in large numbers to the McCloud River in the 1890s and early 1900s – according to elder Wintu informants, “So thick on the McCloud it looked like you could walk across them” (Guilford-Kardell and Dotta 1980, p 82). The runs again declined, and in 1922 there was “no run of salmon whatever in the McCloud River,” due at least partly to abnormally low stream flows (Leach 1923). Clark (1929, p 43) reported spring and fall salmon runs still present in the McCloud River as of 1928, with the fall run “not as heavy as the spring,” but by that time both runs were greatly depleted.

Excessive fishing pressure by commercial gillnetters in the Sacramento River undoubtedly depressed the spawning runs into the McCloud River; for example, illegal fishing in the 1877 season reduced the “unusually large number” of salmon running in the Sacramento River so completely that only “extremely small numbers” reached the McCloud River (Stone 1879, p 799). In the early 1880s, the fishermen reportedly had the Sacramento River completely blocked with their gill nets (CFC 1884; McEvoy 1986). The McCloud River runs were also significantly affected by downstream obstructions in the Sacramento River – first by the Anderson-Cottonwood Dam in the period 1917–1927 (Leach 1922; CFGC 1923, 1927; Clark 1929) and ultimately by Shasta Dam, starting in 1942–1943 (Slater 1963; Reynolds and others 1993). Shasta Dam, about 560 ft high and then the second largest dam in the world, completely blocked access upriver and thereby extirpated all runs of salmon and other anadromous fishes into the McCloud River and other upper Sacramento tributaries (Needham and others 1941).

Pit River (Shasta County). The Pit River formerly was recognized as “a noted salmon stream” (CFC 1886). The Pit River system covers an extensive area, according to Clark (1929) comprising “at least half of the main Sacramento River.” The Achumawi people, historically referred to as “Pit River Indians,” are reported to have controlled about 50 mi of salmon streams in their territory (Olmsted

and Stewart 1978), primarily the mainstem Pit River. They harvested “vast quantities of suckers” by diverting streams as well as salmon “which were taken in great numbers by net and spear” and dried for winter consumption (Curtis 1924a, p 141). The Achumawi fished for a variety of other fishes, including steelhead: “The weir known as *tatsítschi* was set in the main stream for catching *allís* (steelhead trout) on their return to the sea in the autumn” (Curtis 1924a, p 137). The salmon ascended in large numbers at least to Pit River Falls (rm 75), but the falls evidently were not a complete barrier. Voegelín’s (1942, p 175) ethnographic account states that “Salmon ascend Pit River as far as falls at site of Pit 1 power house, in Achomawi area.” The Pit 1 power house was located at the mouth of Fall River (Clark 1929), a major tributary of the Pit River about four miles above Pit River Falls.

The presence of spring-run salmon in Hat Creek, a tributary of the Pit River below Pit River Falls, was noted by Rutter (1902, 1904), and they were also reported to have ascended the Pit River in the spring of 1926 (DFG 1929). The occurrence of a winter run in the Pit River drainage, spawning in “the headwaters,” was indicated by Stone (1874). One ethnographic account stated that among the Atsugewi people (“Hat Creek Indians”), who controlled most of the Hat Creek drainage, “salmon were obtained only by invitation of the western Achumawi on Pit River” (Garth 1978, p 242) to where the Atsugewi made salmon-fishing expeditions in the fall, giving the Achumawi part of the catch as payment to trespass (Garth 1953). Garth’s (1953, p 136) survey of Atsugewi informants indicated that salmon were “rarely seen in Hat Creek,” and Voegelín (1942, p 175), drawing from an interview in 1936 with a 79-year-old Atsugewi informant, recorded: “Not many salmon in Hat Creek; occasionally a good run.” However, Kniffen’s (1928, p 315) earlier ethnographic summary, in describing the Hat Creek Valley, stated that “Formerly the streams contained an abundance of salmon, pike, trout, and suckers.” Garth (1953, p 136) reported that a waterfall located “about a mile below Caasel [Cassel] on Rising River,” was a favorite fishing place of the Atsugewi people, who called it “*ani*” [salmon] “*wecéici*” [jump up]. This reference is evidently to a stretch of Hat Creek which contains cascades and was sometimes called “Rising River”; that stretch is located just downstream of the mouth of the true Rising River. The latter is a wide, slow-flowing tributary to Hat Creek which lacks salmon habitat (E. R. Gerstung, personal observation). Hat Creek was said to have been “where salmon formerly abounded by the thousands during the spawning season,” and the California Fish Commission established a salmon hatchery there in 1885 (CFGC 1914, p 63). However, so few salmon ascended to that point in 1886 and 1887 that the hatchery was abandoned in 1888 (CFC 1888; CFGC 1914; Shebley 1922). Rutter (1908, p 110) described Hat Creek as “a salmon stream of some importance, but it has a number of rapids that make its ascent difficult.” Available spawning habitat and suitable conditions also occur in Kosk and Burney creeks, two other Pit River tributaries where it is likely that winter-run salmon spawned. The Achumawi people owned fish

weirs situated at Burney Falls, where they evidently caught salmon (Garth 1953). Burney Falls, a 129-foot double waterfall located about one mile above the mouth of Burney Creek, was an obvious historical barrier to salmon.

Rutter (1904), in reference to the spring run, stated that “some of the earlier ones even pass Pit River Falls and ascend Fall River to its source.” Those “earlier ones” he referred to probably comprised some number of winter-run fish. Rutter also stated that “they are not found in Pit River above the mouth of Fall River,” indicating that the salmon runs entered the cool and partially spring-fed Fall River for spawning — “mainly in August” — rather than continuing up the relatively warm Pit River. Garth’s (1953) ethnographic account similarly reported that salmon seldom ascended the Pit River above Fall River Mills, located at the mouth of Fall River, and Kroeber (1925, p 309) also noted, “Salmon hardly ascended beyond Fall River...”

Before Rutter’s (1904) report, the California Fish Commission (1880, p 13) wrote of Pit River Falls, located below the Fall River confluence: “The salmon in vast numbers reach the foot of this fall, and are now unable to pass.” The Commission arranged to have a fishway excavated out of the rock formation on the south side of Pit River Falls, in 1881, to enable the salmon to reach suitable spawning gravels above the falls (Throckmorton 1882). A new fishway was later constructed in 1902 (CFC 1904). Pit River Falls (65 ft high, according to Rutter) was “thought by many to rival in beauty any to be seen in the Yosemite Valley” (Rutter 1908, p 110), and which Rutter, in his 1904 paper, also stated had been impassable for salmon before the modification. Yet Rutter (1908, p 110) later noted that “each side is broken by ledges, so that it is possible in high water for fish to pass” — perhaps suggesting that salmon also could have surmounted the falls on the side opposite where the fishway was constructed. In fact, Powers (1874, p 413 and 1877, p 269), in discussing the first salmon ritual (probably for the spring run) of the Achumawi people on the Pit River, wrote: “After the vast crystal volume of Fall River enters and overcomes the swampiness of the snaky Pit, then salmon are caught, the Indians say, though the whites assert that they do not ascend above a certain tremendous cataract which is said to exist on the lower river.” That “tremendous cataract” undoubtedly was Pit River Falls and which may not have posed a complete barrier to the salmon, if the above statement is taken literally. Powers had made his observations on the Achumawi and other native groups during the early 1870s (primarily in the summers of 1870 and 1871; Heizer 1976), well before any attempt to modify Pit River Falls. However, Powers (1874, p 413) also stated in regard to salmon that, “they do not ascend the Pit to the mouth of Fall River,” and it is puzzling why salmon reputedly would not have ascended farther upstream to the Fall River once they had passed Pit River Falls. Overall, it seems likely that spring-run and perhaps winter-run salmon, if only in limited numbers, originally surmounted Pit River Falls and entered the Fall River some distance up its length — probably nine miles up to

the source springs near Dana. Kniffen (1928, p 312) correspondingly noted that the Fall River delimited the easternmost area where salmon were an important component of the native people's food economy in that region, and "Fall River also marked the upper limit of the salmon run." Likewise, Davis (1974, p 19) stated that the Achomawi and Atsugewi met "annually in the autumn in Fall River Valley when the winter supply of salmon was being laid in."

The historical abundance of salmon in the Fall River cannot be clearly determined. Young salmon were reportedly "common" in the Fall River in August 1898 (Rutter 1902). After construction of the new fishway in 1902, salmon were said to have passed over Pit River Falls "in considerable numbers" (Rutter 1908, p 110). It was reported that within two weeks of the opening of the new fishway (on 1 November 1902), "large numbers of salmon were found in Fall River...which was the first time they were seen in any numbers in those waters" (CFC 1904, p 52). Those fish were clearly fall-run salmon, and their newly observed occurrence in the Fall River indicates that the fall run previously had ascended only as far as Pit River Falls which barred their passage.

Clark (1929) stated that the spawning beds extended from the river mouth (where the river joins the McCloud and Little Sacramento rivers) to the Pit 4 dam, and there were suitable beds also in Squaw Creek and two or three smaller creeks. Access up the river was completely cut off by several power projects dams constructed during 1922-1927. Proceeding from the lowest to highest upriver, they were: Pit 4, seven miles below Burney and Burney Falls, 60 feet high and without fish passage facilities; Pit 3, nine miles above Pit 4, impassable to salmon; and Pit 1, near the town of Fall River Mills on the Fall River and also impassable (Clark 1929).

Stone (1874, p 176) stated that the salmon "come up Pit River in great numbers in the spring," but as the weather became warmer in late June or early July the salmon reportedly all "left Pit River for the colder waters of the McCloud." Stone thought it "probable that they ascend[ed] the upper waters of the Pit River also to a limited extent." Clark (1929) later noted both a spring run and a fall run occurring in the Pit River. Comparing with the earlier years of Stone's time, Clark described the salmon population in the Pit River in 1928 as "very small"; he mentioned statements from long-time residents of the river indicating that the Pit River formerly "was one of the best for salmon" but that the salmon had "decreased considerably" (Clark 1929, p 43). Based on observations made in July 1923, Clark estimated that "at the most" 150 to 200 salmon were stopped at the base of Pit 4 dam, and that they probably comprised the entire spring run (Clark 1929). As with the Little Sacramento and McCloud rivers, construction of Shasta Dam eliminated salmon runs into the Pit River drainage.

Cottonwood Creek (Tehama County). Cottonwood Creek, a tributary on the westside upper Sacramento Valley, historically supported both spring and fall runs and, presumably, also a late-fall run. The spring-run fish formerly migrated to the headwaters of the South and Middle forks of Cottonwood Creek—above Maple Gulch on the South Fork (Reynolds and others 1993) and about eight miles into Beegum Creek on the Middle Fork (DFG unpublished data). According to Hanson and others (1940), the North Fork has a two-part falls (15 ft and 10 ft high) that forms a natural barrier about five miles upstream of Ono; below the falls, the stream has only a limited amount of suitable pools and spawning gravel to support salmon.

The past abundance of salmon in Cottonwood Creek reportedly had been “considerable,” but by 1928 there was only “a very slight fall run” (Clark 1929, p 43). Clark stated that the salmon spawned near the mouth of the creek because low water flows did not allow them to ascend farther upstream. He reported the presence of an irrigation diversion (which lacked a fishway) 25 mi above the mouth on the South Fork, although salmon rarely reached that point, and several other smaller ditches for irrigation diversions. Holmberg (1972) also cited low streamflows as the primary factor limiting the salmon population in Cottonwood Creek, despite the presence of “excellent spawning grounds.”

In recent years before 1993, the fall, late-fall and hybrid fall-spring runs occurred in Cottonwood Creek (Reynolds and others 1993). Annual fall-run escapements ranged between “a few hundred” to >8,000 fish, averaging 1,000 to 1,500 (Reynolds and others 1993), and the latest escapements were about 700 fish in 1991 and 1,600 fish in 1992 (Kano 1998a, 1998b). The late-fall run numbered <500 fish, spawning in the mainstem and the lower reaches of the North, Middle, and South forks (Reynolds and others 1993). The spring run is believed to have averaged about 500 fish historically (Reynolds and others 1993), but there are no recent escapement estimates except for about 480 fish in 1998 (DFG 1998 unpublished data). Eight adult spring-run salmon were observed by DFG personnel during summer 1995 near the North and South forks (T. Healey, personal communication, see “Notes”). Low spring flows and high water temperatures may prevent the upstream migration of the spring run during some years (Reynolds and others 1993). In most recent years there has been only the bare remnants of a salmon run in Cottonwood Creek.

Stony Creek (Tehama County). Stony Creek is a west side tributary in the Sacramento drainage and formerly supported spring run and fall runs (Clark 1929). Stony Creek was said to have been “a very good salmon stream” before the placement of the irrigations dams (Clark 1929, p 45). Kroeber (1932, p 295), drawing from ethnographic data, stated that “Salmon, for instance, ran up Stony creek through Wintun as far as Salt Pomo territory.” The downstream (eastern) bor-

der of the Salt Pomo (Northeastern Pomo) tribe has been placed at the confluence of Stony Creek and Little Stony Creek, about five miles below Stonyford (Kroeber 1925, p 224, McLendon and Oswalt 1978), so that point would have been the minimal upstream range of salmon. By 1928, both spring and fall runs were nonexistent due to irrigation diversions that kept the stream dry except during the rainy season (Clark 1929). At that time, there were two permanent dams on the creek: the Orland Project Dam (20 ft high, built about 1914) four miles west of Stonyford, and a dam on Big Stony Creek (90 ft high, "too high for a fish ladder") (Clark 1929). There was also a dam across Stony Creek where an irrigation canal built by the Glenn Colusa Irrigation District (GCID) crossed the creek about three miles upstream of its mouth. This dam was usually washed out in high water, but most of the time it would have been a barrier to salmon, had there been any water in the creek (Clark 1929). Presently there are three storage reservoirs on the creek (Reynolds and others 1993). There is "excellent" spawning gravel within the about 20 miles of stream between the creek mouth and the lowermost dam, Black Butte Dam, which would be a barrier to salmon (Reynolds and others 1993). However, the GCID canal, which crosses Stony Creek downstream of Black Butte Dam, completely bars salmon migration any farther upstream (Reynolds and others 1993; USFWS 1995). This cross-stream barrier is now seldom washed out except when flood control releases are made from Black Butte Reservoir.

Miscellaneous Small Sacramento Valley Tributaries. In addition to Antelope, Cottonwood, and Stony creeks, more than a dozen other small tributaries in the northern Sacramento Valley occasionally supported fall-run salmon spawning stocks during the period 1940–1959 in years of early and heavy rains, and a few of those streams also had spring runs (Fry 1961). In Clear Creek, spring-run salmon were observed in 1949 and 1956 (Azevedo and Parkhurst 1958 unpublished report); they most likely ascended past the present site of Whiskeytown Reservoir to somewhere above the French Gulch area (about 1,400 ft elev.). Clear Creek in some years still supports a substantial fall run, which was estimated to have numbered up to 10,000 spawners in 1995 (DFG unpublished data). Thomes Creek supported a small spring run. Murphy (1946) observed three adult salmon in early August 1946 in a pool situated within The Gorge area below Lake Hollow, eight miles upstream from the town of Paskenta; however, no salmon were observed in that stream during a later survey in the 1960s (T. Healey, personal communication, see "Notes"). In contrast, spring-run salmon probably did not use the Cow Creek drainage to any significant extent either because there is no suitable over-summering habitat (specifically, deep bedrock pools), particularly lacking in the South Fork, or because natural barriers prevented access to the headwaters, as in the other forks. Fall-run salmon presently occur in the mainstem Cow Creek up to where the South Fork joins, and they ascend the South Fork up to Wagoner Canyon. In the North Fork Cow Creek, fall-run fish are stopped by falls near the Ditty Wells fire station of the California Department of Forestry. Occasionally, late-fall

run salmon also occur in Cow Creek. Fall-run salmon reportedly migrated 20 mi up Stillwater Creek to spawn in 1938, when the fall rains began early (Hanson and others 1940). Cache and Putah creeks, two intermittent streams on the westside lower Sacramento drainage, have supported fall salmon runs only during wet years within historical times (Shapovalov 1947). Decades ago, salmon were observed as far upstream as Capay Dam in Cache Creek (Hanson and others 1940, Shapovalov 1947) and near the town of Monticello in Putah Creek (Shapovalov 1947). Based on archaeological remains from earlier times (about AD 1450–1650), Putah Creek long ago provided salmon to the local Native Americans in at least some minor quantity (Schulz 1994 unpublished manuscript). Fry (1961) reported that the combined fall runs (including late-fall) for the miscellaneous Sacramento tributary streams totaled 1,000 to 13,000 fish annually during 1940–1959. The spring-run totals, available for only three years in that period, were <500 fish in both 1944 and 1945 and 1,000 fish in 1956 (Fry 1961). During 1953–1969, the Cow Creek drainage alone supported a fall run that averaged 2,800 fish (Reynolds and others 1993). In most recent years, the combined fall run in these miscellaneous streams, if existent, has been inconsequential and the spring run essentially has not occurred (Reynolds and others 1993).

Conclusion: Quantitative Assessment of Distributional Changes

It has been estimated that before the placement of man-made obstructions in the streams of the Sacramento and San Joaquin drainages there were “at least 6000 linear miles of streambed suitable and available to spawning salmon” (Clark 1929), although the process by which that figure was determined was not explained. Given the sheer magnitude of that estimate, it is evident that not only spawning habitat but all lengths of stream traversed or occupied by salmon (migration corridors and holding areas) were included. The actual amount of spawning habitat that was originally used by, or available to, Central Valley salmon is not clearly known but as early as 1918 the California Fish and Game Commission (CFG) acknowledged that “Fully 80 per cent of the natural spawning grounds of the Sacramento River basin have been destroyed by the mines, and dams constructed for the purpose of generating electricity, and by the diverting of water for irrigation purposes” (CFG 1921a, p 20). For the period 1924–1926, the CFG reported that “approximately 90 per cent of the spawning areas in these two river systems [Sacramento and San Joaquin rivers] have been cut off from the salmon or destroyed” (CFG 1927, p 35). By 1928, the amount of spawning stream habitat in the entire Central Valley drainage had been reduced to an estimated 510 linear miles with reportedly “At least 80 per cent of the spawning grounds...cut off by obstructions” — which included 11 dams in the San Joaquin system and 35 dams in the Sacramento system that posed partial or complete barriers to salmon (Clark 1929, p 28). Van Cleve (1945) later estimated a somewhat lesser loss of 75% of the orig-

inal spawning habitat due to all causes. In 1993, the total amount of existent spawning habitat for salmon and steelhead in the Central Valley drainage was estimated by the California Department of Fish and Game to be less than 300 miles (Reynolds and others 1993).

We estimated from map distances the stream lengths that have been lost as salmon habitat in each of the major Central Valley watersheds due to installation of barriers or the reduction of streamflows that made passage of salmon impossible under usual conditions (Table 2). We included reaches of streams which salmon are known or can be inferred to have had access to, whether for holding or spawning purposes. These estimated stream lengths are minimal estimates because we have considered only the mainstems and the major forks and tributaries as salmon habitat. Numerous small third- and fourth-order streams very likely were used to some degree by spawning salmon, for which records do not exist, although the numbers of salmon using those smaller streams would have been relatively small. In fact, the full extent of the historical distribution of salmon even in the major stream reaches is not clearly known for some watersheds (for example, Middle Fork American River, mainstem and South Fork Merced River). Furthermore, recent studies have shown that juvenile salmon in large numbers, and some steelhead, enter small temporary streams for rearing (for example, Rock, Mud, Pine, and Toomes creeks in the northern Sacramento Valley) even though spawning by salmon may not necessarily occur in those streams (Maslin and McKinney 1994 unpublished report). Undoubtedly, salmon historically used those and other non-natal "nursery" streams, as probably did steelhead (IEP 1998 unpublished report), but we have no way of accurately assessing the distributional extent of such usage.

Based on the available information, our estimates indicate that the amount of habitat that was lost differs greatly from watershed to watershed. In the Bear River, for example, the length of stream accessible to salmon has changed very little, while in Deer Creek it actually has increased by several miles due to artificially improved fish passage over natural barriers. In lower Battle Creek, the salmon were blocked for many years by the Coleman National Fish Hatchery weir, but in recent years access to upstream reaches has been reopened for the winter- and spring-run fish so that much of the historical range is again available to those runs. However, in most watersheds considerable portions of the former salmon-supporting reaches are no longer accessible to salmon, and some watersheds have been entirely removed from salmon production—namely, McCloud, Pit, Upper (Little) Sacramento, and upper San Joaquin rivers. The general pattern has been the elimination of the higher foothill and mountain reaches in the Sierra Nevada and Cascades from the distributional range of chinook salmon.

Summing the stream-by-stream estimates of accessible salmon habitat (for streams tabulated in Table 2) yields a total of 1,126 mi of main stream lengths presently remaining of the more than 2,183 mi of Central Valley streams that we estimate were originally available to chinook salmon—indicating an overall loss of at least 1,057 mi or 48% of the original total. Our estimate of 1,126 mi is remarkably similar to the figure of 1,075 mi of “chinook habitat” in the Central Valley given by Holmberg (1972) almost three decades ago. Our calculations did not include the Sacramento-San Joaquin Delta, comprising about 700 mi of river channels and sloughs (USFWS 1995), available to various degrees as migration corridors or rearing areas for salmon. In contrast to most previously cited estimates specifying only spawning habitat, our figures include the lengths of stream used by salmon mainly as migration corridors (for example, the lower Sacramento and San Joaquin rivers) in addition to holding and spawning habitat. Our figures include about 200 mi in the lower Sacramento River (below Tehama), about 50 mi in the lower San Joaquin River (below the confluence of the Merced River), and the lower reaches of several tributaries which contain no spawning habitat. It is likely that those lower Sacramento and San Joaquin reaches historically were used as rearing areas (at least during some flow regimes) as the juveniles moved downstream, but in recently they have been less suitable for rearing due to alterations in channel morphology and other degraded environmental conditions. In terms of only spawning and holding habitat, the proportionate loss far exceeds 48% because a relatively large portion of the original spawning habitat was located in upper stream reaches that have been cut off by dams. In contrast, much of the remaining lengths of stream in the lower drainages now traversed by salmon cannot be used for spawning. Of the total length of stream courses presently accessible, less than one-third in the San Joaquin River drainage and probably less than a half in the Sacramento River drainage are suitable as spawning habitat. Excluding the lower stream courses that were used only as adult migration corridors (and only minimally for juvenile rearing)—by our estimate amounting to 709 stream miles—we roughly calculate that at least 72% of the original spawning and holding habitat for salmon in the Central Valley drainage is no longer available. Thus, the DFG’s most recent assessment that about 95% of the original spawning habitat has been lost is perhaps somewhat high but probably roughly accurate (Reynolds and others 1993). However, the earlier estimate by Clark (1929, p 28) that there were “at least 6,000 linear miles of stream bed suitable and available to spawning salmon” probably is overly high by a factor of three.

The amount of habitat loss for steelhead most likely was much higher than that for salmon because steelhead were undoubtedly more extensively distributed. Due to their superior leaping and swimming ability, the timing of their upstream migration which coincided with the winter rainy season, and their less restrictive preferences for spawning gravels, steelhead could have used at least hundreds of miles of smaller tributaries not accessible to even the highest migrating winter-run and spring-run salmon.

Table 2 Estimated changes in lengths of stream available to chinook salmon in the major salmon-supporting watersheds of the California Central Valley ^a

<i>Watershed</i>	<i>Length (mi) of stream historically available ^b</i>	<i>Length (mi) of stream presently accessible ^c</i>	<i>Length (mi) of stream lost (or gained) ^d</i>	<i>Percent lost (or gained)</i>
Sacramento River Basin				
Mainstem Sacramento R. ^e	299	286	13	4
Pit River	99	0	99	100
McCloud River	50	0	50	100
Upper (Little) Sacramento R.	52	0	52	100
Eastside Streams				
Battle Creek	43	6 [43] ^f	0	0
Antelope Creek	32	32	0	0
Mill Creek	44	44	0	0
Deer Creek	34	38	(4)	(12)
Big Chico Creek	24	24	0	0
Butte Creek	>53	53	>0	>0
Feather River	211	64	147	70
Yuba River	80	24	56	70
Bear River	16	16	0	0
American River	161	28	133	83

^a The estimates for stream lengths originally available and subsequently lost are in most cases minimal values because the full extent of the former salmon distributions in individual streams is incompletely known. Additional minor streams such as Thomes, Paynes, Cache, and Putah creeks (and perhaps a dozen others in the Sacramento Valley) historically supported salmon (Fry 1961)—probably only the fall run and only during wet years. The historical upstream limits of salmon in those streams is too poorly known to allow inclusion in this table. Current salmon production in those streams is limited because of a number of factors, including low streamflows, habitat degradation and obstruction by irrigation canal crossings (DFG 1993).

^b Lengths of all stream reaches known or presumed to have been traversed or used by salmon in the drainage are included.

^c Length between the mouth of the stream and the current upstream limit.

^d Length of stream gained is given in parentheses; this situation applies only to Deer Creek.

^e From Rio Vista in the north Sacramento-San Joaquin Delta upstream to the confluence of the Upper (Little) Sacramento and Pit rivers.

^f First number pertains to the fall run; second number [in brackets] pertains to the spring and winter runs. The fall run in Battle Creek is stopped by the Coleman National Fish Hatchery weir, six miles above the mouth; the fall run's historical upper limit is not known, but we presume it was not much further upstream of the current limit at the hatchery weir. Spring-run and winter-run salmon currently are allowed to pass upstream and probably ascend to much of the historical range (that is, an additional 37 stream miles above the hatchery weir).

^g From Mossdale in the south Sacramento-San Joaquin Delta upstream to the confluence of the Merced River. This stretch lacks spawning gravels and serves primarily as a migration corridor.

^h Includes the mainstem San Joaquin River above the confluence of the Merced River.

Table 2 Estimated changes in lengths of stream available to chinook salmon in the major salmon-supporting watersheds of the California Central Valley ^a (Continued)

<i>Watershed</i>	<i>Length (mi) of stream historically available ^b</i>	<i>Length (mi) of stream presently accessible ^c</i>	<i>Length (mi) of stream lost (or gained) ^d</i>	<i>Percent lost (or gained)</i>
Westside Streams				
Clear Creek	25	16	9	36
Cottonwood Creek	79	79	0	0
Stony Creek	54	3	51	94
Cow Creek	32	32	0	0
San Joaquin River Basin and Sacramento-San Joaquin Delta				
Lower San Joaquin R. ^g	50	50	0	0
Cosumnes River	31	31	0	0
Mokelumne River	92	64	28	30
Calaveras River	approx. 38	38	0?	0?
Stanislaus River	124	58	66	53
Tuolumne River	104	52	52	50
Merced River	107	51	56	52
Upper San Joaquin R. ^h	173	0	173	100
Kings River	76	0	76	100
Central Valley Total	2183	1126	1057	48

^a The estimates for stream lengths originally available and subsequently lost are in most cases minimal values because the full extent of the former salmon distributions in individual streams is incompletely known. Additional minor streams such as Thomes, Paynes, Cache, and Putah creeks (and perhaps a dozen others in the Sacramento Valley) historically supported salmon (Fry 1961)—probably only the fall run and only during wet years. The historical upstream limits of salmon in those streams is too poorly known to allow inclusion in this table. Current salmon production in those streams is limited because of a number of factors, including low streamflows, habitat degradation and obstruction by irrigation canal crossings (DFG 1993).

^b Lengths of all stream reaches known or presumed to have been traversed or used by salmon in the drainage are included.

^c Length between the mouth of the stream and the current upstream limit.

^d Length of stream gained is given in parentheses; this situation applies only to Deer Creek.

^e From Rio Vista in the north Sacramento-San Joaquin Delta upstream to the confluence of the Upper (Little) Sacramento and Pit rivers.

^f First number pertains to the fall run; second number [in brackets] pertains to the spring and winter runs. The fall run in Battle Creek is stopped by the Coleman National Fish Hatchery weir, six miles above the mouth; the fall run's historical upper limit is not known, but we presume it was not much further upstream of the current limit at the hatchery weir. Spring-run and winter-run salmon currently are allowed to pass upstream and probably ascend to much of the historical range (that is, an additional 37 stream miles above the hatchery weir).

^g From Mossdale in the south Sacramento-San Joaquin Delta upstream to the confluence of the Merced River. This stretch lacks spawning gravels and serves primarily as a migration corridor.

^h Includes the mainstem San Joaquin River above the confluence of the Merced River.

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Shasta Salmon Salvage Efforts: Coleman National Fish Hatchery on Battle Creek, 1895–1992

Michael Black

Dedication

This paper is dedicated to the memory of wily fisherman and indefatigable salmon champion Nat Bingham. Named for a New London, Connecticut, whaling ship's captain, Nathaniel Shaw Bingham knew the best way to chart salmon futures was by peering unflinchingly into their and our own respective pasts.

I. The Early Years on Battle Creek

For well over a century, Californians have sought to compensate for depleted salmon runs in the upper Sacramento River Basin by creating fish hatcheries. Beginning in 1872, fish culturalist Livingstone Stone located the West's first fish hatchery on the lower McCloud River. Between 1870 and 1960, 169 significant public and private fish hatcheries and egg collecting stations were operated throughout the state (Leitritz 1970, p 11). The fifth hatchery to be owned and managed by the US Commission of Fish and Fisheries (later renamed the US Fish Commission), was the Battle Creek Station located near Anderson.

Originating on the western slopes of Mt. Lassen, Battle Creek flows some forty-two miles before emptying into the Sacramento River. Due largely to melting snow, Battle Creek enjoys a cold, year-round supply of filtered water. Porous volcanic rock acts as a sponge to absorb and gradually release stored underground waters. This Cascade stream also enjoys a reasonably steep gradient, falling some 5,000 feet, which made it a prime candidate for early hydroelectric development (Reynolds 1980, p 23). In 1901, five years after fish culturalists began harvesting Battle Creek's thriving populations of fall-, winter-, and spring-run chinook salmon, developers sought to cash in on its hydroelectric potential. The Volta plant would generate peak load power for a proposed copper smelter at Keswick, near Mountain Copper's Iron Mountain mine (Reynolds 1980, p 29).

Before this hydroelectric system went into effect, fish culturalists enjoyed an optimum five-year window for harvesting returning stocks of Battle Creek salmon. In 1893, J.P. Babcock (later named the station's Chief Deputy and director) recommended to California's Fish Commissioners that a new Sacramento River spawning station be established (Leitritz 1970, p 24). In September 1895, a hatchery was erected near the mouth of Battle Creek, in Tehama County (SBFC 1896, p 23). Investigators reported large numbers of salmon entering this stream during the months of October and November. Between October 21, and November 12, 1895, the hatchery's full capacity of 10 million eggs was easily reached (SBFC 1896, p 24). Hatchery personnel noted "...there [was] almost no limit to the numbers of eggs which can be secured there with proper apparatus" (SBFC 1896, p 24). John J. Brice, then US Commissioner of Fisheries, was approached about supplying that "proper apparatus" by erecting a much larger facility on Battle Creek.

In August, 1896, the US Fish Commission erected temporary structures at the Battle Creek site to handle any surplus spawn. During 1896 and 1897, the Battle Creek Station, as it was called, was jointly operated by the State of California and the US Fish Commission (SBFC 1898, p 35). In the 1896 season, the facility gathered twenty-six million eggs and in the following year, forty-eight million eggs (SBFC 1898, p 35). California's Fish Commissioners reported:

The location and operation of the Battle Creek station has been the most successful propagation work ever undertaken on this coast, and in its magnitude and importance equals any work of its kind in the world (SBFC 1898, p 35).

During winter 1897, Congress set aside funding to purchase the State's interest in the Battle Creek facility, and it soon became the fifth federal breederly in the State (Biennial Report 1897-1898, p 35). Upon receipt of payment, California's Fish Commissioners shifted their investment to Mount Shasta City's Sisson hatchery.

In its early years, the Battle Creek facility was capable of producing as many as 60 million fertilized eggs (Leitritz 1970, p 24). In a letter dated December 5, 1904, G. H. Lambson, Superintendent of the US Bureau of Fisheries stations in California, remarks:

There is a large run of fish in both Battle and Mill creeks and there is hardly any limit to be placed on the number of eggs we could take if we had the room. We could have taken fully eighty to one hundred million at Battle Creek and about sixty million at Mill Creek if we could have fished daily (SBFC 1904, p 107).

Recognizing the need to overcome "...the double odds of natural and human enemies," biologist Cloudsley Rutter pointed toward artificial propagation as

the sole hope for the Sacramento River salmon (SBFC 1904, p 106). Believing that “the relative efficiency of natural versus artificial propagation is about one percent and eighty-five percent, respectively,” (SBFC 1904, p 105) Rutter wrote:

Artificial propagation is keeping up the supply of salmon in the Sacramento River. With one exception, there are now no natural spawning beds in the Sacramento basin that amount to anything. All of the Feather, Upper Sacramento, and Pit rivers, with their tributaries have been practically abandoned, with the exception of the streams where the hatcheries are located. The only natural spawning beds still occupied are in the main river, between Redding and Tehama, which are yet visited by a considerable number of salmon (SBFC 1904, p 106).

When Rutter assisted at the Battle Creek Station in August, 1897, he and his colleagues helped catch a record number of fall-run Sacramento salmon ascending Battle Creek (8,784 fish were spawned yielding 48,527,000 eggs). Between their weirs and nets, Schofield reports they “took almost every fish in the river,” making artificial propagation the sole tool of choice for saving the Sacramento’s beleaguered salmon (Jennings 1996, p 16; Schofield, as cited in SBFC 1898, 1900, p 69). Writing four years later, a confident Rutter concluded: “Artificial propagation of salmon has not yet reached such proportions as to entirely supplant natural propagation, with the exception of the work on the Sacramento River” (Rutter, as cited in SBFC 1904, p 105).

The Battle Creek Station remained in operation through 1945 when a new set of threats to fish and fisheries was felt throughout Western watersheds. From the Pacific Northwest’s Columbia River to California’s Sacramento River, federal agencies like the US Bureau of Reclamation (the Bureau) built pharaonic dams like Grand Coulee and Shasta. Attempts at reconciling anadromous fish losses with massive water development stemmed from the Grand Coulee Dam’s construction. In rapid succession, experimental “fish salvage” efforts occurring on the Columbia River were attempted in the Sacramento River basin where the Coleman National Fish Station was erected¹.

1. As former DFG biologist Richard Hallock points out, the original Battle Creek Station site was essentially abandoned.

II. Columbia River Antecedents

Upon its completion in 1941, the Columbia River's Grand Coulee Dam prevented roughly 100,000 chinook, sockeye, and steelhead from ascending 1040 miles of prime upstream habitat. Originally slated by the US Army Corps of Engineers to have been a "low dam" like Bonneville, the project had, by 1935, metamorphosed under Franklin D. Roosevelt's Public Works Administration and the Bureau, into the largest dam ever erected in North America (Reisner 1986, p 162-163). Impassable to migratory fish, it also became the proving grounds for subsequent, large-scale "fish salvage" efforts throughout the arid West. When it came to federal and State-level institutions, personnel, scientific, and technological precedents, fish rescue strategies at Grand Coulee foreshadowed what was later attempted on California's Sacramento River.

Willis H. Rich greeted the big dam era with trepidation (Rich 1939). The Stanford University professor (a classically educated biologist) was retained in 1938 by the Oregon Fish Commission to direct their new Research Division (Taylor 1996, p 355)². Rich was dubious about excessive reliance on hatcheries as a means of mitigating fishery losses (Lichatowitch, personal communication, see "Notes"). In 1939, speaking before assembled ichthyologists at Stanford University, Rich concluded:

Biologists in general are skeptical of the claims made for artificial propagation...because these claims have often been extravagant and the proof is entirely inadequate. Indeed, many conservationists feel that the complacent confidence felt by fishermen, laymen, and administrators in the ability of artificial propagation to counterbalance any inroads that man may make...is a serious stumbling block in the way of the development of proper conservation programs (Rich as cited in Taylor 1996, p 354).

Rich was more circumspect in his criticism of hatcheries. He recognized that enormous dams transformed hatcheries into self-fulfilling prophecies: dramatically shrinking natural habitats meant escalating hatchery programs (Taylor 1996, p 352). During the 1920s and 1930s, Alaska and British Columbia provided rare instances where hatchery-driven salmon production was deliberately scaled back due to excessive costs. Within these unique cases, however, artificial propagation could only be traded for intact spawning grounds (Taylor 1996, p 348; Calkins and others 1939b, p 6). Rich had no alternative but to accommodate himself to the big dam era, hoping that some day "general principles" might be discovered which reconciled massive water develop-

2. This account greatly benefits from Joseph E. Taylor's thoughtful synopsis of fish salvage efforts surrounding Grand Coulee Dam (Taylor 1996, p 350-360). The narrative that follows refers to the various roles Willis H. Rich played in his advisory capacity.

ment with the biological requirements of anadromous fish (Taylor 1996, p 355).

There was also the added matter of federal institutional precedents which had, for seventy years, informally mitigated for habitat losses by means of technological remedies like hatcheries (Black 1995). National fish mitigation policies accompanying dam construction finally became formalized under the Federal Power Act of 1920, spelling out compensatory obligations accompanying water projects. States, too, exhibited a strong predilection toward relying on hatcheries to rescue fisheries blocked by dams. Beginning roughly in 1906, Washington State shifted toward a policy of hatcheries "in lieu" of dams. Oregon began embracing the practice in 1909 (Taylor 1996, p 351).

The Mitchell Act³ was passed by Congress in 1938 directing the Bureau and the Army Corps of Engineers to assist the US Bureau of Fisheries in saving salmon (Taylor 1996, p 357). The traditional mix of technological mitigations was amended by the desire to relocate, to downstream tributaries if possible, fish stocks displaced by massive dams. For example, the Grand Coulee Fish Maintenance Project (GCFMP) was designed to sustain the production of mid-Columbia River salmon and steelhead populations at levels comparable to those before dam construction. By restoring natural propagation within the downstream Wenatchee, Entiat, Methow, and Okanogan tributaries, biologists hoped to expand suitable substitute habitats for displaced wild fish (Mullan 1992, p iii; Hobart, personal communication, see "Notes"). Returning migratory species were trapped at downstream Rock Island Dam before being hauled and released upstream of temporary weirs, or transferred to the Leavenworth, Entiat, and Winthrop national fish hatcheries for artificial propagation (Mullan 1987, p iii).

As environmental historian Joseph Taylor observes, the Grand Coulee Fish Maintenance Project required that a century's accumulated managerial and technological precedents be systematically recombined and directed at relocating and producing fish on an undreamed of scale. Successful fish salvage efforts hinged upon: (1) identification and restoration of downstream tributaries suitable for fish transplantation and reproduction; (2) construction of a greatly expanded hatchery system; and (3) invention of a new means of moving fish around (Taylor 1996, p 358).

Several stages were required to achieve the objectives of the Grand Coulee Fish Maintenance Project. The initial task necessitated gathering a comprehensive inventory of downstream watersheds and their inhabitants. This included devising a means of measuring existing fish populations, evaluating their ecological suitability for fish habitats, and identifying adverse conditions

3. See Statute 345, 75th Congress, 3rd Session, May 11, 1938.

capable of undermining fish survival (like unscreened irrigation diversions and pollution). Works Projects Administrations' laborers cleared streams of obstacles like beaver dams, constructed fishways around instream blockages, and screened irrigation diversions.

Next came a program for significantly increasing hatchery production. Initially, Bureau policymakers presciently suggested setting aside "...some streams as fish refuges on which no conflicting water development would be made" (Bureau memorandum, as cited in Taylor 1996, p 358-359; ff. 76). However, Bureau leaders lacked sufficient power and political gumption to risk angering competing developmental interests, many of whom were agency supporters (Taylor 1996, p 358). Instead, they resorted to fine tuning and expanding existing hatcheries and constructing new facilities such as the Leavenworth plant on Icicle Creek.

As a tributary of the Wenatchee River, Icicle Creek proved to be a curious hatchery site. This facility, which anticipated handling 76.5 million eggs annually, sought to reproduce an annual run equivalent to 36,500 fish (Calkins and others 1939b, p 4)⁴. However, the creek's waters completely dried up during late summer months. Bureau engineers nonetheless guaranteed Leavenworth a year-round supply of water by boring a two-thousand-five-hundred foot tunnel from nearby Upper Snow Lake. With sufficient engineering talent and money, even significant mitigation obstacles like these were retired with dispatch.

The project's final task lay with moving salmon around. By May, 1939, federal and State workers began trapping incoming salmon at Puget Sound Power and Light's Rock Island Dam. During the first year alone, eight Bureau-supplied tank trucks relocated 36,000 salmon to the Wenatchee, Methow, Okanogan, and Entiat rivers (Taylor 1996, p 359). In 1940, once holding ponds at the new Leavenworth hatchery had been completed, US Fish and Wildlife Service personnel began hauling fish to be ripened for artificial propagation. Finally there was the matter of sockeye (or "blueback") salmon, which had once migrated to reproduce in upper Columbia River nursery lakes. Most sockeyes were transported for rearing in Wenatchee and Osoyoos lakes, located on Wenatchee and Okanogan rivers (Mullan 1987, p 31).

Board of Consultants Recommendations: Round One

In 1938, Secretary of the Interior Harold L. Ickes appointed a "Board of Consultants" (Board) to review fish salvage proposals on the Columbia (and later the Sacramento) River. Consisting of two Stanford University professors and a

4. Consisting of 41 million chinook, 21.5 million sockeye, and 14 million steelhead eggs (Calkins and others 1939, p 4).

third faculty member from the University of California. (Stanford contributed W. F. Durand, Professor Emeritus of Mechanical Engineering and Willis H. Rich, Professor of Biology. Berkeley supplied R. D. Calkins, Professor of Economics). Their selection reflected the Department of the Interior's and the Bureau's predisposition toward finding cost-effective engineering solutions in significantly altered western watersheds. Doubtless these individuals were chosen for their particular areas of expertise, for their perceived autonomy as faculty members at prestigious universities, and for subtly distancing the sponsoring agency from any political repercussions arising from the Board's judgment.

Within their October 3, 1938 letter of appointment, Secretary of the Interior Ickes instructed Professors Calkins, Durand, and Rich that:

Your report should review all phases of the situation and the proposed plans of the state with a view to determining their feasibility from physical and biological standpoints, and whether the program as a whole, and the various features thereof, are economically justifiable...Your recommendation is also desired as to what proportion of the cost of such works...should be charged against the funds provided by the federal government for the construction of Grand Coulee Dam and what proportion should equitably be borne by other agencies such as the State of Washington and the US Bureau of Fisheries (Calkins and others 1939b, p i).

Their Columbia River document was subdivided into two sections; the first of which addressed temporary means for salvaging some portion of the threatened 1939 and 1940 salmon runs. Washington State Department of Fisheries biologists counted a total of 28,000 chinook and sockeye salmon and steelhead passing upstream from Rock Island Dam. Of this total, biologists estimated that 10 percent entered the Wenatchee, Methow, Okanogan, and Entiat rivers, while 90 percent proceeded upstream from the Grand Coulee site into the upper Columbia River Basin (Calkins and others 1939, p 4). The Board of Consultants report recommended: (1) peak run fish trapped at Rock Island Dam be temporarily transported upstream of Grand Coulee Dam; (2) eight 1,000-gallon tank trucks be secured to experimentally transport anadromous fish; (3) during 1940 and 1941 Grand Coulee reservoir levels be maintained at an optimum level to facilitate downstream fish passage; and (4) a source of "eyed eggs" be secured for placement within the four tributaries between Grand Coulee and Rock Island dams (Calkins and others 1939a, p 14-15).

The blue ribbon panel instructed the Bureau to construct a hatchery for, among other species, steelhead trout, which they called "...one of the principal sport fish of the area" (Calkins and others 1939a, p 15). In 1937, Washington State authorities issued a total of 199,000 state and county hunting licenses. Hunters and sportfishers expended some four million dollars a year on addi-

tional recreational goods and services, leading panelists to conclude: "...that a serious importance [be] attached to this form of recreation and to the game fish in the Upper Columbia River..."(Calkins and others 1939a, p 17). While a hatchery capable of propagating steelhead, chinook and sockeye was to be built at federal expense, its subsequent administration, operation and maintenance would fall to the State and remain entirely a State enterprise (Calkins and others 1939a, p 18)⁵.

Part Two of "Fish Problems of the Upper Columbia River" responded to a detailed fish salvage plan submitted by the Washington State Department of Fisheries. The scheme sought to transfer fish once spawning above Grand Coulee Dam to the four tributaries immediately below (Calkins and others 1939b, p 65). Biologists proposed expanding the carrying capacity of the Wenatchee, Methow, Okanogan, and Entiat rivers to raise their fish populations to historic levels. Two hundred seventy-five thousand dollars in State monies were allotted to accomplish "stream rehabilitation." In addition, Board members ratified State recommendations calling for a combination of "...artificial spawning, hatching, feeding, rearing, and planting..." sufficient to compensate for 1,100 miles of blocked, upper river habitats. Up to one million chinook salmon fingerlings were also to be raised and released just before their seaward migration. (Calkins and others 1939b, p 1-2, 10, 77).

Under the guidance of Service biologists like Fred J. Foster, Regional Director of Seattle's Division of Fish Culture, artificial propagation figured prominently in the overall fish salvage effort⁶. Washington State's plan called for an initial expenditure of \$2,760,000 at an annual operating cost of \$184,000 (Calkins and others 1939b, p 65)⁷. In addition to the prominent Leavenworth facility, other "auxiliary hatcheries" capable of handling "eyed eggs" were called for on the Entiat, Methow, and Okanogan rivers (Calkins and others 1939b, p 3). Citing a "factor of safety" provided by hatcheries, Board members characterized the overall effort "...as an experiment in fish culture on a large scale..." (Calkins and others 1939b, p vi).

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5. The Board of Consultants recommended that the whole project be administered by "...the Federal Bureau of Fisheries, with the organization of a joint Advisory Board representing the states of Washington and Oregon and the US Bureau of Reclamation" (Calkins and others 1939b, p 8). State of Oregon resistance to federal interference in its fisheries are well documented by Taylor (1996).
 6. See Fred J. Foster, "Outline of Artificial Propagation of Fish on the Lower Columbia River" (c. July 1937), box 611, fldr. 826.53, Entry 269; cited in Taylor 1996, p 357.
 7. The document notes parenthetically that the Washington State Report of 1938 was "...later modified by some reduction in the size of proposed hatchery plants" (Calkins and others 1939b, p v).

Board members were candid in acknowledging the unpredictable nature of their proposed undertaking:

...[W]e recognize fully the experimental nature of the attempt to replace natural propagation above Grand Coulee by artificial propagation of the same fish populations at hatcheries located below the dam. We believe that no one can be assured of the success of such a venture but, on the other hand, this plan appears, in the present instance, to be the only feasible means to the desired end (Calkins and others 1939b, p 7).

The hoped for gamble was twofold: artificial propagation could eventually be replaced by natural propagation within restored lower river tributaries, and, among intensely exploited fisheries, hatcheries could support much higher levels of fish productivity (Calkins and others 1939b, p 6-7).

By 1943, dam boosters (including the Bureau), touted the success of the Grand Coulee Fish Maintenance Project. Queried by a Reader's Digest editor, one representative of the US Fish and Wildlife Service (the Service) characterized the entire program as "highly satisfactory" (Taylor 1996, p 360). Assuaging a skittish public of their legitimate concerns about threatened sportfish may have invited an optimistic rush to judgment. Not all participants were as sanguine, however. Willis H. Rich wrote of artificial propagation:

...[that] actual accomplishment has seldom shown a sufficiently clear improvement over natural propagation to warrant the expenditure except in the case of a few small isolated runs (Rich, as cited in Calkins and others 1939b, p 6).

Rich knew that this was no small project. Biologists like Rich, however, lacked the luxury of contemplation, as large dams continued being erected throughout the arid West. One such was at Kennett, on California's Sacramento River, where prior institutional precedents, personnel, techniques and rationale were recast in a renewed effort at salvaging salmon.

III. The Central Valley Project Era

When Shasta Dam construction began interfering with salmon passage on November 8, 1942, the Central Valley Project's centerpiece drastically affected an array of migratory salmon stocks. Sacramento River runs were once distinguishable by their many attributes including run-timing, size, and varying spawning habitats. Winter-run stocks once relied upon spring-fed headwaters like those provided by the Little Sacramento, the Pit, the McCloud, and Fall rivers, and in nearby Battle Creek (Yoshiyama and others 1998, p 490-491; Ward and Kier 1998, p 10-11; USFWS and Richardson 1987c; USFWS 1998)⁸. Spring-run stocks arrived in "pre-reproductive and peak physical condition" and frequented extreme elevations within mountainous streams fed by snow-melt. Late fall-run stocks spawned within the upper Sacramento's mainstem and those tributary reaches blocked by the Shasta-Keswick complex (and perhaps in upper tributaries like the American River). Fall-run stocks arrived about ready to spawn but the fish were often in a somewhat compromised physical state. They predominated within the lower river and its foothill reaches at elevations of 500 feet or less (Yoshiyama and others 1996, p 312-313; Rutter 1904; Fisher 1994)

Once erected, the Shasta-Keswick complex excluded now-endangered winter-run salmon from all of their historic spawning grounds (save for Battle Creek) (Hedgpeth 1941; Slater 1963). Spring-run salmon also lost access to their extreme headwater habitats. The late fall-run was cut off from most of its historic spawning beds. Least adversely affected were fall-run fish, whose lower river spawning gravels remained relatively intact. By one estimate, fall-run chinook salmon lost an estimated 15 percent of its upper river habitat due to the erection of Shasta-Keswick dams⁹.

US Bureau of Fisheries biologists Harry A. Hanson, Osgood R. Smith, and Paul R. Needham, among others, were given barely three years to complete their Bureau sponsored investigation into the dam's full effects. Working at a breakneck pace, the investigating team made a number of recommendations

8. At the turn of the century, biologist Cloudsley Rutter captured newly emerged winter-run salmon fry in September and early October within Battle Creek's waters (Rutter 1902, 1903). As fisheries scientists Michael Ward and William Kier observe, the fish could not have originated within the downstream Sacramento River's mainstem due to lethal water temperatures (Kier and Ward 1998, p 10). Recently compiled Fish and Wildlife Service evidence documents existing Coleman hatchery-origin winter-run stocks in addition to "...a remnant population of wild winter-run [fish]" (USFWS 1998, as cited in Kier and Ward 1998, p 10).

9. See the accompanying historic run estimates provided by the California Department of Fish and Game within this document's appendix.

for “salvaging” some portion of the estimated 27,000 chinook salmon which passed the damsite in 1939¹⁰. Within their 1940 report, *An Investigation of Fish-Salvage Problems in Relation to Shasta Dam* (also called “Special Scientific Report Number 10”), Hanson, Smith and Needham proposed four competing mitigation plans for consideration by members of an advisory panel appointed by the Department of the Interior.

During winter 1940, discussions ensued between members of the Board of Consultants and the federal and State fisheries biologists charged with proposing possible salvage plans. As had occurred on the mid-Columbia River, the blue ribbon panel was again called upon to evaluate cost-effective salmon salvaging efforts on the soon-to-be-dammed Sacramento River. Professors Calkins, Durand and Rich reviewed reports submitted by the US Bureau of Fisheries and the California Department of Fish and Game (DFG).

In March 1940, additional meetings occurred at Stanford University with a broader representation of Bureau of Fisheries personnel. In attendance were Fred J. Foster, Regional Director of Seattle’s Division of Fish Culture (within the Bureau of Fisheries), together with Seattle-based Harland B. Holmes, Director of the North Pacific Fishery Investigation. Foster provided specific knowledge about the potential role of artificial propagation in the project while Holmes advised Board members on the proper design of fish ladders, traps, and other fish engineering problems. At this session, informal draft copies of “Special Scientific Report Number 10” were circulated and “...discussions resulted in some suggestions for [its] modification” (Calkins and others 1940a, p 1).

In early April, 1940, the final version of Hanson, Needham and Smith’s document was made available to all parties. It included three detailed plans for rescuing upper Sacramento River salmon and a fourth whimsical proposal for hauling displaced fish to the Trinity River. The detailed schemes included “The Stillwater Plan,” “The Battle Creek Plan,” and “The Sacramento River Natural Spawning Plan” (Hanson and others 1940, p 95)¹¹. Before revealing

10. Within a 1943 “Supplementary Report on Investigations of Fish-Salvage Problems in Relation to Shasta Dam,” Paul Needham, Harry Hanson, and Lewis Parker concluded that 1940 and 1941 salmon populations “...could not have been less than 50,000...and were probably much greater than 60,000.” They wrote that “...the salvage plan must be adjusted to great fluctuations in numbers of salmon and that no count to date has established the maximum numbers of salmon that may have to be handled” (Needham and others 1943, p 14).

11. The Trinity River strategy proposed relocating displaced Sacramento River fisheries into the Klamath Basin. That plan was soon dropped, however, due to costs, to probable competition with existing, indigenous Trinity River salmon stocks, and to pending dam construction on the lower Trinity.

particular aspects of each proposal, however, the document's general recommendations deserve some scrutiny.

Within their report, Hanson, Needham and Smith noted a number of critical problems dogging any kind of fish salvage effort. First and foremost was the issue of run-timing, for, as Shasta Dam neared completion, 1941's returning fish would already find themselves excluded from their ancestral spawning grounds. Second, in addition to fall- and spring-run fish, the report cited the "possible existence" of a separate "winter-" or "black" run of salmon on the McCloud River, which may be dispersed throughout the entire upper river basin (Hanson and others 1940, p 42-43)¹². Third, and importantly, they warned of the dangers of releasing excessively warm Shasta reservoir waters to downstream salmonids. This was particularly threatening to spring-run fish which arrive "green" from the ocean and hold for long periods before spawning. Advising biologists urged the Bureau to significantly lower the dam's penstocks below the reservoir's warm water thermocline. Finally, there were the issues of dangerous levels of mining leachate in and around Shasta Reservoir, maintaining minimum instream flow requirements, and unscreened agricultural diversions. Aspects of their document remain prescient to this day.

Hanson, Needham, and Smith's fish salvage recommendations fell into three broad categories and reflected what had been attempted on the mid-Columbia River. These recommendations included (1) sustaining the runs by means of artificial propagation; (2) capturing and transferring the fish to suitable downstream tributaries for re-establishment in a new stream; and (3) some combination of artificial and natural propagation (Hanson and others 1940, p 14)¹³. After weighing these various options, the biologists dismissed reliance solely on artificial propagation as being too costly, too risky, and too fraught with unknowns. On the other hand, a paucity of year-round tributaries within the lower-middle Sacramento Basin (from the mouth of the Feather River to the proposed Keswick Dam site) ruled out exclusive confidence in natural habitat replacement for upper river fish¹⁴. Hanson and his colleagues settled on a combined natural and artificial strategy. They came to believe that a balanced combination of each would prove most biologically tenable and cost effective

12. The winter-run had been identified as early as 1882 by Livingston Stone in his reports on the McCloud River salmon. See Slater (1963) and Fisher (1994).

13. The Trinity River proposal was to be completely reliant on natural reproduction.

14. As will become clear, many promising downstream tributaries like Battle Creek were fraught with a multitude of competing water development interests. Members of the Bureau and the Service were loath to challenge those individuals and interests who long since held riparian or appropriative rights to California's precious water.

because each separate propagation path could serve as a “buffer” or a “safety factor” on the other (Hanson and others 1940, p 17).

Attending biologists reasoned that a hatchery-dominant path would require handling roughly 100 million eggs annually, and, in addition, there was the vexing problem of the spring-run salmon. This stream-type stock must be held in their natal streams for months before spawning. “Where would that be accomplished?” they asked. Hatchery sites required cold, pristine spring water, or so they believed. One location mentioned was Darrah Springs on upper Battle Creek, but its 35 cubic feet per second was no match for this scale of operation (Hanson and others 1940, p 14). In conclusion, they wrote:

The risk as well as the high initial and permanent costs of handling the entire run artificially at either Big Springs [on the upper McCloud] or Fall River Mills have made it necessary to omit these possibilities from further consideration. (Hanson and others 1940, p 15)

Attending biologists were openly skeptical about using hatcheries to sustain incoming year-classes of spring-run fish.

As had been done on the Columbia River, an exhaustive stream survey to identify candidate streams for “naturally” transferring the upper Sacramento River salmon was conducted. Between the Shasta dam site and the Feather River, twelve tributaries entering the Sacramento from the east were counted. Of the twelve, eight showed no promise for housing displaced runs of fish. Only Churn Creek, Battle Creek, Deer Creek and Stillwater Creek exhibited attributes conducive to a potential salmon restoration effort¹⁵. Of the five streams emptying into the mainstem from the west, most were dry an appreciable part of the year. Larger tributaries like the American and the Yuba rivers were also evaluated but each was eliminated due to the century-old accumulation of mining debris. Finally, and perhaps in desperation, investigating biologists turned to the Klamath Basin’s Trinity River as a potential transplant site. But it, too, was ruled out due to its excessive distance, to existing indigenous runs of fish, and to pending proposals for dams along its lower reaches.

Hanson, Needham and Smith developed alternative plans, a summary of which follows, along with discussion of the principal advantages and disadvantages of each.

15. To date, I have discovered no mention by the Bureau of setting aside certain downstream tributaries as “refugia” for returning migratory fish. Apparently that idea was stillborn on the Columbia River in 1938.

“The Stillwater Creek Plan”

The aptly named Stillwater Creek is dry during the summer and early fall months before it enters the Sacramento River near Redding. It had several advantages over other candidate tributaries including prime potential salmon habitat, downstream proximity to proposed salmon trapping facilities at Keswick Reservoir, and excellent prospects for being “rewatered.” Most significantly, due to its intermittent flow, Stillwater Creek was unencumbered when it came to competing water rights. Hanson, Needham and Smith recommended diverting and importing 150 cubic feet per second from the upper McCloud River (alternative sources included either the Pit River or the still less desirable water from Shasta Reservoir) via some combination of gravity-flow supply ditch (40 miles long) or tunnel (14 miles long) and a suspension bridge over the Pit River¹⁶.

The Stillwater Plan called for constructing a separate “standby reservoir” at its highest point together with a hatchery and holding ponds suitable for rearing 50 million eggs. In the event a breakage interrupted their water source, biologists proposed a closed-loop watering and cooling system for all hatchery operations. The biologists calculated that a rewatered 24-mile-long stream had sufficient room for 5,000 redds. They set their total combined artificial and natural production objectives at 30,000 salmon.

Several of Stillwater’s advantages stemmed from an assurance of the best upriver water available—fabled McCloud River water¹⁷. Secondly, and importantly, there were no conflicting interests with other water users. In addition, hauling distances from fish trapping sites at Keswick Dam to release points were the shortest of any proposed plan. Finally, since Stillwater Creek lay downstream from the proposed Keswick trapping operations, it was hoped that future returning migrants could reenter the creek on their own.

16. No doubt biologists also had winter-run chinook on their minds as they sought to import McCloud River water into the lower middle Sacramento River Basin.

17. Livingston Stone referred to the McCloud River “as the last best hope for the Sacramento River salmon,” a sentiment subsequently echoed by biologist Joel Hedgpeth. See Hedgpeth (1941).

Stillwater's liabilities stemmed from its excessive construction and maintenance costs. Construction alone was appraised at \$4.3 million dollars (Hanson and others 1940, p 102). Somewhat paradoxically, these same scientists faulted Stillwater Creek's limited areas for natural spawning and they cited downstream erection of the proposed Iron Canyon Dam (above Red Bluff) as deeply troubling¹⁸. Since the whole operation was contingent on a dependable upriver water supply, a break in the system remained an ever-present danger. Finally, diverted McCloud River water at Shasta Dam's turbines were calculated by Bureau engineers at an annual firm power loss of \$62,500 (Hanson and others 1940, p 101).

"The [Combined] Battle Creek / Deer Creek Salvage Plan"

Due to its year-round flow and its existing US Bureau of Fisheries Hatchery, Battle Creek held promise in any fish recovery effort (Hanson and others 1940, p 102). This salvage plan revolved around establishing a large hatchery facility (or two hatcheries working cooperatively), while using lower Battle Creek for natural spawning. The trick would be to avoid jeopardizing Battle Creek's native fall and spring runs. In addition, a variation on the proposal called for transferring as many spring-run salmon into Deer Creek as possible.

This design required a permanent hatchery "salvage" program for a total of 16,000 fall-run and 6,000 spring-run fish. Biologists believed that fall-run migrants passing Shasta Dam would produce 50 million eggs annually, well beyond the modest capability of the long existing Battle Creek Hatchery (at 12 million eggs)¹⁹. Hanson, Needham, and Smith recommended building a sizable hatchery capable of handling 75 million eggs, inclusive of those already handled by the historic Battle Creek facility.

The report specifies Battle Creek's native runs as occupying a restricted space between the river's mouth and Pacific Gas and Electric's Coleman Power-

18. Citations about the proposed Iron Mountain and Table Mountain dams were scattered throughout the report. Should a lower river dam be built, biologists warned, all efforts to mitigate for the Shasta-Keswick complex would be "nullified." In 1944, federal and State biologists minced no words when they declared that "adequate protection should be provided [salmon] during [dam] construction periods: to [among many grounds,] prevent any man-made catastrophe which might eliminate for all time a portion of, or a whole, annual cycle of salmon." They urged a reexamination of the entire Table Mountain Dam project, for, "...as presently proposed, the dam will probably spell the doom of salmon and steelhead runs into the upper Sacramento River" (Rich and others 1944, p 7, 11).

19. In one year, peak production at the turn-of-the-century Battle Creek Hatchery produced 60 million eggs. However, substantial water development, aggressive broodstock harvesting, and intense fishing pressures reduced that number to a modest 12 million-egg capacity. (Leitritz 1970, p 25; USFWS and Richardson 1987a, p 4).

house. A stream survey cites room for 720 redds within a three mile reach between the upper racks and Coleman's tailrace (Hanson and others 1940, p 103). The two racks were installed to trap and hold fall-run chinook salmon. Additional spawning grounds above Coleman Powerhouse are dismissed as too limited "...to warrant the expense and difficulty of purchasing the power development on Battle Creek (Hanson and others 1940, p 103)." Biologists tailored their strategies so as not to disturb PG&E's existing operations and water rights²⁰.

Spring-run fish, the biologists specify throughout, require ripening and holding under tightly bounded conditions. Hanson, Needham and Smith believed Battle Creek to be excessively warm during the summer months (at one point a lower stretch reached 73 degrees Fahrenheit). Darrah Springs was suggested as one local source for cold, pure, spring water, where holding ponds might prove satisfactory. However, its modest 35 cubic feet per second (cfs) flow would be suitable for only a limited number of salmon. There was also the matter of a lengthy 32 mile commute from the trapping site near Redding. In addition, PG&E's consent would also be required before the facility could become fully functional to raise water some thirty feet to exit the hatchery (Hanson and others 1940, p 105).

Deer Creek is mentioned as the only other suitable lower Sacramento River tributary where spring-run salmon might also be transferred. In a Combination Battle Creek/Deer Creek Plan, Hanson and his colleagues record that the latter has sufficient spawning area for about 3,700 salmon between its mouth and the falls above Polk Springs (Hanson and others 1940, p 107). During summer months, however, irrigators pumped enough water out of Deer Creek to dry up its lower reaches. "Rewatering" Deer Creek required moving water around. Scientists urged that mainstem Sacramento River water be pumped to irrigators to compensate for Deer Creek's proposed restoration. This proposition was dismissed by members of the Board and others as being too costly.

20. For instance, they recommended supplying the proposed hatchery with water derived from Coleman Powerhouse's tailrace rather than from the creek itself. Service biologist Scott Hamelberg points out that "[e]ven though placing the [water] intake in Coleman Powerhouse's tailrace may have been "non-disruptive" to PG&E operations, we still recognize today there are major advantages to having the intake located at this site" (USFWS and Hamelberg 1999, p 1).

The formal Battle Creek proposal called for a 75 million-egg hatchery to be located below the Coleman Powerhouse for fall-run salmon. The Darrah Springs facility was to house at least 30 million spring-run eggs, or a second facility was to be located on or near Deer Creek²¹. Weirs, collecting systems, traps, and the like, would capture incoming fish. A fleet of 18 tanker trucks could haul fish the 60 miles required to their destinations. Interestingly, Hanson, Needham and Smith prepared no accompanying cost estimates for this plan. While they were operating under tight time constraints, evidence suggests they favored the much more costly Stillwater Plan.

The Combined Battle Creek/Deer Creek plan's advantages are "...its lower initial costs and the fact that it would not entail a power loss at Shasta Power Plant" (Hanson and others 1940, p 109). Biologists also believed they would find an "ample supply of cold water in Deer Creek" suitable for spring-run salmon to become reestablished. Liabilities included complete "[d]ependence upon artificial propagation as the sole salvage measure" (for the fall-run at least), total reliance upon Coleman Powerhouse's tailrace for incoming hatchery water, and excessive competition possibly culminating in overcrowding hatchery and native runs in both Battle and Deer creeks. They also lamented long hauling distances to Deer Creek, and, last but not least, the "necessity of replacing irrigation water with a permanent pumping plant if Deer Creek is to be used" (Hanson and others 1940, p 109).

"The Sacramento River Natural Spawning Plan"

Under the Sacramento River Natural Spawning Plan, most of the fall-run would be held within the river's mainstem where they could naturally reproduce. Two or more racks would be installed to disperse incoming fish to achieve their maximum sustained reproductive yields. Whatever remainder occurred, including all of the spring-run fish, were to be trapped and hauled to a Battle Creek hatchery situated at either Coleman or Darrah springs. Deer Creek was also specified as a possible holding area for naturally spawning spring-run fish.

The plan specified the building out of a hatchery facility capable of rearing 47 million eggs. Such a plant would supplant the existing Battle Creek operation as well as handle incoming fish from the Sacramento River. The plan called for building three removable racks in the mainstem Sacramento River, together with trapping and hauling facilities. The endeavor would cost an estimated \$1.6 million with annual operating expenses of \$40,000 (Hanson and others 1940, p 112).

21. A spring-run hatchery on or near Deer Creek was called for in the event that the combined Battle Creek/Deer Creek Plan was embraced.

Advantages of a Sacramento mainstem holding plan included low initial capital costs, more natural spawning areas than were presented in other plans, and suitably cool water temperatures for 75 percent of the fall run. Disadvantages stemmed from uncertainty. How would fish behave behind in-river weirs? Would they tend to fall back, bunch up and overcrowd one another, or disperse downstream as hoped for? Biologists just didn't know. There was also the controversial matter of copper contamination from Iron Mountain and other upriver sites. Excessive water temperatures posed yet another hazard to incubating eggs and young salmon. Biologists were especially concerned with the mainstem Sacramento (below Redding) because stream temperatures reached well beyond 60 degrees Fahrenheit from May through October (Hanson and others 1940, p 113). Such elevated temperatures could be raised ever higher by drought conditions, potentially culminating in the loss of entire year-classes of fish. Finally, and perhaps most ominously, proposals loomed to construct either Table Mountain or Iron Canyon dams which would inundate mile upon mile of remaining prime spawning areas²². In closing their document, Hanson, Needham and Smith refer to fish salvage programs at both Grand Coulee and Shasta dams as little more than "large-scale experiments" (Hanson and others 1940, p 115).

Board of Consultant's Recommendations: Round Two

The Board of Consultants entrusted with selecting among the range of fish mitigation strategies presented by biologists Hanson, Needham and Smith eventually embraced a hybridized plan. Details of the "Sacramento River, Battle Creek, and Deer Creek Plan" (also called "The Foster Plan") were spelled out in a supplemental report prepared by Fred J. Foster. The report had several essential elements:

- Trapping and hauling an estimated 1,500 spring-run fish (about one quarter out of a total of 6,000 spring-run fish) to Deer Creek for natural spawning (Calkins and others 1940a, p 9-10).
- Trapping and hauling an additional quarter spring-run to a natural-type holding pool in Deer Creek.

22. In a 1947 California Department of Fish and Game report, biologists stated that "Iron Canyon [D]am will destroy the entire salmon run now spawning between its site and Keswick Dam..." Members of the Statewide Water Committee of the California State Chamber of Commerce took issue with this assertion. Their research department argued that ample spawning gravel existed downstream from the proposed dam sites, that recent biological conclusions about the ill effects of Shasta-Keswick dams were contradictory, and that spiny rayed fishes had a significant place in the new West. See Blote 1946, p 175.

- Trapping and hauling the remaining spring-run to a holding pond at Darrah Springs on upper Battle Creek.
- Trapping and hauling about 4,000 early fall-run fish to planned holding ponds at Battle Creek's Coleman Hatchery site (to avoid potentially lethal Sacramento mainstem temperatures).
- Holding the remaining fall-run between racks within the mainstem Sacramento where they would spawn naturally.
- Construction of a hatchery at the Coleman site on Battle Creek suitable for 42 million eggs and/or advanced fry and 21 million fingerlings.
- Abandonment of the Bureau's historic Battle Creek Station but with retention of holding ponds for use by Battle Creek's fall-run salmon.

Low capital costs, extensive use of natural spawning areas, and suitably low mainstem water temperatures for perhaps three quarters of the fall-run were this plan's advantages. Its drawbacks included uncertainty of fish behavior when fish are caught behind racks, copper pollution from upriver mining leachate, high instream temperatures during summer and early fall months, and pending construction of Table Mountain and Iron Mountain dams (Calkins and others 1940a, p 10).

The Board of Consultants embraced Foster's Sacramento, Battle Creek, and Deer Creek Plan, but with a twist. They recommended deferring the Deer Creek portion until a better understanding of summer water temperatures was obtained. Once conditions looked sufficiently promising, they advised installing a Deer Creek natural-type pond which, they believed, should prove adequate for ripening and holding spring-run fish. Board members rejected outright a Sacramento River pumping station and means of conveyance to compensate irrigators for rewatering lower Deer Creek (Calkins and others 1940a, p 26).

The Board of Consultants endorsed installing three racks in the Sacramento mainstem, the lowermost falling just upriver from Battle Creek's mouth (Calkins and others 1940a, p 28). They suggested locating a fish counting device on the lowest rack and keeping precise fish passage records. The Board advocated combining a trapping device with one of the instream weirs. Calkins, Durand, and Rich sanctioned a fleet of four trucks to ferry captured salmon to the proposed Coleman hatchery and to other holding ponds at Darrah Springs and within Battle Creek. Capital costs were placed at \$1,064,500 (not including Deer Creek) with an annual operating expense of \$35,000. Their justification for these expenditures invites a look at their calculations.

Board members believed they were compensating for a run of salmon from between 20,000 to 25,000 fish arriving at Redding in two well-marked peaks (Calkins and others 1940a, p 18). The spring run reached Redding between the middle of April and July, and consisted of 5,000 to 6,000 fish. The fall run arrived between mid-September and late-November and consisted of 15,000 to 20,000 fish. Any mention of a possibly existing winter-run went unacknowledged within their report.

Economist R. D. Calkins probably penned the Board's cost-benefit analysis on economic losses attributable to fish blockage at Shasta Dam. Any figures (he noted, and the Board ratified) depended on the "number, weight, and value of the fish taken in the commercial fishery" (Calkins and others 1940a, p 21). They recorded that one million pounds of fish were caught annually by an in-river net fishery while four million pounds of fish derived from ocean trolling. Since "...no more than half of the river catch is derived from above Redding," they reasoned that half of the Sacramento River District's current \$57,000 fishery was in jeopardy. Board members concluded "...that no more than half, or \$28,000, of this [in-river fishery] may be regarded as the value of fish derived from spawning above the Shasta Dam" (Calkins and others 1940a, p 22).

As for the more indeterminate ocean fishery, Board members reasoned that "...probably no more than one third to one half the California ocean catch is derived from the Sacramento [River]" (Calkins and others 1940a, p 23). Since between 1929 and 1938, ocean catches below the Mendocino County line averaged 1,781,000 pounds, their total assessed market value was \$139,000. Assuming further that "...one third of these fish are from the Sacramento-San Joaquin river systems, and that one half of these are from above Redding, we reach a value of \$23,000" (Calkins and others 1940a, p 24). By combining this figure with the in-river figure, the Board placed the gross value of upper Sacramento River salmon to commercial fishermen at \$51,000, or possibly as high as \$87,000 (Calkins and others 1940a, p 24).

The Board dismissed the value of salmon loss to California's sports catch as indeterminate. They stated that sports fishing losses, like steelhead, stemming from Shasta Dam, "...[were] of small or even negligible value" (Calkins and others 1940a, p 32-33). Calkins, Durand, and Rich echoed a sentiment expressed in their mid-Columbia River Report by questioning whether the Bureau had any role whatsoever in compensating for sports fisheries losses. Lester A. McMillan, Executive Officer of the State of California's Division of Fish and Game, took issue with this omission. In a letter to W. F. Durand dated August 12, 1940, McMillan concluded:

An additional economical value of the salmon run was brought to your attention in that a considerable sports catch of salmon occurs in California. Recent figures...[show] that 160,000 salmon were taken by sportsmen in 1939. This

is between 1,600,000 and 2,000,000 pounds of fish. If one quarter of these fish, or 500,000 pounds, would have reached the Redding Dam, and represent a value of \$1.00 per pound, which we have placed upon other sports fishes, the value of the run at Redding increases considerably (McMillan, as cited in Calkins and others 1940b, p 12).

DFG members did a far better job than federal representatives in defending the recreational interests of sportsmen loath to abandon prized sports fish as an inevitable price of progress. It would require another six years before steelhead achieved sufficient status to warrant artificial propagation at Coleman.

On October 5, 1940, the Board of Consultants formally responded to the State of California's concerns within a "Supplemental Report" (Calkins and others 1940b)²³. Board members appeared responsive to a future enlargement of the Battle Creek Hatchery and to possible construction of another hatchery on Deer Creek. They raised from eight to fourteen the number of rearing ponds at the Battle Creek hatchery. Calkins, Durand and Rich concurred in using Battle Creek's natural holding ponds solely for adult fish. They increased the number of fish transport trucks from four to seven. Federal reviewers agreed that Keswick Dam should serve both as a river regulating structure and as a fish trapping site. Finally, on the sticky legal point of formalizing an agreement between the State of California and the Department of the Interior over fish salvage matters, Board members stated that it was not within their power to define the "...jurisdiction and responsibility of each agency" (Calkins and others 1940b; Moffett 1949, p 79)²⁴.

Implementing Fish Salvage Principles

The Board of Consultants 1940 recommendations were implemented with a few "minor revisions" (Needham and others 1943, p 7). By June 1, 1943, the

23. Recall that on the mid-Columbia River, Bureau of Fisheries biologists and members of the Board of Consultants responded to a fish salvage program prepared by the Washington State Department of Fisheries. On the Sacramento River, although one may have existed, I find no evidence of a separately existing, state-commissioned, fish salvage report. From the outset, it appears that state and federal regulators were in broad agreement about what needed to be done to save threatened Sacramento River salmon. Grand Coulee Dam's plan may have provided a compelling model for subsequent state and federal fish rescue efforts.

24. State fisheries regulators also proposed an experimental plan to ferry some salmon fingerlings above Shasta Dam to see what would become of them. Throughout the early 1950s, the US Army Corps of Engineers conducted experimental fish passage studies through Shasta Dam's turbines. Coleman's 1953 Annual Report makes mention of a lone, tagged salmon which managed to migrate from Shasta Reservoir and out to sea before returning to the Keswick trap. Board members dismissed the proposal as unworkable.

Bureau had placed in operation the following features of the “Sacramento River, Battle Creek, and Deer Creek Salvage Plan” (called by the Bureau “The Sacramento River Migratory Fish Control Program,” or more generally known as “The Shasta Salmon Salvage Plan”):

- Fish ladder, traps and lifts in the Keswick Afterbay Dam and the Balls Ferry Rack for capturing and removing salmon under high and low water conditions, respectively (Needham 1943, p 8; Moffett 1949, p 79).
- Seven tank trucks for transferring salmon from the Balls Ferry and Keswick Dam traps to the Coleman National Fish Station on Battle Creek, and to Deer Creek;
- Construction of a Battle Creek hatchery infrastructure capable of handling 58 million eggs and approximately 29 million fingerlings. Twenty-eight outdoor rearing and holding ponds were constructed.
- Five racks in Battle Creek provide four holding and ripening areas for adult spring-run transferred from the Sacramento River (Needham 1943, p 8).
- Three removable Sacramento River racks, the lowermost at Balls Ferry. The Balls Ferry rack serves as a trap, as an aid in upstream spawner distribution, and as a barrier to incoming fish.
- One rack on Deer Creek for holding transferred fish upstream and for counting the native runs of fish.
- A fish ladder around Deer Creek’s lower falls to open up five additional miles of spawning stream.

Within a 1943 supplemental report (“Special Scientific Report Number 26”) issued on The Shasta Salmon Salvage Plan, Paul R. Needham, Harry A. Hanson, and Lewis P. Parker amended and updated efforts already underway to save threatened salmon. In it, scientists estimated at greater than 60,000 the actual number of salmon migrating past Redding, a sizable increase over 1939 and 1940s modest, drought-modulated estimates (numbering some 20,000 to 25,000 fish). The updated report warned that “...the [original] salvage plan must be adjusted to great fluctuations in numbers of salmon and that no count to date has established maximum numbers of salmon that may have to be handled” (Needham and others 1943, p 2). Biologists nevertheless recommended transferring 10,000 spring-run fish to Deer Creek with an additional 2,000 being held within Battle Creek for artificial propagation. Eighteen-thousand “summer” fish²⁵ (as they termed them) or early-fall-run fish would be

25. By “summer” fish, I can only assume that Needham and others meant fall-run fish which, they believed, were particularly vulnerable to high water temperatures during the late summer and early fall period (Needham and others 1943).

transferred to Battle Creek for artificial propagation, while 30,000 fall-run salmon would be distributed between Sacramento River mainstem racks for natural propagation (Needham and others 1943, p 7). The biologists reached the conclusion that only two Sacramento River tributaries, Battle and Deer creeks, held any promise for transplanting displaced upper river salmon.

“Special Scientific Report 26” also documents heavy losses occurring among the 1943 year-class of spring-run fish. Mortalities derived from:

A long delay in the completion of trapping facilities in Keswick Dam [which] resulted in serious losses to the 1943 spring-run. Many salmon confined below the dam during this delay were so badly bruised by jumping against the rocks and base of the dam that they died before the transfers began (Needham and others 1943, p 23).

A 24.4 percent mortality occurred among spring-run salmon before successful spawning within Deer Creek²⁶.

Theories are often humbled by the acid tests of time and reality. Implementation of the aforementioned goals began disintegrating from the outset. Moreover, beginning in 1945, the leading institutional role being played by the Bureau (in tandem with the Central Valley Project beneficiaries), was being reevaluated and substantially rescinded. Piece by institutional piece, the Bureau abandoned to the Service (and indirectly, to the DFG) the responsibility for caring for, paying for, and operating ongoing fish salvage efforts.

Throughout the remainder of the 1940s, multiple components of the Shasta Salmon Salvage Plan broke down or were abandoned as unworkable. These fundamental features included (1) the failure of the Sacramento River’s mainstem fish racks; (2) the Coleman National Fish Station’s retreat from and abandonment of its attempts to ripen, hold, and propagate spring-run chinook salmon; (3) the Fish Transport System having higher than expected mortality rates, and (4) the spring-run transfer to Deer Creek being abandoned as unworkable. Finally, in June of 1950, the on-again, off-again Keswick Fishtrap and Loading Facilities were turned over to the Service by an exiting Bureau.

Sacramento River Fish Racks

Bids for the first of three proposed mainstem racks, at Balls Ferry, were received on August 15, 1941 (Needham and others 1943, p 11). This weir was

26. Mention was made of the winter-run fish which “...were very ripe and on several occasions deposited eggs in the truck while enroute from Keswick Dam” to [Deer Creek] (Needham and others 1943, p 23). Once transferred, winter-run salmon deposited their spawn almost immediately in Deer Creek.

the lowermost downstream and it contained a low-water salmon trapping and removing device. Construction began in September 1941 but was discontinued by December due to high water. Construction resumed the following May with the base of the rack completed by year's end. However, in January 1943, a modest flood (73,000 cfs) "...washed out four bents and damaged several more" (Needham and others 1943, p 12)²⁷. The rack had been repaired and made fully operable by late spring. This on-again, off-again pattern continued until this rack was finally abandoned as unworkable in 1945 (Moffett 1949, p 86).

A middle rack was located about 12 miles upstream from the Balls Ferry structure. Substantially completed by September or October 1942, it could never be made "fish-tight" due to a combination of uneven bedrock and unstable gravels (Needham and others 1943, p 16). On November 14, 1942, a modest rainfall occurred, washing downstream great quantities of debris from construction at Shasta and Keswick dams. On the night of November 17, dam debris put sufficient pressure on the structure to "bend 8 by 8 inch stringers" (Needham and others 1943, p 16). The structure became increasingly unstable as workers were unable to clean out accumulating debris. Within a matter of days it washed out, save for an isolated segment near one bank. Engineers concluded that "...it may not be possible to maintain fish-tight racks without permanent sills on which to set tripods" (Needham and others 1943, p 16).

By early 1943, participants decided to abandon constructing a third rack. None of the weirs was ever made "fish-tight" and the units seldom survived longer than the next freshet. By 1946, any pretense of functioning instream racks was dropped as unworkable. Instead, the Bureau entered negotiations with the Anderson Cottonwood Irrigation District (ACID) to use its seasonal diversion dam at Redding as an upstream fish barrier (Moffett 1949, p 87). On November 6, 1950, the Fish and Wildlife Service suspended this weir practice due to excessive fish mortalities observed. The first element of the salvage plan was branded a failure.

The Keswick Fishtrap

Closely tied to the combination Balls Ferry rack and trap was the upstream Keswick Dam Fishtrap. If the former were operable under low water conditions, the latter remained functional at higher rates of flow²⁸. Consisting of a fish ladder, sweep chamber, brail and trap, loading crane and elevator,

27. "Bents" were posts upon which the removable fish racks were held in place.

28. Controversy later erupted because the Keswick Fishtrap became inoperable at flows in excess of 16,000 cfs. The Service asked the Bureau for a significant redesign and negotiations ensued over making the facility functional during periods of high flow.

Keswick Dam's permanent fishtrap began at a slow pace. A temporary "stop-work order" issued by the War Production Board all but halted its construction. Alarmed Service biologists pointed to accumulating year-classes of salmon below and urged some sort of emergency measure. During spring 1942, Service and Bureau personnel improvised a solution from materials they had on hand. By June 1, 1942, the temporary fishtrap began operation (CAR 1943, p 7).

Construction by the Bureau of a permanent trap began during March 1943. However, once it was erected, improvisation was necessary to make it fully functional. The Keswick Fishtrap began operating on April 22, 1943 and continued through August 31, 1943. In the process, surprised biologists learned that "...although the Balls Ferry rack has been installed and closed for some time, fish continued to enter the trap at Keswick Dam" (CAR 1944, p 8). Passing migrating salmon continued defying the lowermost Balls Ferry rack and the upstream rack until both racks washed out altogether.

Considerable fine-tuning was required of Keswick's Fishtrap over the next two years for it to become dependable. During mid-February 1944, experimental trapping of winter-run fish was conducted at the Keswick Dam site. By the end of May, 145 fish were captured and hauled to Coleman Hatchery for "experimental holding purposes" (CAR 1945, p 4). By late August of that same year, 894 winter- and spring-run salmon were captured and moved to other locations.

Following a fairly routine year of trapping, the 1946 season turned things upside down. Failure and abandonment of both lower Sacramento River spawning racks raised fears about serious upstream overcrowding. The Bureau began negotiating with the ACID to use their dam near Redding as an upstream fish barrier. Consequently, the Keswick Fishtrap was "neither required nor in operation" throughout the entire year (CAR 1947, p 1). This would continue through 1950.

While the Bureau continued operating the Keswick Fishtrap, language shifting responsibility between the Bureau and the Service was contained within a September 21, 1948 Memorandum of Agreement. It read: This agreement "...does not specifically provide for the operation of the Keswick Fishtrap or for the transportation of fish therein to the Coleman Hatchery" (CAR 1949). The trap was used minimally during 1947 and the Bureau continued reimbursing the Service's transport costs.

On November 6, 1950, the ACID irrigation dam ceased operating as a fish barrier and the Keswick Fishtrap was again placed in operation. Fish and Wildlife Service personnel questioned the dam turned fish weir's "...value and the extreme probability that numbers of adult salmon were being injured and

destroyed before they could spawn" (CAR 1950, p 3). The Bureau was amenable a discontinuance of ACID's lease as a fish blocking device. The continuing operation of the Keswick Fishtrap remained a cooperative effort between both agencies.

Fish Transport

During 1941, spring-run salmon were captured in a temporary loading and trapping facility located at the ACID dam near Redding. Fish left that site in a tanker truck loaned by the national hatchery at Leavenworth, Washington (CAR 1942, p 15). Fish were hauled to nearby Battle Creek where, lacking suitable unloading facilities, they were released in a way meant to prevent injury.

The following year, Service personnel learned from the Bureau that it had been unable to obtain seven new truck frames which were to be fitted with tanks. Trucks were critical to the ongoing war effort and fish salvage was deemed "nonessential". The Bureau arranged for and received seven semi-trailers upon which tanks were mounted. Describing the results as "very dissatisfactory," Service personnel launched their own campaign to secure new trucks. They eventually succeeded and took delivery of them in early May 1942 (CAR 1943, p 9).

Major difficulties subsequently encountered hinged upon the significant distances between Sacramento River trapping sites and Deer Creek.

Deer Creek was a distant 92 miles from Shasta Dam, thus creating a taxing ride for the fish. To make matters worse, salmon that were held before being transported began the journey in a weakened state. While there were subsequent improvements, the added stress of transporting fish may have influenced decision makers to abandon Deer Creek altogether.

By late 1950, the Service was poised to assume responsibility for the fish transport operation from the Bureau. Service personnel anticipated transferring fish from the Keswick Fishtrap to the Coleman Hatchery and other sites for years to come. Coleman's Director wrote:

It is contemplated to continue the transfer of the adults for an indefinite number of years in the future, or until the run in the Sacramento River so stabilizes itself as not to require further transfers (CAR 1950, p 3).

The Deer Creek Natural Spawning Option

Stream surveys conducted throughout the 1940s concluded that Deer Creek had sufficient space for 15,000 salmon (Moffett 1949, p 93). Reconciling those high expectations with low native stock counts (ranging from 635 fish in 1941

to a high of 4,257 in 1946) was one of many puzzles facing biologists (Moffett 1949, p 89). Despite its obvious problems, Deer Creek still provided the best hope for transferring displaced spring-run salmon.

Experiments conducted during 1941 demonstrated that it was feasible to haul and establish fish in Deer Creek from upstream Sacramento River sites. However, early on, fish were left in a vulnerable state due to hauling delays before their arduous overland journey. Through the end of June 1943, the entire spring- and "summer" -run was trapped and hauled to Deer Creek. A total of 5,243 fish was transferred to Deer Creek with another 944 interned at Coleman Hatchery holding ponds (CAR 1943, p 8). By July 21, known mortalities reached 1,273 fish, almost a quarter of those transferred (Moffett 1949, p 90).

That following year, the spring-run was largely hauled to Deer Creek with the remainder moved to Battle Creek. Upon completion of the seasonal hauling, with 7,868 fish instream, Deer Creek's temperatures rose to 82 degrees Fahrenheit. Within three days, 1,135 fish perished, raising total observed mortalities to 16 percent (Moffett 1949, p 90). Excessive instream temperatures continued to erode efforts at establishing spring-run fish in Deer Creek.

During 1945, 1,606 spring-run salmon were hauled to Deer Creek while only 167 were transferred the following year (Moffett 1949, p 90). Numbers declined for several reasons. First, biologists theorized that significantly cooler water temperatures within the mainstem Sacramento River caused this race to hold and ripen farther downstream than ever before. Second, Deer Creek's status as a first-rate salmon stream fell prey to high agricultural diversions, unscreened irrigation diversions, and significant instream obstructions (like the Stanford-Vina Dam). A means of substituting Sacramento River water for Deer Creek's diversions was never created, thereby making the latter untenable for supporting large populations of fish. Despite the installation of fish ladders and other fish passage improvements, excessive losses "...cast doubt on the ultimate success of the transfer activities" (Moffett 1949, p 91). Serious spring-run transfers ceased by 1946.

Writing in 1948, Service biologists Cramer and Hammack summarized Deer Creek's potential this way: "The progeny of the transplanted salmon are doomed to a gradual or rapid extinction unless the conditions under which both populations are forced to live are changed enough to accommodate them" (Cramer and Hammack 1948, p 15). Without development of a substitute irrigation supply from the Sacramento River, "judicious channelization" at the creek's mouth, and removal of instream dams and obstructions, Deer Creek transfers would remain pointless.

Coleman National Fish Station

A hatchery on Battle Creek was always viewed as essential for perpetuation of the Sacramento River's spring-run fish and for a small segment of the early fall-run. Especially critical times were 1943 and 1944, "...when both Shasta and Keswick dams blockaded upstream passage but stored insufficient water to adequately lower downstream river temperatures" (Moffett 1949, p 79).

Recall that Professors Calkins, Durand and Rich had instructed that one half of what they believed constituted the spring run (or 3,000 out of 6,000 total spring-run fish) and about 4,000 early fall run (of 16,000 total fall-run fish) be transferred to the Coleman Hatchery site on Battle Creek. Coleman was designed to handle about 58 million eggs or advanced fry with any surplus space going to fingerlings.

Under the Bureau contract, hatchery construction began at Coleman in 1942 with the hatchery building completed in November of that year (Needham and others 1943, p 10). It was not until the early summer 1943, however, that Coleman's rearing ponds were capable of receiving spring-run salmon.

Some "experimental holding" of spring-run salmon on Battle Creek was attempted during the 1942 season (CAR 1942, p 15). In early July, a pond was created at an irrigation intake adjacent to Battle Creek. Forty percent of the fish held there died within 16 days of being transferred from the ACID dam. None of the 126 transplanted salmon were recovered for subsequent spawning at Coleman, signaling possible trouble ahead (CAR 1942, p 15-16). Simultaneously, 40 spring-run salmon were placed between racks within Battle Creek to commingle with its native fish. Transplanted and native fish mortalities were high, with 34 fish dying during July, 34 during August, and 27 during September. Thirty-six thousand five hundred eggs were eventually recovered but there was no way of identifying the parent stock (CAR 1942, p 16).

During 1945, Coleman's Annual Report estimated populations of Sacramento River spring- and fall-run chinook salmon to be in excess of those established during the previous year (while their formal counts were diminishing). Biologists resolved this paradox by arguing that spring-run salmon "...did not ascend the river due to the lower water temperatures" (CAR 1945, p 2). They speculated that prevailing cooler water temperatures "...may have caused these salmon to lay in the river until [becoming] near ripe instead of trying to get to the upper waters in the early summer" (CAR 1945, p 4). Whatever the cause, there would be fewer spring-run fish transferred either to Coleman Station, Battle Creek or to Deer Creek. Which fish stocks would take up the slack? The answer, as depicted in Table 1, was predominately lower river, fall-run fish.

Table 1 Annual egg production at Coleman Hatchery, 1943–1950^a

<i>Year</i>	<i>Spring chinook salmon</i>	<i>Fall chinook salmon</i>	<i>Steelhead trout</i>
1943	1,053,665	8,320,853	
1944	4,040,650	11,298,880	
1945	1,281,272	20,759,463	
1946	2,763,000	25,178,000	
1947	165,000	10,875,000	31,250
1948		3,770,000	18,104
1949	206,513	13,221,464	178,052
1950	870,469	10,590,509	326,303

^a Source: CAR 1950, p 17.

By 1945, Coleman raised 16 times the number of fall-run as spring-run fish, a ratio which generally climbed through 1950 (CAR 1946). In 1947, the hatchery raised roughly 66 times the number of fall-run as spring-run salmon. That following year, spring-run production plummeted to zero. The widening gap between spring- and fall-run production may have presented Coleman's Superintendent John Pelnar with an opportunity: he could substitute new species of sportfish – specifically steelhead – for diminishing spring-run fish and maximize production at his large hatchery facility.

In 1946, spring-run transfers to Deer Creek were rejected as unattainable. Beginning in 1947, hatchery production struck out in new directions with an experimental program involving steelhead. By 1950, Coleman accepted all of Keswick Fishtrap's spring-run transfers despite the hatchery's difficulty at holding and propagating these stream-type fish. In retrospect, we now know that it takes heroic measures and 1990s technologies to propagate winter-run salmon. It is no wonder Coleman failed fifty years earlier at replicating similar conditions to save diminishing spring-run fish. In late 1951, Service personnel concluded that perpetuation of the spring-run fish was best served by leaving them undisturbed within the mainstem Sacramento River (CAR 1952).

Early Steelhead Production at Coleman

It is ironic that steelhead were included among sportfish rescued under The Grand Coulee Fish Maintenance Program while they were dropped, initially at least, from consideration under The Shasta Salmon Salvage Plan. How can we account for this historic omission? There are biological, cultural, economic,

institutional, and political factors that underscored an exclusive focus on Sacramento River salmon mitigation.

Recall that members of the Washington State Department of Fisheries wrote the initial draft of the Grand Coulee Fish Maintenance Program. From the outset, that state agency placed a significantly higher economic and political value on the role played by tens of thousands of sportfishers than did their federal counterparts.²⁹ In addition, they argued that the economic “multiplier effects” arising from a vigorous recreational industry made steelhead integral to the region’s economy. Lose steelhead production, so the argument went, and whole communities dependent upon outdoor recreational sports would miss out on a substantial part of their yearly incomes.³⁰

Within their March, 1939 report, members of the Board of Consultants portrayed steelhead in a much less flattering light. They dismissed steelhead production in the mid-Columbia Basin as “not of great commercial importance.” Even worse, however, the Board cautioned that “steelhead are predatory on the salmon.” Hence, to boost the value of commercial fisheries, Rich and his colleagues urged,

...it would seem far better to center attention upon the production of Chinook salmon in the streams of this region and to eliminate rather than attempt to increase the steelhead (Calkins and others 1939b, p 10).

Leavenworth Hatchery’s eventual annual production of 14 million steelhead eggs is more a compromise between the states of Oregon and Washington and federal authorities than a reflection of the Board’s actual preference of exclusively focusing on salmon restoration.

In their 1940 Bureau of Fisheries report, federal biologists Hanson, Needham, and Smith placed steelhead in their “coarse” fish category, together with various species of native eels, Sacramento pike minnow, and the like. Members of the Board of Consultants reiterated that, in addition to being salmon predators, steelhead had little to no commercial value. The Board of Consultants also dismissed the numbers of steelhead passing the Shasta Dam site as “negligible” (Calkins and others 1940a). Steelhead advocacy eventually fell to Service personnel like Coleman Superintendent John Pelnar, members of the DFG, and inland recreational fisheries advocates like Henry Clineschmidt.

29. The same can be said for the California Department of Fish and Game. See Executive Director Lester A. McMillan’s letter to W. F. Durand, dated August 12, 1940 (Calkins and others 1940b, p 11–13).

30. Additional pressure may have been exerted by sportsmen organized to protect their threatened major resources. For a general treatment of sportsmen and the conservation movement, see Reiger (1986).

Clineschmidt was a close friend of John Pelnar and a “very active” Commissioner with the DFG (Hallock, personal communication, see “Notes”). The fact that “Steelhead Unlimited” and “Kamloops, Incorporated” were the same organization went a long way toward explaining the more or less simultaneous introduction of kokanee, Kamloops, and steelhead production at Coleman National Fish Station.³¹ Beginning in 1947, the hatchery experimentally undertook steelhead propagation, a program which continues to this day.³²

The Myth of a Successful CVP Mitigation

Throughout the 1940s, Coleman National Fish Station gradually abandoned its first objective of producing sufficient spring-run fish to perpetuate one-half of the upriver race. The Coleman facility did succeed at the propagation of lower-river, fall-run fish, thereby meeting its 1940 goal of reproducing one-quarter of the fall run among early migrants.³³ Beginning mid-February 1944, the facility experimentally held and attempted rearing winter-run salmon. No evidence pointed to any degree of success. Three years later, Coleman undertook producing steelhead for the first time. Immediately following the decade’s close, Coleman’s hatchery production objectives were broadened as hatchery personnel began stocking Shasta and later Whiskeytown reservoirs with “put-and-take” Kamloops trout and kokanee salmon from British Columbia. Coleman hatchery production objectives diversified from exclusive focus on salmon production to a broader range of recreational fisheries.

31. Under Clineschmidt’s leadership, “Steelhead Unlimited” would later channel money to Coleman via The California Department of Fish and Game and “California Kamloops.” California Kamloops issued the checks for steelhead propagation on behalf of Steelhead Unlimited (USFWS 1956).

32. A recent U. S. Fish and Wildlife Service Draft Report argues that “[construction of Shasta and Keswick dams] potentially denied [steelhead] access to large areas of natural spawning and rearing habitat” (USFWS 1997; USFWS and Hamelberg 1997, p 4).

33. It would take over two decades to recognize that late fall-run chinook salmon constituted a genetically unique stock. During the early years, mixing sometimes occurred at Coleman Hatchery of fall- and late fall-run stocks (Hallock, personal communication, see “Notes”).

This significant transition began during July 1944, in a series of yearly Memoranda of Understanding (MOUs). Bureau administrators began making clear that they wanted to remove themselves from the fish salvage business. It is important to remember that the Bureau consisted of dam builders who moved rivers around as opposed to fish tenders. Fish maintenance, they insisted, was the business of the Service.³⁴ Why not let the Service tend to fishery affairs while the Bureau stuck to what it did best? There was also the contentious issue of signing over to the Service, mitigation budgets over which the Bureau had little or no control. Ron Brockman, Fisheries Program Manager with the Bureau's Sacramento office, believes the Service, via Coleman, sought an autonomous foothold in their California salmon restoration efforts (Brockman, personal communication, see "Notes"). Brockman observes a kind of historic tug-of-war occurring between the Bureau and the Service over who did what, when, (and for how much) at the hatchery facility. From Brockman's point of view, there was always reluctance to have the Bureau involved in shaping operations at Coleman Station.

If precedents on the Columbia River were any guide, Bureau administrators also sought—as soon as practicable—to declare victory and get out of the fish mitigation business (Taylor 1996, p 360). Nor was it the Bureau's intent to remain saddled with costly, long-term mitigation expenditures (Calkins and others 1939b, 1940a). On both the Columbia and Sacramento rivers, or so the theory held, hatcheries constituted capital-intensive means for artificially augmenting fish production within downstream tributaries until natural propagation might take hold. Bureau-supported hatchery mitigations were never intended to be an open-ended proposition with no end in sight (Calkins and others 1939b).

Such views were reflected within successive MOUs as each generation contained more and more equivocal language about the Bureau's responsibilities and obligations to the Service under the original "Sacramento River Migratory Fish Control Program." By mid-year 1948, an institutional mitosis ensued whereby both agencies inventoried, then cleaved, their separate properties and holdings. Initially at least, the Service enjoyed a cost-free, lease-back arrangement. However, that external support did not last for long.

Negotiations discussing Coleman's fate continued to intensify. In June 1947, Coleman Station's Superintendent John Pelnar reported that the station was

34. Roy Wingate, archivist at the Bureau of Reclamation's Denver Regional headquarters, advised me that comprehensive Bureau records ceased being assembled in 1945. That means that events like these occurring subsequent to that year would be difficult to track and were perhaps better retrievable at the regional office level. My trip to the Service's Portland Regional Office was due, in part, to his advice (Wingate, personal communication, see "Notes").

being “...contemplated for abandonment and closure” (CAR 1947, p 50). One month later, the MOU dated July 5 specified the withholding of Bureau funds for fish culture. In addition, the 1948 MOU did “...not specifically provide for the operation of the Keswick fishtrap or for the transportation therein to the Coleman Hatchery” (CAR 1948).

Within the September 21, 1948 Memorandum of Agreement (MOA), the Bureau of Reclamation formally launched the process of a hatchery transfer to the Fish and Wildlife Service. In retrospect, there appears to have been a simultaneous “push” and “pull” to this transaction. Significant numbers of returning mainstem spawners (above and below Red Bluff, and within Battle Creek) left many to argue that the Bureau-funded salvage program had indeed succeeded. For example, biologist James Moffett cites rough estimates of fish spawning above Red Bluff (144,000 in 1944, 106,000 in 1945, and 96,900 in 1946) and concludes that “Natural spawning in the Sacramento River was remarkably successful as is indicated by examinations of dead salmon and the hourly rate of catch in fyke nets of young salmon” (Moffett 1949, p 101). Indeed, a clause within the 1948 MOA stated:

WHEREAS, the Bureau and the Service are agreed that as a result of the salmon maintenance program and the operation of Shasta Dam with a regard for the welfare of the fishery, the salmon runs above Shasta Dam appear to have become established below the dam in numbers equal to the numbers existing before the dam was built...(Engle 1957, Part II, p 421).

Negotiations transferring Coleman from the Bureau to the Service did, however, require the resolution of one final stumbling block. A September 8, 1948 memorandum stated the Service sought to compel the Bureau to underwrite “...the excessive cost of replacing the present Balls Ferry Fish Rack with a good fish-tight structure” (USFWS 1948b). The memorandum concluded that responsibility for the fish rack was “...the only matter upon which there had been a difference in interpretation of the terms of the proposed agreement...” (USFWS 1948b). Acting Service Director Johnson clearly wanted to take possession of a functional Balls Ferry Fish Rack. In a memorandum dated August 11, 1948, he complained the rack “...has not resulted in a fish-tight barrier and because of this, has never been a satisfactory facility for use in connection with operation at the Coleman Fish Hatchery (USFWS 1948a).

Bureau Commissioner Michael B. Straus countered that replacing the structure “would run into seven figures” and, instead, proposed to maintain the temporary structure “...as long as it [stood]” (USFWS and USBR 1948). The Coleman facility enjoyed Bureau funding during the first half of 1949 after which the Service assumed full funding responsibility (CAR 1949, p 1). In addition, the July 1, 1949 MOA declared Coleman Station to be separate from the Bureau’s Central Valley Project obligations.³⁵

The US Fish and Wildlife Service was eager to assume control of the Coleman facility. As former Coleman Superintendent Jerry Grover explained, by seeking a direct appropriation from Congress, the Service could run the facility and pocket a ten percent administrative overhead charge (which once reverted to the Bureau). Absorption of the Coleman facility also “built up” the national hatchery budget by approximately four percent, while the Service picked up added national and regional stature (Grover, personal communication, see “Notes”). A Service-run Coleman was also freed up to operate in a fundamentally new way. In something resembling a paradigm shift, Superintendent Pelnar could diversify Coleman’s production objectives in accordance with a broader, nonreimbursable set of “recreational” criteria, and forego haggling with the Bureau over funding. Since the upstream reservoirs were created by a federal project, federal obligations existed to “...provide and maintain a sports fishery...” (USFWS 1963, p 33; USFWS and Richardson 1985). No longer exclusively tied to CVP mitigation objectives, the Service saw new opportunities in stocking Shasta (and later Whiskeytown) reservoirs with exotic game fish like Kamloops trout and kokanee salmon, in folding in steelhead production, and in achieving additional recreational objectives.³⁶ A heightened federal interest in sports fisheries surely drew applause from California’s senators and congressmen, as well as from California’s Department of Fish and Game.

In the end, elevated egg takes and salmon populations persuaded many State and federal biologists that the Shasta Salmon Salvage Plan had succeeded. Citing State Bureau of Marine Fisheries reports, Martin Blote of the California Chamber of Commerce recounts that catch records were broken in 1945 when salmon landings in California totaled 13,367,523 pounds. This commercial peak was exceeded in 1946 with a total catch of 13,649,673 pounds of fish

35. The Bureau and the Service’s 1948 MOA did contain one fragmentary reminder about CVP fishery responsibility. “WHEREAS, the continued maintenance of the Sacramento River salmon runs is recognized as one of the purposes of the Central Valley Project in operating Shasta Dam,...” This clause reappeared 35 years later as a reminder that the Bureau was responsible for Coleman’s attempts at mitigating for disappearing salmon (and steelhead). See Forbes (1983, p 4).

36. Concomitant to the Service’s takeover at Coleman, Kamloops trout eggs were introduced into California from British Columbia in June of 1948 (CAR 1949, p 43).

(Blote 1948, p 7). Salmon landings in the upper San Francisco Bay, the Sacramento-San Joaquin Delta, and the Sacramento and San Joaquin rivers, totaled 5,467,960 pounds in 1945 and 6,642,050 pounds in 1946 (Blote 1948, p 7). Egg takes at Coleman were also invoked as grounds for optimism. Counts from 1945 (22,040,735 eggs) were surpassed by Coleman's 28,297,100 eggs captured in 1946 (Blote 1948, p 32). In 1947, Superintendent John Pelnar summarized Coleman's artificial propagation and fingerling rearing activities:

...the station, being one of the most efficient and producing units in the world, planned to attain a record undreamed of by fisheries workers. We successfully held and reared 25,794,652 chinook salmon fingerling, all of which had been fed for considerable time before being released....[T]he weight of the fish reared at Coleman during 1947, totaled 109,799 pounds, which is a record for other fisheries workers to look at with wonder and admiration (CAR 1947, p 1).

The temperature regime within the lower river had been so improved by the Shasta-Keswick complex, or so argued Blote, that spring-run salmon "spawned themselves" within the lower mainstem Sacramento River (Blote 1948, p 32). Blote also pondered how continuing reservations about the success or failure of the Shasta Salmon Salvage Plan could be reconciled with record numbers of returning fish (Blote 1948). Although clearly impressed by these and subsequent high abundance figures, biologist James Moffett withheld final judgment, cautioning, in a paper's closing remarks, that "Experience has been insufficient to establish definitely the success or failure of the [Sacramento River] salmon maintenance work..." (Moffett 1949, p 102). What was held as true among many, however, was the belief that a sizable salmon fishery had become reestablished on yet another dramatically altered western river.

A Failed Mitigation Program Confronts Historic Salmon Populations

In retrospect, we can forgive those caught up in events for having made the best judgments possible at a given historic moment. History is sometimes less forgiving, however, as cumulative choices and events often give rise to a cascading series of institutional, economic, and ecological backlashes. Unanswered is how does Coleman's primary failure to mitigate for upstream losses (like spring-run fish) affect the achievement of other key 1940s Bureau of Reclamation "Sacramento River Migratory Fish Control Program" objectives? A reflection on what occurred among other key features of the Shasta mitigation program may answer the query. To reiterate:

- The Sacramento River fish racks essentially failed before being used.
- The Keswick Fish Trap operated on an on-again/off-again basis, and it became inoperative at moderate flows exceeding 16,000 cfs.

- The Fish Transport service often delivered weakened fish to inferior waters.
- Coleman National Fish Station was never able to propagate one half of the threatened spring run.
- The Deer Creek fish transfer was completely abandoned as unworkable by 1946.

In the end, what is concluded is that the mitigation failed.

The two surviving pieces of the original Shasta Salmon Salvage Plan were the Coleman Station itself and the Bureau-run Keswick Fishtrap. From the Service's point of view, Coleman Station did succeed at producing significant numbers of fall-run chinook salmon.

Although perhaps not in direct alignment with the [originally] proposed mitigation responsibility, the contribution of Coleman NFH in maintaining the ocean and sport fishery and upper river escapement of fall chinook salmon, while the quality of the Central Valley watershed was continually degraded, (Yoshiyama and others, this volume; USFWS and Hamelberg 1997, p 7).³⁷

Within ensuing years, the Bureau's Keswick Fishtrap also continued being called upon to capture incoming cohorts of salmon. Most of the time the fishtrap functioned satisfactorily. However, even under moderate flow conditions of 16,000 cfs or greater, the fish trapping apparatus became inoperative (Hallock 1987, p 32).

What was lost with the building of the Central Valley Project's keystone Shasta-Keswick complex? Based upon initial 1940 run-estimates, the answer is roughly:

- 15% of the fall-run's upriver habitat.³⁸

37. An earlier version of this document was reviewed by unnamed Service biologist(s) stationed at Red Bluff's Northern Central Valley Fish and Wildlife Office. Subsequent correspondence attributed those comments to biologist Scott Hamelberg. This final version is clearly stronger for Hamelberg's efforts (USFWS and Hamelberg 1997, 1999).

38. Late fall-run fish would require years before being identified as a separate phenotype. Their upriver spawning habitats were more adversely affected than those of the fall-run salmon. DFG biologist Richard Hallock observes that late fall salmon eggs taken at Keswick Trap (between January and March) sometimes made up one-half to one-third of the total Coleman egg take. He adds that Coleman stopped taking late fall eggs when too many "green" salmon (winter-run) were being hauled back to Coleman hatchery (Hallock, personal communication, see "Notes").

- Save for upper Battle Creek, 100% of the winter-run's historic habitat.
- 100% of the spring-run's habitat in the watershed above Keswick.
- 90% of the steelhead's habitat.³⁹

However, this was not all. Within their supplemental report to the original 1940 Shasta salmon salvage estimates, biologists Needham, Hanson, and Parker concluded that 1940 and 1941s runs were "...near 60,000 salmon by early December" (Needham and others 1943, p 14). Admitting that total runs "...might actually have been far greater than 60,000..." these scientists concluded that 1940 and 1941s combined runs

...could not have been less than 50,000 in either season " ...and that the salvage plan must be adjusted to great fluctuations in numbers of salmon and that no account to date has established the maximum numbers of salmon that may have to be handled (Needham and others 1943, p 14).

The salmon abundance estimates of 1943 roughly doubled previous drought-moderated figures under the Shasta Salmon Salvage Plan. Their new benchmarks included:

- 12,000 spring-run salmon (captured between January 1 and June 30).
- 18,000 summer and early-fall salmon (captured between June 16 and October 10 for artificial propagation).
- 30,000 fall-run (captured between October 1 and December 31 for natural propagation within the mainstem Sacramento River) (Needham and others 1943, p 7).

39. Recall from earlier discussions that steelhead propagation was folded into Coleman's operations in 1947. We have scant evidence of historic steelhead populations. I assume that historically, steelhead may have used spawning beds as far as 10 miles below Keswick Dam, hence the approximation of a 90 percent loss. If one assumes steelhead never spawned within the Sacramento River's mainstem, then estimates for what is missing climb upwards toward 100 percent.

More sobering still are recently prepared DFG spawning habitat estimates of historic salmon and steelhead populations above Keswick and Shasta dams (see Appendix A)⁴⁰. Using recent and early spawning gravel surveys⁴¹, biologists computed the number of nesting sites lost above Keswick and Shasta dams as a percentage of the entire Sacramento River run. These calculations assumed that each redd was 40 square feet above Shasta Dam (Hanson and others 1940) and 50 square feet downriver (Rieser and Bjorn 1979). In 1939, roughly 15 percent of the total fall run's estimated spawning areas occurred above Keswick Dam. Computations were based on 24,847 salmon spawning sites upriver from Shasta Dam and 5,945 salmon spawning sites occupying the stretch between Shasta and Keswick dams. The recommended space for spawning pairs during the mating process is 145 square feet for spring run and 215 square feet for fall-run salmon (Rieser and Bjorn 1979).

The most critical feature of the lost spawning grounds above Shasta and Keswick dams was not the absolute number of fish excluded but rather the quality of that drought-proof habitat. The McCloud River, the Little Sacramento River, and the Pit River were resistant to drought and the mortality caused by elevated water temperatures. These upper watersheds produced high quality habitats because of their higher elevations and their volcanic geomorphology. These rivers absorbed much of the wet seasonal runoff, then gradually released it in abundant cold spring flows throughout the dry season. The respectable counts of salmon and steelhead returning to the areas above Shasta Dam at the close of 1939's drought cycle attested to the drought-resistant character of these stream reaches. The habitat above Shasta Dam also provided for the natural spatial separation of the different races of salmon; especially spring-run and winter-run chinook.

Estimates of usable spawning habitat available in the first 130 river miles below Keswick Dam varied greatly among the four available studies. The pre-Shasta Dam estimates of 1939 occurred immediately following one of the worst droughts in recent history. That makes redd counts extremely low compared to the post-Shasta Dam era where estimates climbed due to higher and cooler river flows. The 1939 estimate for the 60-mile reach between Keswick and Red Bluff was placed at 18,413 spawning sites, while figures for this same

40. Within an unpublished paper, H. D. Radtke and S. W. Davis use Northwest Power Planning Council methodologies to estimate historic Central Valley salmon abundance. They reconstruct populations at between 2 million to 4 million fish (as cited in Gresh and others 1998, p 7). Using commercial catch figures, DFG biologist Frank Fisher estimated historic Central Valley salmon populations to have been 2 million fish (Fisher 1994). By drawing on USFWS derived run-size estimates, Thomas Richardson estimates pre-1915 peak Sacramento River salmon runs to have been between 800,000 to one million fish, with a yearly average of 600,000 (Richardson 1987, p 6; USFWS 1984).

41. Historic survey data derive from Hanson and others (1940, p 25, 31, 48).

reach after Shasta Dam averaged 120,588 sites. There was no comparable 1939 estimate for the 70-mile reach below Red Bluff Diversion Dam because it appeared to observers to be of excessively poor quality. However, if it is assumed that in 1939 there were the same numbers of sites above as below Red Bluff (18,413), this was significantly lower than the estimate of 70,908 sites determined in a 1976 mapping.

The spawning habitats below Shasta Dam were apparently increased during periods when there were cold high volume water releases from Shasta Dam. There is a danger, however, in counting on these conditions if they were transitory (as described in Moffett 1944). Even if there were assurances of making the lower elevation habitats below reservoirs reliable, they certainly did not possess quality conditions comparable to those found above Shasta Dam. The below-dam habitats remained drought-prone and they did not provide spatial isolation between overlapping stocks of spring- and fall-run salmon. Currently, below Shasta Dam, the winter-run salmon have 40 miles of river with suitable spawning habitat available during 90 percent of the water years with no available habitat under the worst drought conditions (USBR 1991; DFG 1992; NMFS 1992). To make matters worse, DFG biologist Richard Hallock demonstrated that over a 17-year period, Red Bluff Diversion Dam greatly undermined downstream reproductive conditions where lower river water temperatures were suitable for winter-run spawning and incubation 22 percent of the time (Hallock 1987, p 55).

Above-Shasta populations of winter-run salmon once had an estimated 34,634 spawning sites available in the Little Sacramento, the McCloud, and the Pit river systems. Save for Battle Creek, 100 percent of the winter-run race spawned upriver from the Shasta-Keswick complex (Hallock and Rectenwald 1989).

Pre-Shasta populations of spring-run salmon once had at least 51,377 spawning sites dispersed throughout the Little Sacramento, the McCloud, and Pit rivers. In the 1920s, Pacific Gas and Electric's Pit River dams cut off an additional 7,444 upriver spawning sites without benefit of mitigation.⁴²

Despite substantial evidence of widespread failure, the Bureau, the Service, the DFG, and many interested observers, convinced themselves that the "Sacramento River Migratory Fish Control Program" had succeeded. In the end,

42. This figure is based upon DFG computations. For insights into the proposed damming of the lower Pit River, see Hopson and Means (1915). G. H. Clark observes that Pit Dam No. 4, PG&E's lowermost dam on the Pit River, blocked upstream passage of salmon. The structure was completed in May 1927, and, as biologist Clark observes, "...is impassable with no provisions to take care of the fish." Pit No. 3 is located nine miles upriver. Also impassable, it was completed in 1925 (Clark 1929, p 42-43).

the spectacle of considerable fish in the Sacramento River provided the screen to hide the salvage program's cumulative failures. A myth had been created and it would require considerable time before the Shasta Dam's full effects came into plain view.

IV. Coleman Hatchery Production: The 1950s

Throughout the 1950s, a Service-directed Coleman Station produced a wider assortment of fish species reared for a greater number of northern California destinations and clients. In addition to fall-, winter- and spring-run chinook salmon, Coleman produced or handled coho salmon, steelhead, rainbow trout (mostly provided by the State of California), Kamloops trout, kokanee salmon, and even a few warm water fishes. Specific clients came to include "Kamloops, Incorporated" and "Steelhead Unlimited" of Redding, Beale Air Force Base (near Marysville), and Stead Air Force Base.

Between 1949 and June, 1957, the Bureau of Reclamation sponsored cooperative state and federal research consisting of life cycle assessments and data accumulation on the continuing fish maintenance program. Writing within their summary report, Service biologists Robert L. Azevedo and Zell E. Parkhurst observed that:

...during the 1943–1949 period [the upper Sacramento River changed]...from primarily [being] a salmon salvage program to a program of maintenance and evaluation. The Bureau of Reclamation continued to finance the fishery program beyond the salmon salvage stage because evaluation studies, as well as hatchery operations, were considered an integral and necessary part of the conservation of natural resources associated with the Central Valley Project (Azevedo and Parkhurst 1957, p 3–4).

The ensuing eight-year program principally consisted of:

- Spring-run chinook salmon being left to spawn naturally within the Sacramento mainstem and other accessible tributaries.
- Fall- and some winter-run chinook salmon being taken at Keswick Fishtrap and hauled to Coleman Hatchery for artificial propagation.
- Fall-run chinook spawners being diverted from Battle Creek into the Coleman facility.
- Data gathering to determine annual fluctuations in populations, fishing pressures, adverse effects of mining leachate, and so forth (Azevedo and Parkhurst 1957, p 4–5).

Within what Kai Lee has subsequently called an “industrialized ecosystem,” riverine studies such as these were useful in determining how best to coordinate Coleman’s migratory releases coincident with natural fish migrations and other identifiable windows of opportunity (Lee 1993; Azevedo and Parkhurst 1957, p 6). For instance, water temperature records aided in determining optimal periods for releasing salmon fingerlings. In addition, by carefully tracking upriver pollution deriving from sites like Iron Mountain mine, Coleman Hatchery’s personnel even sought to avoid excessive fishkills.

These and other similar data provided Coleman Superintendent John Pelnar with means of maximizing fish escapement. Within a dramatically altered ecosystem, Coleman-reared fish arguably possessed certain advantages never enjoyed by their wild counterparts. For instance, Superintendent Pelnar knew the best times of the year to avoid hatchery releases due to excessive downstream irrigation (Hallock, personal communication, see “Notes”). It was certainly helpful knowing about mainstem Sacramento River water exports considering the “...335 separate diversions, utilizing a total of 448 pumps, along the Sacramento River between Redding and Sacramento” (Hallock and Van Woert 1959, p 263). Coleman also provided State and federal biologists with increasingly sophisticated means of marking outgoing and incoming cohorts of anadromous fish (Cope and Slater 1957). DFG biologists, in particular, conducted elaborate marking experiments for tracking the whereabouts, perils, and life cycle patterns exhibited by anadromous fish.

Fall-run chinook salmon and steelhead production predominated at Coleman with a small but steady supply of imported Kamloops trout and kokanee salmon for Shasta Reservoir. The hatchery’s last major attempt at spring-run production occurred in 1951 (after which it was begrudgingly abandoned).⁴³ In 1955, an experimental trapping of winter-run salmon occurred in which only two females out of 184 total fish spawned (CAR 1955, p 20). Experimentation with winter-run stocks reoccurred during 1958 when they stripped eggs and milt from a total of 191 fish (CAR 1958, p 20). Attempted propagation of winter-run fish ceased during the following year, only to occur again in 1962.

In 1952, British Columbia- and Montana-derived Kamloops trout and kokanee salmon were obtained by Coleman Hatchery for a recreational fishery in Shasta Reservoir.⁴⁴ Henry Clineschmidt’s Redding-based group(s), “Kam-

43. Well, almost. During 1954 they propagated a total of four spring-run chinook (CAR 1955).

44. Richard Hallock observes that during the 1950s, marked yearling Kamloops trout were also released in the Sacramento River to produce a resident trout fishery near Redding. The fish, however, took an unexpected turn and headed out to sea, only to return with incoming steelhead. Hallock also points to evidence of hybridization between Kamloops and steelhead (Hallock, personal communication, see “Notes”).

loops, Incorporated," (and "Steelhead Unlimited") forged several funded, cooperative agreements with the Bureau of Sports Fisheries and Wildlife and the DFG, to propagate specific game fish. Clineschmidt, like Pelnar, was a significant force in northern California fisheries circles, and together, they made formidable advocates. Clineschmidt and Pelnar's plan was simply to introduce Kamloops trout into Shasta (and later Whiskeytown) reservoirs, to be followed by kokanee salmon (Hallock, personal communication, see "Notes"). They hoped to mirror ecological conditions found in Idaho's lake Pend Oreille, in which legendary forty pound Kamloops trout fed off an established kokanee population. Anticipation of landing a forty pound Kamloops trout on light tackle went a long way toward explaining why "Kamloops, Incorporated" and "Steelhead, Unlimited" were founded by the same individual and consisted of complimentary memberships.

In 1955, Coleman's production was drafted by the US Air Force. The Commander at Beale Air Force Base (near Marysville) sought advice and assistance in stocking waters adjacent to his geographically-isolated personnel. Beale's base population would soon swell to over 15,000 individuals as it became a Strategic Air Command base.⁴⁵ Rainbow trout as well as some warm water fishes were planted. A subsequent agreement signed between the Service and the Air Force directed Coleman to stock waters near two northern California bases (CAR 1955, p 5). Some rainbow trout were reared at Coleman while the majority came from State of California hatcheries.

In March 1956, 43,025 yearling coho salmon were introduced into the Sacramento River basin from Washington's Lewis River (Hallock and Fry 1967, p 15). In late September 1957, Coleman Hatchery trapped 910 coho salmon for the continuing experiment in artificial propagation (CAR 1957, p 5).⁴⁶ Cohos were promoted by Jim Baucum, President of the Sacramento River Resort Owners Association. Baucum, himself a resort owner (in Los Molinos), saw an opportunity in introducing these prized sports fish into the Sacramento's mainstem. Resort owners sought to convince biologists that cohos might fill a seasonal recreational fishing "gap" without unfairly competing with other anadromous fish.⁴⁷ The Resort Owner's Association promised to foot the bill

45. In 1960, Congress passed the Sikes Act which institutionalized cooperative arrangements between the US Fish and Wildlife Service and other federal agencies which were interested in stocking and managing, among others holdings, Indian and military reservations (USFWS and Hamelberg 1997, p 7).

46. Of this total, 125 were females, yielding a total of 386,971 eggs (CAR 1957, p 5).

47. Richard Hallock, personal communication, see "Notes." DFG biologists presumed that coho would come upriver after steelhead and remain within the mainstem Sacramento rather than proceed on into upriver tributaries and compete with other salmon.

if Leo Shapovalov of DFG and John Pelnar of Coleman Hatchery were agreeable. Coho salmon trapped at Coleman were part of a three year study conducted by Richard Hallock of the DFG (Hallock, personal communication, see "Notes"; Hallock and Fry 1967, p 15-16).

Over the next three years, Coleman and Darrah Springs hatcheries sought to establish a run of coho in the Sacramento River basin. Hatchery personnel later discovered that eggs taken from returning fish were unsuitable for artificial propagation. The eggs themselves were soft and failed to fertilize properly. The experiment seemed to have been quietly discontinued in 1960 when 63 coho were released into Battle Creek (CAR 1960, p 6). Superintendent John Pelnar was pleased to be rid of the project because, in the words of biologist Richard Hallock, "it made his numbers look bad" (Hallock, personal communication, see "Notes"). By the fall of 1963, Hallock and Fry reported that cohos were as scarce in the Sacramento River as they had been before this recreational experiment (Fry and Hallock 1967, p 16).

Throughout the 1950s, the DFG reported a general increase in steelhead populations throughout the remaining mainstem Sacramento River. By 1958, artificial propagation of steelhead at Coleman Hatchery shifted from its prior experimental status to becoming a more fully established program. Collaboration with members of Steelhead Unlimited and the DFG helped solidify Coleman's steelhead production objectives. Azevedo and Parkhurst reported that roughly 5,000 chinook salmon and 2,500 steelhead were caught by sportfishers in the upper Sacramento River between 1952 and 1954 (Azevedo and Parkhurst 1958, p 70). These biologists also noted that Sacramento River fishing resorts "...increased from eight in 1951 to twenty in 1954" (Azevedo and Parkhurst 1958, p 70). Kamloops, kokanee and steelhead production at Coleman was bolstered by outside recreational interests who shared a sizable economic stake in the hatchery's recreational production.

Throughout the 1950s, disease remained a serious problem at Coleman Hatchery. In 1953 through 1955, biologists believed a filterable virus of unknown origin hit hatchery salmon stocks.⁴⁸ Heaviest losses occurred during March, April, and May of 1955 when almost 17 percent of the salmon stock affected died (CAR 1955, p 5). Biologists observed the disease outbreak diminishing when water temperatures rose in late Spring. Again during 1958 and 1959, the station was hit by considerable losses among salmon fingerlings, prompting personnel to write: "Since the advent of this station's fish operations a steadily increasing loss was suffered by all age groups of chinook salmon, various

48. Biologists believed that with sufficient filtration, they could prevent the onset of this disease. The disease was probably Infectious Hematopoietic Necrosis (IHN) which was finally identified in 1962 after several years of study.

remedies were made use of but to no avail" (CAR 1959, p 7). Scientists from Seattle's Western Fish Disease Laboratory were called in to study the problem.

As hatchery personnel busily contained disease outbreaks, Coleman's director observed there was growing public interest in hatchery activities and production. A steady stream of visitors prompted Superintendent Pelnar to write:

Considerable interest has been shown by commercial and sport fishermen in the station's work, due to the general down trend of the chinook run in California. Many feel that the natural reproduction is no longer practical and far too much loss occurs from natural spawning (CAR 1957, p 3).

Throughout the 1950s, Coleman National Fish Station's diversification strategy appears to have been opportunistically motivated. Saddled as it was with running a very expensive facility, the Service had little choice but to continually seek sympathetic outside constituencies, external funding, and broad-based public support. By 1960, the sole remaining formal piece of the Bureau's original "Sacramento River Migratory Fish Control Program" was booming production of predominantly lower-river, fall-run chinook salmon. In 1960, Coleman hatchery combined the stripped eggs of 6,849 female salmon with the milt of 2,225 males to yield 41,612,640 fertilized eggs. Of this total, 96 percent survived to become fingerlings (CAR 1960, p 26). Although not originally part of the Bureau's upriver mitigation efforts, steelhead production continued at Coleman where 357 females and 207 males were stripped yielding a total of 791,000 fertilized eggs. Almost 79 percent survived to the fingerling stage (CAR 1960, p 26). Meanwhile, due to increasing habitat degradation, water exports, and stock hybridization, among other causes, naturally-reproducing Sacramento River salmon and steelhead populations continued their long, steady decline.

V. Coleman Hatchery Production: The 1960s

Well established production patterns originating in the late 1940s and early 1950s continued at Coleman National Fish Hatchery through the 1960s with a few notable exceptions. In 1961, a small number of Kamloops trout was produced for stocking Shasta reservoir and fall-run chinook salmon and steelhead trout remained the primary fish reared at Coleman.⁴⁹ The DFG supplied Coleman with catchable rainbow trout for stocking Beale Air Force Base (CAR 1962, p 3) and the following year, brown trout were imported from Massachu-

49. In 1961, Donald Fry identified a separate late fall-run of chinook salmon on the Sacramento River when substantial numbers of spawning fish were captured at Keswick Fishtrap and hauled to the Coleman National Fish Hatchery (Fisher 1994, p 871; Fry 1961).

setts to stock California sites (CAR 1962). Twelve coho salmon made their way back upstream to the Battle Creek hatchery while the Keswick Fishtrap was used to trap 2,625 winter-run salmon for re-release below the ACID dam.⁵⁰ One hundred fifty-five winter-run salmon were also trapped and hauled to Coleman's ponds for ongoing experimentation.

Biologists at the DFG cooperatively marked one half million hatchery chinook salmon fingerlings for the third year in a row. A third of the fish was released into adjacent Battle Creek and a third was trucked to Rio Vista. The final third was hauled to Rio Vista and then transported downstream by boat for eventual release at 50 percent salinity (CAR 1961, p 13). By planting fingerlings within different parts of the river basin, scientists sought to understand issues like optimal escapement size, straying effects, and eventual upriver recruitment of mature fish. Those fish released at Rio Vista "contributed significantly more [1.5 times]...to the fisheries than those released at the hatchery," while downstream transplants "strayed considerably [more] from the parent stream when returning to spawn" (Hallock and Reisenbichler 1979, p 3). DFG also conducted a jointly run Kamloops marking program.

Outbreaks of the "Sacramento River Chinook Salmon Disease" (Infectious Hematopoietic Necrosis) continued at Coleman Hatchery. During 1960, fish disease specialist Tom Parisot substantiated prior observations that a subtle increase in hatchery water temperatures to between 54 and 56 degrees "rendered the virus agent inactive" (CAR 1961, p 13). Biologists constructed a system capable of blending, then re-using, warmer temperature well water with cooler Battle Creek waters to obtain the desired 54 degree temperature. Unfortunately, the experimental system easily clogged up with mud, silt, or debris, causing high mortalities among fry. Various parasitic and bacterial invasions continued to dog production efforts at Coleman National Fish Hatchery as it had throughout the 1950s.

In 1966, Coleman's disease specialist Elmo Barney prescribed "antibiotic therapy" to nullify the ill effects of disease on Coleman's fish stocks (CAR 1966, p 9).⁵¹ It was not until February 1967, that an experimental water rehabilitation system existed for regulating water temperatures. Hatchery personnel pinned high hopes on temperature stabilization, calling it "The first real breakthrough in the control of the Sacramento River Chinook Salmon Disease..." (CAR 1968, p 4). That optimism was dashed the following season

50. Biologists believed that winter-run below Keswick Dam could become entrained in irrigation canals upstream from ACID (CAR 1961, p 11).

51. To quote from the annual report, "Healthy and diseased fish were challenged with new parasiticides and bactericides for fish toxicity and biological control. Satisfactory control of Myxobacterial infections in juvenile fish populations has been attained through antibiotic therapy" (CAR 1966, p 9).

when three times the normal precipitation fell upon the Battle Creek watershed, keeping water temperatures well below normal for over six weeks. Sacramento River Chinook Salmon Disease “ran rampant” through the chinook salmon stocks, save for those few enjoying elevated temperatures within a Burrows water re-use system (CAR 1969, p 6).

Throughout the early 1960s, Coleman Hatchery personnel continued cooperating with other federal agencies including the US Bureau of Reclamation and the US Army Corps of Engineers. The Bureau continued operating the Keswick Fishtrap and attempted to control, as best they could, for toxic mining leachate harmful to anadromous fish (CAR 1962, p 8).⁵² When pulses of heavy metal contamination exited Spring Creek, Bureau personnel trapped, then hauled, downstream winter-run salmon for re-release below the ACID dam. Members of the Army Corps of Engineers used Coleman fish in a lengthy series of elaborate studies of fish passage through Shasta Dam’s turbines.

Winter-run Salmon

During 1962, 140 winter-run chinook were hauled to Coleman for experimental holding and propagation. The first full length report on the occurrence of the Sacramento River winter run occurred the following year, when Service biologist Dan Slater published a seminal article on the salmon. Slater observed that, historically, winter-run were “...uniquely adapted to streams fed largely by the flow of constant-temperature springs arising from the lavas around Mount Shasta and Mount Lassen” (Slater 1963, p 8). In 1884, Livingston Stone identified the winter run (he also called them “black salmon”) as one of three major stocks inhabiting the upper Sacramento River (Stone 1874; Fisher 1994, p 871). In its 1888–1889 Biennial Report, the State Board of Fish Commissioners records that, “it is a fact well known to fish culturalists that winter and spring run salmon, during the high cold winters, go to the extreme headwaters of the rivers if no obstructions prevent, into the highest mountains” (SBFC 1890, p 33; Hallock and Rectenwald 1989, p 4) Ironically, mention of the winter run also occurred among early biological investigators charged with creating Shasta Salmon Mitigation Plan proposals (Hanson and others 1940). Although never included among the Board of Consultants mitigation obligations, the winter-run waited until the late 1960s before its life history details were fully understood.

Combining life history traits common to both “stream-” and “ocean-type-” salmon, the winter-run was something of a behavioral anomaly (Healey, as cited in Groot and Margolis 1991, p 319). Mike Healey observes,

52. Bureau personnel sought to remove mature fish from the river when Spring Creek’s pollution was present (CAR 1962, p 8).

[winter-run fish] enter the river green and migrate far upstream. Spawning is delayed for some time after river entry. Young winter-run chinook, however, migrate to sea in November or December, after only four to seven months of river life (Healey, as cited in Groot and Margolis 1991, p 319).

Biologists Slater and Richard Hallock combined their talents to estimate inland catch and population. Concomitantly, Slater approached Pacific Coast fisheries agencies to determine if there were other similar stocks. When that answer came back “no,” it became clear winter-run were uniquely adapted to the Sacramento River (Hallock, personal communication, see “Notes”).

Independently of Slater’s work, questions about the winter run continued to pique Hallock’s interest. Hallock questioned whether the winter-run constituted a truly distinctive population. Over the course of three years, and working together with five assistants, Hallock seined, fin-clipped, and released several hundred thousand juveniles along the shores formed by Red Bluff Diversion Dam. Seining occurred “almost entirely in September” when the juveniles were 35 to 45 mm in length (Hallock, personal communication, see “Notes”). Adult returns allowed Hallock and his colleagues to construct the first life history profile on where the fish went in the ocean, age at spawning, eggs per female, catch to escapement ratio, and migration timing (Hallock, personal communication, see “Notes”; Hallock and Reisenbichler 1980; Hallock and Fisher 1985).

Red Bluff Diversion Dam

In 1987, Richard Hallock identified the Bureau of Reclamation’s Red Bluff Diversion Dam (RBDD) as “One of the major causes, and perhaps the single most important recent cause of the decline of salmon and steelhead in the Sacramento River...” (Hallock 1987, p 33). Originally promoted as a “fish-enhancer,” the structure was located two miles downstream from Red Bluff and it diverted water into the Tehama-Colusa Canal and to the Corning Canal Pumping Plant. During average water years, each canal shunted 700,000 and 50,000 acre feet, respectively (Hallock 1987, p 33).

Completed in 1964 (it became fully operational in 1966), the dam included elaborate fish protection measures. Closed circuit television monitored fish passage through separate fishways. A built-in trap assured biologists access to incoming adult fish. Louver-type fish screens sought to limit fish losses within canals while a (never-used) Service hatchery was eventually constructed on site to harvest roe and milt from excessively ripe fish.⁵³ The 3,000 salmon which once occupied RBDD's immediate upstream spawning riffles were to be more than compensated by newly engineered downstream spawning channels suitable for holding 30,000 fish (Hallock 1987, p 58).⁵⁴ Jack Savage of the Fish and Wildlife Service promoted the idea of spawning channel enhancements (Hallock, personal communication, see "Notes"). The mitigation strategy partially stemmed from Washington State and British Columbia precedents with considerable help provided by Columbia River-based engineering and hatchery staffs (Grover, personal communication, see "Notes").⁵⁵ There were just two problems: it never worked, and, to make matters worse, it required 20 years to discover that fact.⁵⁶

Richard Hallock observes that the Red Bluff Diversion Dam radically altered the existing distribution of fish within the lower and remaining reaches of the Sacramento River. Before its full operation, 90 percent of the fall-run spawned upriver from the damsite. After operating for a decade, less than 40 percent of the fall-run chinook salmon spawned above and greater than 60 percent were distributed below the dam site (Hallock, as cited in Lufkin 1991, p 100).

53. Female salmon were considered ripe upon losing eggs when handled. The Service constructed the temporary 3 million-egg incubation station near the dam's left bank fishway. Fish were released back into the river in the hope that they would spawn naturally. The facility became fully operational in 1979, but due to a "...lack of personnel and management interest," the 7 million egg hatchery was never used (Hallock 1987, p 33). Within a subsequent cooperative study, biologists demonstrated that "...an average of almost 2,500 (3.4%) of those [fish] passing the dam were ready to spawn immediately..." (Hallock and others 1982, p 17).

54. Tehama-Colusa Fish Facilities enhancements were calculated at 27,000 fish, a hypothetical number which "...made the entire [diversion dam] water project much more feasible" (Hallock 1987, p 58).

55. In 1950, Harold Gangmark operated a federally sponsored artificial spawning channel in Mill Creek at the site of the old abandoned hatchery at Los Molinas (Hallock, personal communication, see "Notes"). Dale Schoeneman was brought in to manage the newly constructed RBDD spawning channels from Washington State where he oversaw a similar spawning channel venture.

56. Cost for building the Tehama-Colusa Canal "salmon enhancement facilities" was \$23 million dollars. Engineers originally called for building a "dual-purpose" irrigation-spawning canal, including water turn-outs, for spawning fish at Thomes and Stony creeks. For a particularly biting assessment, read Zeke Grader's commentary (Grader 1988a).

Although historical information was lacking, declines among other races of anadromous fish followed these same disturbing trend lines. Hallock reported:

Between 1969 and 1982,...RBDD has caused an estimated loss in the upper Sacramento River system's adult salmon population of 114,000 fish: 57,000 fall run, 17,000 late fall run, and 40,000 winter run. These losses have deprived the fisheries of about 228,000 salmon a year at a catch-to-escapement ratio of two-to-one...In addition, an estimated decline of 6,000 sea-run steelhead...has been attributed to RBDD (Hallock, as cited in Lufkin 1991, p 101).

Biological investigations document upstream salmon passage delays of one to forty days, while an additional 26 percent never even made it past the dam (Hallock 1987, p 36). Particularly hard hit were winter-run salmon which remained ill-suited to spawning within the warmer lower river. Downstream from Red Bluff Diversion Dam, Hallock reports that "...water temperatures were suitable for winter-run spawning and incubation...only four out of eighteen years (only 22 percent of the time) between 1967 and 1984" (Hallock 1987, p 55). By comparing the 1967-1969 average salmon counts passing RBDD with those between 1970-1982, Hallock and Fisher demonstrated a decline of 58 percent (or 40,364) among winter-run salmon. If records from the three drought years of 1979-1980 and 1982 were included, the percent winter-run decline was 79 percent (79,289 fish), or a 52 percent decline in each successive generation (Hallock and Fisher 1984, p 9).

Hallock observes that upstream dam passage delays increased with river flow, for mature fish experienced greater difficulty finding fishways under higher than lower water conditions (Hallock, as cited in Lufkin 1991, p 100). Downstream passage by juvenile fish was equally problematic, as excessive downstream dam turbulence disoriented emigrating fish and forced them toward the river's surface. Whereas adult fish held their own against predators like Sacramento pike minnow, striped bass, steelhead and shad, younger fish often were eaten. Among juvenile salmon, 1974 Service studies estimated downstream migratory salmon losses at between 55 to 60 percent during daylight hours (Hallock, as cited in Lufkin 1991, p 100). Within another document, ocean sampling data among marked Coleman salmon indicated that fingerlings freed below RBDD "...survived better than those released upstream from the dam...Losses among those released upstream from the dam ranged between 29 percent and 77 percent (Hallock 1983, p 5). To this day, many fish conservationists still consider the Bureau's Red Bluff Diversion Dam to be a "fish killer."

Quite unlike the once proposed Iron Canyon or Table Mountain dams, however, the Red Bluff Diversion Dam did not "nullify" the attempted Shasta Salmon Salvage Plan of the 1940s. Serious delays in upstream fish passage did

render remaining spawning grounds inaccessible to a quarter of the fall run alone. Excessive dangers accompanying downstream fish passage further undermined escapement, and, among Coleman managers at least, raised the size, distribution and age of fish at release. If the original "Foster Plan" sought to balance natural propagation within the mainstem Sacramento with artificial propagation at Coleman National Fish Hatchery, then RBDD hurt the former while selecting for the latter. Coleman's personnel could plan rearing fish to larger sizes, and release these same cohorts below the offending structure. Naturally spawning spring- and winter-run salmon did not enjoy these same artificial advantages and were left as they were to fend for themselves within the river's mainstem. Yearling steelhead, which were released below Red Bluff Diversion Dam enjoyed twice the rate of return to the Coleman Hatchery as those released directly into Battle Creek (Hallock 1976, p 2). Declining numbers of returning migratory fish began to worry biologists who became aware of a troubling portrait of irreversible declines.

Diminishing Anadromous Fisheries

Within a July 11, 1968 memorandum, Walter T. Shannon, Director of the DFG, called for severe cutbacks in commercial and recreational salmon harvests (Shannon July 1968). King salmon populations, he noted, were at historically "low levels," as reflected by falling ocean harvests and depleted Central Valley spawning populations. Department of Fish and Game biologists singled out "...a reduced survival rate of young fish" as the primary factor in the crisis. Shannon said that the "emergency situation" nevertheless warranted "...placing some restrictions on both the river and ocean sports fisheries" (Shannon July 1968).

DFG biologists observed in an accompanying report that ocean caught king salmon dropped from about 800,000 in 1964 to a low of 400,000 in 1967 (Fry and others 1968, p 1). The report noted that ocean harvested fall-run chinook had diminished since 1959 while, for the moment at least, record numbers of returning winter-run fish masked the severity of the crisis. Propelling the emergency was

Increased predation, partly from a larger steelhead population, losses in unscreened irrigation diversions, water quality and quantity problems in the San Joaquin and its tributaries, diseases, or unknown changes in the ocean environment (Fry and others 1968, p 1).

No specific mention was made of the Central Valley Project Tracy pumps, nor of the Bureau's Red Bluff Diversion Dam. The report highlighted (and quite literally underlined) that,

The Fishermen are not to blame for the decline, but the survival rates of young fish have become so low that the adult population has been unable to support both good catches and a good spawning population returning to the rivers (Fry and others 1968, p 2).

DFG sought to bolster escapement and adult salmon recruitment by implementing a “small reduction” in the size of the sports and commercial catches between 1969 and 1972 (Fry and others 1968, p 5).

On the evening of July 23, 1968, DFG Director Walter Shannon and Fish and Game Commission President Henry Clineschmidt convened a public meeting to discuss matters (Kier 1998). Clineschmidt had already solicited support for the shut-down among sympathetic sportsmen. What DFG required was a buy-in by commercial fishermen. Fishermen appeared grudgingly compliant with a fishing ban except for Fort Bragg fishbuyer Bill Grader who staunchly opposed any reduced catch (Kier 1998). Grader’s fervent opposition, together with that of many others, marked a watershed point in the fisheries debate: simply shutting down the fisheries was no longer deemed sufficient to save salmon.

The following day Bill Grader visited Senate aide William M. Kier in his Sacramento office with proposals for at least fifteen separate pieces of fisheries legislation. In Kier’s words,

One created the Citizen’s Advisory [Committee] on Salmon and Steelhead; another attempted State fish protections at federal water projects; another sought tightening of fish screen laws; another [an] extension of the spawning gravel protections (Kier 1998).

Subsequently, Grader became chair of the Advisory Committee and he funded the entire project himself. DFG provided clerical and biological assistance to the committee.

It would require a full decade to attribute serious migratory fish declines to a largely-impassable Red Bluff Diversion Dam. In addition, the full impact of the Delta’s combined federal and State water projects constituted, in the words of retired DFG biologist Frank Fisher, a literal “black hole” (Fisher, personal communication, see “Notes”). Between 1967 and 1983, members of the Upper Sacramento River Salmon and Steelhead Advisory Committee wrote that fish counts past RBDD “...indicate[d] substantial declines in the fall and late fall runs, a serious decline in the spring run and the almost complete loss of the unique winter run.” (Frost and others 1984, p 5), The report also singled out steelhead as having all but “disappeared,” save for Coleman Hatchery’s Battle Creek production.

The man-made origins of the fishery collapse were eerily reminiscent of conclusions reached in 1944 by Willis Rich, Paul Needham, A. C. Taft, and Richard Van Cleve, who wrote:

It has been relatively recent that recognition has been given to the importance of dams and diversions to the continued existence of the salmon runs in many of our western rivers. As the ultimate plan for water development is approached, the effect is cumulative and the present proposed postwar projects bring the problem to the acute stage (Rich and others 1944, p 5).

What was more, many of these water projects hinged upon massive and continuing governmental intervention. In 1962, a Bureau of Sports Fisheries and Wildlife report complained that it was man's activities in California which have,

...generally proceeded counter to the best interests of the anadromous salmon and trout resources. In fact, they have destroyed substantial segments of these resources while employing only token efforts to ameliorate the damage. Activities conducted, sanctioned, sponsored and supported by the Federal Government have been prominent in the history. The [following] dam list...documents the major harmful results of direct federal activity (USFWS 1962, p 5).

No wonder this unattributed Fish and Wildlife Service document bore this prominent stamp on its cover: "Official Use Only: Not for Public Release."

Coleman Summary

Throughout the 1960s, several "limiting factors" were identified at the Coleman National Fish Hatchery including an insufficient availability of fresh water necessary to sustain high levels of production (USFWS 1963, p 33). While new rearing ponds constructed in 1962 did boost capabilities, concerns about excessive crowding among fish and disease limited production to about 250,000 pounds a year (USFWS 1963, p 33).⁵⁷ The Coleman Master Plan of 1963 explicitly called for a new hatchery facility to be constructed near Keswick to accommodate incoming fall- and winter-run fish. Diversification would permit the Coleman Hatchery to focus on rearing Battle Creek chinooks to a larger size while concentrating on producing incoming winter-run fish (USFWS 1963, p 34).

57. Within Coleman's 1963 Master Plan, annual production objectives were reassessed at 40 million chinook salmon, steelhead trout and Kamloops trout eggs, fingerlings, and yearling fish weighing 250,000 pounds" (USFWS 1963).

Throughout the 1960s, hatchery personnel continued experimenting with new fish foods. Rather than grinding up spawned out salmon carcasses, Sidney Campbell constructed an automatic fish feeder for delivering moist pellets into several raceways in 1962 (CAR 1963, p 3). Additional mechanical fish feeders followed, coincident with an ongoing debate over which pelleted fish foods to use: Abernathy dry diet versus Oregon Moist Pellets (CAR 1967). During 1967, chinook salmon eating the Abernathy pellets "...suffered a severe mortality" and, during that year at least, the tests were halted (CAR 1968, p 7). Refinements in feeding strategies continued throughout the ensuing decade.

Additional experimentation occurred as Coleman Hatchery sought to produce other kinds of fish. In addition to their Kamloops, rainbow and brown trout stocking programs, coho salmon were again brought into the Sacramento River Basin. In 1967, 550,000 eggs were imported to Coleman Hatchery from Eagle Creek, Oregon. Of these numbers, 390,000 coho salmon were released into the Sacramento River during July, 1968, at a weight of 25 fish per pound (CAR 1971, p 24). During 1970, 81 coho returned to the hatchery. As had occurred during the previous decade, poor quality eggs deposited by returning adults were deemed a total loss before the eyed stage. Consulting DFG found evidence of Sacramento River virus (CAR 1970, p 9). The following year, the coho stocking program was discontinued as 226 unspawned coho were transported and released into an upriver Shasta Reservoir (CAR 1971, p 7).

VI. Coleman Hatchery Production: The 1970s

Throughout the 1970s, fish production at Coleman National Fish Hatchery followed 1950s and 1960s precedents. Fall chinook salmon and steelhead production remained Coleman's bread and butter objectives. In 1969, the Service co-signed a "Salmon-Steelhead Accelerated Production Program" with the DFG. The agreement paved the way for Coleman to accept more fall-run chinook salmon and steelhead eggs (or stocks) from state hatcheries like Nimbus on the American River. The program was designed to maximize primary production at Coleman in exchange for fulfilling certain state restoration priorities (in other words, stocking steelhead on the Yuba river). A second, continuing, cooperative federal-State stocking and fish exchange program required Coleman to produce, rear and/or stock Kamloops trout, brown trout, rainbow trout, coho salmon, and hybridized Kamloops and rainbow trout in designated state waters. In 1978, trout production was suspended and much of the federal-State exchange program was discontinued or substantially renegotiated.

Late in the decade, severe drought exacerbated an established pattern of anadromous fisheries decline. A 1978 drought reduced salmon and steelhead returns to Coleman Hatchery to one of their lowest on record. In 1977, William Sweeney, Area Manager for the Fish and Wildlife Service, became increasingly alarmed by steadily diminishing numbers of returning fall-, winter- and spring-run chinook salmon and steelhead (Sweeney, personal communication, see "Notes"). Sweeney sought, and obtained, DFG's cooperation in redirecting Coleman's activities back to its original 1940s mandate – salmon and steelhead production. Coleman's trout production was curtailed in fiscal year 1978, but not before the epizootic IHN infected the hatchery's state-supplied Kamloops population. As Coleman responded to the growing anadromous fisheries problem, 795,000 Kamloops were buried (CAR 1978, p 2).

Coleman Hatchery began with a series of crises in the 1970s. The initial fall chinook salmon harvest on Battle Creek looked promising until January freshets flooded out many of Coleman's holding ponds (CAR 1970, p 8). High water not only made Battle Creek's winter harvests difficult, it also wreaked havoc on the Keswick Fishtrap. In addition, the previous year's stream "rehabilitation" along lower Battle Creek by the US Army Corps of Engineers had transformed a natural stream into "an ideal spawning channel." Unfortunately, the paltry numbers of incoming fish belied this ideal. The remains of lower Battle Creek were no exception. Biologists believed that homogenization of the stream bed significantly undermined returning spring steelhead and chinook salmon stocks to Coleman Hatchery (CAR 1970, p 8 and 13).

During 1970, Coleman's steelhead and trout rearing programs suffered a 50 percent reduction in funding. Concomitantly, poor quality Kamloops eggs were "...believed to be the result of accidental introduction of steelhead and rainbow trout into the brood lot over the past years" (CAR 1970, p 9). New, "pure," disease-free Kamloops broodstock would be obtained from Idaho's Clark's Fork Hatchery. While Sacramento River Chinook Salmon virus remained the most serious disease at Coleman, coagulated yolk, columnaris, bacterial gill, and external parasites also caused considerable headaches. William Waldsdorf, the hatchery's Supervisory Fishery Biologist, was also assigned to Nevada's Lahontan National Fish Hatchery. That hatchery's discovery of "Whirling Disease" required emergency measures and Coleman⁵⁸ was called upon to provide diagnostic expertise for several years to come (CAR 1970, p 11).⁵⁹ For a matter of months, biologist Waldsdorf would even

58. Concern over Nevada's nearly extinct Lahontan trout is Coleman's first attempt at returning a threatened fish species from altogether disappearing.

59. The Environmental Protection Agency also cited Coleman for being in violation of its pollution discharge permits. Emergency pollution abatement measures were taken until longer term abatement facilities could be constructed.

relocate his family to Nevada as he dedicated his time to resolving Lahontan fisheries emergency.

Within the 1970s, ongoing cooperative agreements between the Service and the DFG bore real benefits. Coleman relied on the State to stock southern California reservations and military bases in exchange for rearing rainbow trout for Whiskeytown and Shasta reservoirs. A 76-mile commute in a tank truck beat a 1400 mile round trip to stocking sites east of San Diego (CAR 1970, p 12). Previously cited cooperative marking programs for salmon and steelhead also paid biological dividends as scientists could better track what became of ocean-bound and incoming fish.

In 1973, Keswick Fishtrap's fall-run chinook never materialized. Since Keswick contributed 50 percent of the spawn to Coleman's production, what accounted for the lowest return of adult fish on record? (403 adults were taken). Biologists attributed the loss to December 1969's deadly overflow from Spring Creek's Debris Dam (CAR 1973, p 4). Scientists believed that copper, zinc, cadmium, and other heavy metal contaminants killed eggs and young fish immediately downstream from Keswick Dam. Other possible contributors included downriver plants at Rio Vista in which 30 percent of the salmon fingerlings returned to stray up the American or Feather rivers (CAR 1973, p 6). DFG biologists also speculated that "unknown changes in the ocean environment" may have further undermined returning numbers of fish (CAR 1973, p 6).

Throughout the 1970s, Coleman Hatchery constructed more and more temperature-controlled rearing ponds to contain Sacramento River Chinook Salmon virus. In February 1974, five new temperature-controlled raceways were added bringing the total available to 20 (CAR 1974, p 6). These ponds, however, were only as reliable as the technological systems serving them. In 1975, the station's water recirculation system failed on two occasions, causing mortalities among greater than six million fish (CAR 1975, p 4). That year unusually cool winter and spring water temperatures compounded the virus problem and Coleman Hatchery suffered heavy fingerling salmon losses. Fish losses also stemmed from high ammonia and nitrite levels in holding ponds.⁶⁰ Coleman simply lacked an efficient water reuse and filtration system capable of keeping pace with the high levels of production being sought (CAR 1976, p 6).

Between 1976 and 1978, chronic disease among trout populations, persistent drought, and declining salmon populations, forced a reconsideration of Coleman's fundamental mission. The combination of poor rainfall (below 50 per-

60. Concern over Nevada's nearly extinct Lahontan trout is Coleman's first attempt at returning a threatened fish species from altogether disappearing.

cent of normal), poor instream flows, and dangerously elevated water temperatures, spelled trouble ahead. By 1977, 18,000 fall-run salmon were blocked at the Red Bluff Diversion Dam and hauled "...to tributaries above and below Red Bluff and to Coleman and the Tehama-Colusa [S]pawning Channel" (CAR 1977, p 3).⁶¹ That year's fall steelhead populations also stood at one-quarter their normal size, casting doubt on even achieving the coming year's propagation requirements. To bolster escapement, all of Coleman's salmon and steelhead plants occurred below Red Bluff Diversion Dam.

Watching the crisis unfold was recently arrived USFWS Area Manager, William Sweeney. In a letter dated March 28, 1978, Sweeney wrote DFG Director E. C. Fullerton that the Service wanted to substantially renegotiate its long standing joint stocking agreement with the State (USFWS 1978, p 1). Sweeney identified producing fall- and spring-run chinook salmon at Coleman Hatchery as his highest priority and he expected that water chillers would be "on-line" within the year. Sweeney proposed that during summer 1978, Coleman start harvesting incoming spring-run fish for an artificial propagation program. Due to space limitations, Sweeney suggested replacing Coleman's entire Kamloops rearing program by focusing instead on spring-run production. He wanted to eliminate any disparities in the federal-State exchange agreement "...by rearing 55,000 pounds of 10-15 [per pound] spring chinook salmon instead of Kamloops trout (USFWS 1978, p 1). Sweeney asked that as part of the exchange, DFG consider picking up Coleman's military program obligations."⁶² (Footnote on next page.)

61. By June 1975, members of the DFG's Sacramento River Task Force had reported that "...the numbers of fall-run king salmon spawning above Red Bluff [Diversion Dam] have declined from an average of about 118,000 per year (1964-69) to an average of 51,000 per year (1970-74)" (Burns and others 1975, p 8). Speculations as to why ranged from the design and operation of the Bureau's Red Bluff Diversion Dam to the deterioration of spawning beds below Keswick Dam.

In 1978, Coleman's disease plagued Kamloops "...was discontinued and the production program redirected to include Winter and Spring Chinook salmon rearing" (CAR 1978, p 1). Winter-run salmon were dry-spawned at the Keswick Fishtrap and transferred to Coleman hatchery. Eighty-four percent of the eggs "eyed-up" yielding 102,000 eggs: but all but 12,500 perished when Coleman's water chiller broke down (CAR 1978, p 2). The same season that Sweeney advocated a return to spring-run production, no spring-run fish entered the Keswick Fishtrap.

During 1978-1979, migration of salmon and steelhead into Coleman Hatchery was one of the lowest on record. Slightly over 2.1 million Battle Creek fall chinook salmon eggs and just under a million steelhead eggs were harvested at Coleman Hatchery (CAR 1979, p 1). To bolster its flagging salmon production, Coleman obtained an additional 3.7 million fall chinook salmon eggs from the State's Nimbus hatchery and 816,000 fingerlings arrived from the Mad River Fish Hatchery (CAR 1979, p 1). The first season that Coleman consciously separated out late fall-run chinook salmon stocks (1.7 million eggs were harvested) arriving at the Keswick Fishtrap from those of the earlier Battle Creek run occurred in 1979.

In late spring 1979, IHN virus was finally isolated from coastal fall chinook salmon stocks at the Mad River Fish Hatchery. Due to their lengthy struggle with the disease, Coleman's superintendent was comfortable importing diseased fish from the Mad River Hatchery for rearing within Coleman's temperature-regulated 58 degree waters (CAR 1979, p 2). Unbeknownst to Coleman's

62. William Sweeney also closed his letter with a significant managerial shift. Sweeney proposed that ever hereafter, all DFG "...requests received for stocking and/or transfer of fish and eggs..." be referred through the Service's Sacramento Area Office (USFWS, Coleman files, Sweeney, March 1978, p 1). Historically, Coleman Hatchery enjoyed an unusually high degree of managerial autonomy. John Pelnar's long and distinguished tenure as Coleman's Superintendent greatly insulated the hatchery from excessive meddling, either by the State of California or by Washington, D.C. As many have observed, Pelnar's colleagues deferentially treated him as something of a "God" when it came to California's fisheries matters (Kier, personal communication, see "Notes"; Black, personal communication, see "Notes"). Lou Garlic, the Service's former Washington Hatcheries Program Administrator confirmed that historically, the Service had never dictated fish policies among its various hatcheries. Specific programs, Garlic insisted, derived from hatchery superintendents making decisions on site in accordance with budgetary constraints. "Whatever gave [Michael Black] the idea," Garlic wondered, "[that hatchery] policy was dictated from Washington" (Garlic interview conducted by George Black, see "Notes"). Occasional exceptions, like the Sikes Act, simply formalized what had once been handled informally among discrete hatcheries and other federal agencies. Former Coleman Hatchery Superintendent Jerry Grover remarked that it was not until 1984, when Donald Hodel was President Ronald Reagan's Secretary of the Interior, that a comprehensive policy on hatchery programs was finally spelled out (Grover, personal communication, see "Notes"). It was at this point that modern management substantially reshaped policy formulation at the hatchery level.

personnel, however, Mad River's cohort of fall-run salmon bore Enteric Red Mouth Disease (ERM). In early August of 1979, mortality among transferred fish increased sharply and during 1981–1982, ERM again infected Coleman juvenile steelhead and late fall chinook salmon. As an anonymous Coleman memorandum explained, "This was the first recorded outbreak of ERM in either species" (USFWS 1988, p 1).

Coleman National Fish Hatchery continued its production of fall-run chinook salmon and steelhead rainbow trout throughout the 1970s. A cooperative rearing arrangement with the DFG assured maximizing production at Coleman even as disease and overcrowding plagued the hatchery. While a substantially modified water reuse system was completed in December 1979, the hatchery remained saddled with inadequate funding, a decaying infrastructure, soaring power charges for new equipment (like chillers), and remained marginally able to tackle new artificial propagation objectives like spring- and winter-run salmon. Plummeting numbers of salmon reminded some that a long awaited reckoning had come due.

VII. Coleman Hatchery Production: The 1980s and The Richardson Reports

Coleman Hatchery returns of 1980 marked a significant improvement over the previous several years. Over 15.5 million fall chinook salmon eggs were harvested at Coleman and a record number of steelhead arrived during fall 1979, culminating in a 3.2 million egg harvest (CAR 1980, p 1). One hundred fifty-thousand late fall chinook salmon were held over for spring stocking in 1981, but no mention is made of attempts to rear either winter- or spring-run chinook salmon (CAR 1980, p 1).

Throughout the early 1980s, Coleman continued focusing on fall and late fall salmon and steelhead production. In 1982, experimentation resumed with 57 winter-run salmon which were captured at Keswick Fishtrap and hauled to Coleman Hatchery. A total of seven females was spawned. By the close of the spawning cycle, however, water temperatures peaked at 60 degrees. Two power outages interfered with the hatchery's water chilling systems. Coleman's Superintendent wrote that: "The eggs from two females were no good. The rest of the winter chinook salmon adults died before spawning." By the late September 1982, 14,700 of the 15,000 surviving eggs hatched successfully (CAR 1982, p 1).

Nineteen eighty-three's fall chinook salmon run was the largest in Coleman's history. Just shy of 20,000 fish made the upriver journey, yielding a total of 26,624,000 green eggs (21,137,000 eyed-up). Of this total, in October 1982, 4,856 fish died due to low dissolved oxygen in Coleman's ponds. Mortalities were blamed on PG&E's water operations just upriver from Coleman's water

intakes (CAR 1983, p 2). A total of 11,548 winter-run salmon was released into the Sacramento River Basin. In addition to the fall run, 958 late fall fish yielded 1,888,000 green eggs, 1,629,000 of which eyed-up. Steelhead numbered 958 this year, yielding 1.4 million eggs (a half million of these were imported from the State's Feather River Hatchery).

Coleman Hatchery's Operational Plan (1981)

In 1981, Coleman Hatchery manager Thomas B. Luken co-authored (with Terrence Merkel and Richard Navarre) an "Operational Plan" for rebuilding and greatly expanding Coleman National Fish Hatchery (Luken and others 1981). A subheading titled "Authorization and History" trails its brief introduction. As though to remind readers, the subsection's opening lines read:

The Coleman hatchery was built under the authority of the Federal Reclamation Laws-Act of June 17, 1902, 32 state. 388, and acts amendatory thereof or supplementary thereto. The Coleman station and its many associated facilities were included in the reimbursable costs of the Central Valley Project (Luken and others 1981, p 1).

A two-page history underscores that the Service assumed the "operational costs" and "responsibility" for Coleman during fiscal year 1950. A detailed description of Coleman's infrastructure comes next, followed by a summary of current and proposed production capabilities. Winter- and spring-run salmon receive passing mention as do Coleman's water chilling capabilities. "At this time [the reports authors concede, Coleman's] production program does not include the [winter and spring] runs" (Luken and others 1981, p 16). The authors also attribute 40 percent of the Sacramento River's steelhead production to Coleman's "hatchery sustained run" (Luken and others 1981, p 16).

Coleman's production objectives include rearing chinook salmon for sport and commercial fisheries and steelhead for sport fisheries (Luken and others 1981, p 21). Under the draft Central Valley Strategy Plan, targeted current and long-term salmon hatchery objectives (catch plus escapement) are 68,000 and 314,000 adults, respectively. Short- and long-term steelhead production is pinned at 13,000 and 19,000 adults, respectively (Luken and others 1981, p 21). With sufficient help from DFG hatcheries, a substantially expanded Coleman Hatchery should be able to meet various proposed long-term goals.

Ambitious future objectives, however, contrast sharply with 1982's declining abundance figures. Based upon a ten year cycle (adjusted) of fish counts at Red Bluff Diversion Dam, we learn that "...the relative abundance of the various runs since 1971 have been approximately 53 percent, 15 percent, 23 percent, and 9 percent for the fall, late-fall, winter, and spring runs, respectively" (Luken and others 1981, p 22). During the 1953-1960 period, fall chinook

salmon averaged 257,000 spawners. Between 1961 and 1976, that number fell by greater than 50 percent to stabilize near 121,000 adult spawners (Luken and others 1981, p 22). Between 1953 and 1976, spring-run chinook salmon averaged 9,000 spawners. Throughout the 1970s, late fall- and winter-run salmon averaged roughly 50,000 fish. The winter-run returns were profoundly affected by the drought of 1976–1977, however, and 1978–1979 counts past Red Bluff Diversion Dam numbered a mere 2,242 fish, dropping to 1,156 fish in 1979–1980 (Luken and others 1981, p 22–23). Steelhead counts in 1977–1978 were approximately 13 percent of those counted in 1967 (Luken and others 1981, p 25).

Coleman’s “Operational Plan” closes by identifying hatchery strategies to arrest and reverse serious anadromous fisheries declines. Specific problems cited include finding sources for obtaining sufficient milt and eggs for winter- and spring-run salmon. Holding facilities for these stream-type fish must also be constructed, necessitating running chillers 24 hours a day. In 1981 dollars, power costs to operate Coleman’s existing chillers would be \$27,000 per month (Luken and others 1981, p 26). For some spring-run salmon, this would require continuously operating chillers for four months or more, resulting in very expensive power bills. Studies would identify Coleman’s optimal fish release timing, escapement sizes, and release sites, for steelhead and all four salmon runs. Specific tagging studies would determine the percentage of hatchery contributions to commercial and sports fisheries.

Luken, Merkel and Navarre argue that achieving Coleman’s future operational objectives required an infusion of roughly \$5.5 million. Under the sub-heading of “Future Development,” a four-phase program prioritizes strategies for substantially rebuilding and expanding the hatchery’s production capacities. Personnel services, utilities, and fish food are singled out as the hatchery’s three main expenditures. In view of the high cost of running chillers, means of reducing power costs required immediate consideration (Luken and others 1981, p 26). The Coleman Hatchery could either generate its own power on site or seek to obtain Department of Energy Central Valley Project power at “preferred rates.” It was up to USFWS policy makers to select among four production options, thereby bolstering the Sacramento River’s plummeting anadromous fish populations (Luken and others 1981, p 29–30).

USFWS Report on Problem A-6 (1982)

In May 1982, a second Service report built from Coleman’s previous “Operational Plan” to argue for a substantial expansion and rehabilitation of the Sacramento River’s salmon and steelhead mitigation program. This sophisticated document (entitled *Report of the US Fish and Wildlife Service on Problem A-6 of the Central Valley Fish and Wildlife Management Study*, or referred to simply as “A-6”)⁶³ embeds activities and future expansion at Coleman Hatchery and the

Keswick Fishtrap within a historical narrative and a comprehensive policy framework (USFWS 1982).

The document notes that hatchery objectives at Coleman have been recently expanded to increase chinook salmon contributions to commercial fisheries (USFWS 1982, p 3). Improved hatchery escapement is to be bolstered by "...increasing survival of juveniles by releasing them at size;" releasing smolts at optimum time and location (while assuring proper imprinting); and making certain hatchery production reinforces these prior objectives (USFWS 1982, p 2-3). Primary production of winter- and spring-run chinook salmon are made pivotal among Coleman's formal objectives.

The A-6 document argued that expansion and modernization of the Coleman National Fish Hatchery required the implementation of a five year development program initiated in 1977 (Luken and others 1981). Construction priorities necessitated investigating additional sources for groundwater, increasing fish rearing capacity, and, for disease-containment, achieving effective temperature control (by completing the partially constructed water reuse systems) (USFWS 1982, p 4). For an additional \$5.487 million, Coleman Hatchery could rear 12 million chinook salmon fingerlings annually, weighing 115,000 pounds (USFWS 1982, p 4). The report further specified that, due to severe spawning gravel losses below Keswick dam, the Keswick Fishtrap must capture as many incoming salmon as possible for relocation to suitable substitute habitats or for artificial propagation at Coleman Hatchery.

Following this general statement of objectives, the document circled back to the historic 1949 MOA between the US Bureau of Reclamation and the US Fish and Wildlife Service. A precedent-setting disclaimer followed a general restatement of that document:

This agreement, while recognizing that salmon were successfully spawning in the Sacramento River downstream from Shasta Dam, should not be construed as a concession on behalf of the Service that the Bureau had satisfied its mitigation obligation for the Shasta Dam Project (USFWS 1982, p 6).

This may have been the first time in 33 years that Service personnel sought to consciously extricate themselves from the myth of a successful Shasta Salmon Salvage Plan. For heightened dramatic effect, Service biologists took language from the 1949 MOA and inverted its originally intended meaning:

63. "A-6" referred to an anadromous fisheries team assigned to "Determine the need for additional support for ongoing evaluation of Coleman National Fish Hatchery and Keswick Fishtrap operations, and providing this support if necessary" (USBR 1985, p 8).

Despite the now obvious failure of the Sacramento River-Butte Creek-Deer Creek Plan...to fully mitigate for pre-project salmon resources, and the inability of the Central Valley Project to maintain salmon runs below Shasta Dam in numbers equal to the numbers existing before the dam was built, operation of the Coleman NFH is still funded entirely by the Service (USFWS 1982, p 7).

In spite of substantial Service improvements made at Coleman National Fish Hatchery over the previous four decades, the A-6 document repeats that runs of chinook salmon and steelhead continue to decline. It noted that gravel degradation, heavy metal toxicity, unfavorable flow patterns, the Red Bluff Diversion Dam, predation, increased Delta pumping, unscreened diversions, and over-fishing, were all factors contributing to overall fisheries decline (USFWS 1982, p 27). Despite these problems, Coleman nevertheless continued producing 10 percent of the fall chinook salmon run and 70 percent of the steelhead run left below Keswick Dam (USFWS 1979; Hallock as cited in USFWS 1982, p 32). "Because of declining runs of all four races of chinook and steelhead trout to the upper Sacramento River," the document concludes that "the Service is committed to improving efficiency of the Coleman NFH" (USFWS 1982, p 32).

Before a summary statement of "problems" and "recommendations" was made, biologists identified the winter- and spring-runs as being particularly deserving of study for artificial propagation. Additional loss of natural habitats (for example, suitable spawning gravel, favorable seasonal flows, and suitable water temperatures), "may eventually necessitate" artificially propagating winter- and spring-run stocks (USFWS 1982, p 33). The report concluded that heightened hatchery efficiency is the best means of sustaining these badly depleted populations of fish.

Redefining Coleman Hatchery's mission, the report asserts, departs from these two fundamental premises. First the Bureau and the Service must:

Assess the need for revising the 1949 Memorandum of Agreement...pertaining to the operation and maintenance of Coleman National Fish Hatchery in view of the deterioration of salmon and steelhead runs resulting from long-term impacts of Keswick and Shasta Dams (USFWS 1982, p 35).

Second, redefining Coleman's mission hinges upon successfully receiving Central Valley Project electrical power at preferred rates.

Electrical water chiller operation is necessary to initiate production of and [to] provide protection [for]...the depressed run of winter chinook salmon in the Sacramento River. Estimated annual cost of operating chillers on [the] existing rate schedule is \$129,600 (USFWS 1982, p 35).

The Service basically invites the Bureau of Reclamation to reexamine that agency's historic and future salmon mitigation obligations by using the precarious status of winter-run salmon.

Coleman Station Development Plan (1984)

During October 1984, a second Coleman report was issued by the Service on the status of Battle Creek's antiquated Coleman National Fish Hatchery (USFWS 1984). The Coleman Station Development Plan called for a significant hatchery upgrade

To restore chinook salmon stocks of the upper Sacramento drainage to levels of the 1950s (adult contribution 673,000 fall chinook, 50,000 late fall chinook, 80,000 winter chinook and 130,000 spring chinook (USFWS 1984, p 9).⁶⁴

Hatchery goals ranged from energy-efficient means of controlling disease to increased hatchery size to accommodate winter-run chinook. A historical subsection underscores that "Construction of the facility was authorized as an integral part of the Central Valley Project" (USFWS 1984, p 5). Within yet another subsection on water rights, Coleman Hatchery's legal entitlement to Battle Creek's waters "...are [called] the lowest priority known on Battle Creek" (USFWS 1984, p 15).

Coleman's Station Development Plan specifies a three phase development program in which the term "rehabilitate" figures prominently. Initial priorities included rebuilding the hatchery's badly undercut diversion dam, expansion of pollution abatement facilities, installation of an ozone generator for water treatment, installation of emergency power generators, and the digging of several wells (USFWS 1984, p 26-28). Intermediate priorities included replacing the original redwood incubation troughs installed in 1942, replacing the deteriorating hatchery building's badly leaking roof, repairing chillers for water temperature control, and constructing new broodstock holding ponds for adult winter- and spring-run salmon (USFWS 1984, p 30-32). Costs for accomplishing the whole development program (in extrapolated 1986 dollars) are \$6,524,800 (USFWS 1984, p 25).

Petitions to List the Winter-run Chinook Salmon

Driving this latest Coleman document was a litany of woes contained in 1981's Coleman Report. Also disturbing were winter-run stocks which had plunged from 1969's estimated high of 117,808 to a 1983 figure of 1,381 fish (USBR and Richardson 1985, p 13). Within the same time frame, spring-run

64. This objective was taken verbatim from the Regional Resource Plan. Hoped for production figures included catch plus escapement.

chinooks also fared poorly, falling from 26,471 to 3,491 fish (USBR and Richardson 1985, p 13). Similarly, steelhead diminished from 10,995 to 1,968 fish (USBR and Richardson 1985, p 13). With the sole exception of hatchery-driven fall- and late fall-run stocks, the Sacramento River's anadromous fisheries were in trouble and the Service, the National Marine Fisheries Service (NMFS), and the DFG needed to formulate credible responses.

Tension was heightened by the potential listing of winter-run chinook salmon under the State and federal endangered species acts. The threats of a "listing" carried significant political muscle, as it focused statewide and national political attention-desired or not-on a regulatory agency's rationales and performance. Considerable opposition would be triggered by this State and federal action and the DFG, the Service, and NMFS exhibited reluctance to act. Meanwhile, independent advocates concerned with diminishing anadromous fisheries were clamoring to have the fish listed.

Partial justification for both State and federal ESA winter-run listings derived from the status report prepared by Richard Hallock and Frank Fisher and by subsequent counts (Hallock and Fisher 1985). The Tehama Fly Fishers (the Sacramento River Preservation Trust later joined them) petitioned the State of California for a listing, while, in October 1985, the California-Nevada Chapter of the American Fisheries Society (AFS) petitioned NMFS to list the winter-run as "threatened" under the federal Endangered Species Act (16, USC 1531, et. seq.). The Sierra Club Legal Defense Fund handled court proceedings against the federal government (Hallock, personal communication, see "Notes"). Annual winter-run counts between 1982 and 1988 averaged 2,334 fish, a 97 percent decline from prior levels (Williams and Williams, as cited in Lufkin 1991, p 107).

In 1986, NMFS responded with a non-binding, ten point action plan:

1. Resolving the fish passage problems at Red Bluff Diversion Dam.
2. Instituting a hatchery program for winter-run at the Coleman Hatchery.
3. Restoring spawning habitat in the Redding Area.
4. Developing measures to control Sacramento pike minnow at Red Bluff Diversion Dam.
5. Restricting in-river sport fishing.
6. Developing water temperature control for drought years.

7. Correcting Spring Creek pollution problems.
8. Correcting the problem at the Anderson-Cottonwood Irrigation District Dam (due to flow fluctuations and an inadequate fish ladder).
9. Correcting the spilling basin problem at the Keswick Fishtrap.
10. Continuing to expand studies on winter-run chinook salmon (after Grader 1988, p 2).⁶⁵

Pacific Coast Federation of Fishermen's Associations General Manager Zeke Grader observed that AFS and NMFS staff were in agreement that "...the problem facing the winter run [was] from water temperature and diversions and not fishery pressure..." (Grader 1988, p 2).⁶⁶ The sole permanent step taken was a restriction of the in-river sport fishery. The Bureau of Reclamation did open the gates at Red Bluff Diversion Dam but closed them again without notifying NMFS (Grader 1988, p 2). Without a "threatened" listing, many, including Grader himself, believed it "...may be impossible to force agencies such as the Bureau of Reclamation to make the necessary changes in their [water] operations to protect the winter run" (Grader 1988, p 3).

With their ten point recovery plan in place, NMFS determined in February 1987 that a winter-run listing was "not warranted" (Williams and Williams, as cited in Lufkin 1991, p 110). A year later, the Sierra Club Legal Defense Fund filed suit on behalf of AFS and others against the federal government, arguing that under the Endangered Species Act, the federal government had a "non-discretionary obligation" to list the nearly extinct fish (Williams and Williams, as cited in Lufkin 1991, p 111). All it would take were additional droughts or accelerated habitat losses accompanying new water projects to undermine the precarious status quo. "Threatened" ESA status for the winter-run fish would not be forthcoming until August 4, 1989 (Williams and Williams, as cited in Lufkin 1991, p 113).

65. Wally Steucke asked the Service's FAO-Red Bluff Project Leader to develop the preceding "Suggested Management Actions" which were intended to benefit the beleaguered winter-run salmon. On June 16, 1986, DFG's John Hayes participated in formulating these recommendations. Tellingly, a final eleventh suggestion was dropped from the list. It called for "Oppos[ing] any new [water] projects that would adversely impact winter-run chinook. With current severely depressed run sizes, winter-run cannot sustain additional adverse impacts." (USFWS 1986).

66. Grader clearly spelled out the PCFFA's interest in the winter-run case. "If listed as a threatened species," Grader wrote, "NMFS would be required to declare critical habitat, and to develop, adopt and implement a [fish] recovery plan. All federal agencies would be obligated, by law, to assure that their actions would not jeopardize the winter run. A threatened listing would not require restrictions on [ocean] fisheries, [however] an "endangered" listing would..." (Grader 1988, p 2)

Initially, the DFG withheld listing the winter-run under the state's ESA. Managers at DFG believed that the non-binding NMFS ten point conservation program would prove sufficient to reverse winter-run declines. Legal wrangling, mounting political pressures and declining numbers of fish eventually overwhelmed opposition to a listing. On August 7, 1986, the petition to list the winter-run as endangered was submitted to the California Fish and Game Commission (pursuant to subdivision (a) (2) of Section 2074.2 of the Fish and Game Code, as a candidate species defined in Section 2068 of the Fish and Game Code). The State Commission eventually accepted the petition at their February 4, 1988 meeting (Grader 1988, p 2). Implementation, however, still required a written report by DFG indicating that the petitioned action was warranted. In February 1989 the DFG had not yet completed its recommendation on winter run listing, so the Fish and Game Commission delayed action until its March 1989 meeting. At the March meeting the Commission accepted the DFG recommended to not list winter run but required the DFG to provide 60-day updates on the status of the resource and adherence to the 10-point plan. At the May 1989 meeting, the DFG changed its recommendation in favor of listing the winter run and the Commission made a finding at that meeting to list the species as Endangered. At its August 3-4, 1989 meeting, the Commission added winter-run chinook salmon to Section 670.5, Title 14, California Code of Regulations as an Endangered Species (Robert R. Treanor, Executive Director, Fish and Game Commission, personal communication).

Problem A–6 and the Bureau's Coleman Hatchery Action Plan (1984)

As State and federal fisheries agencies mobilized to stave off diminution of winter-run salmon stocks, the Bureau of Reclamation began responding with new programs of their own. Throughout the 1970s and into the 1980s, the Bureau funded collaborative, coded-wire tagging studies to determine optimal fish size at release and solve fish passage problems stemming from Red Bluff Diversion Dam. The Bureau also pumped resources into resurrecting the ill-fated Tehama-Colusa Fish Facilities. It also sought to overcome long-standing problems surrounding the Keswick Fishtrap. Resolution of issues arising from Red Bluff Diversion Dam and its compensatory spawning channels fell under a Bureau program termed "Interim Action Measures" (USBR and Richardson 1985, p 32). In November, 1984, the Bureau initiated the Coleman Hatchery Action Plan (CHAP) which was intended to "...assist the US Fish and Wildlife Service...in the fishery mitigation effort at the Keswick Dam fish-trap and the Coleman [National Fish Hatchery]" (USBR and Richardson 1985, p 32).

CHAP's objectives included identifying problems at Coleman Hatchery and Keswick Fishtrap, selecting cost-effective alternative solutions, determining which agencies had the ultimate authority and responsibility to implement solutions, prioritizing effective solutions by using cost/benefit analysis, and

setting a reasonable timetable for achieving desired results (USBR, Richardson 1985, p 32-33). As Service biologist Thomas Richardson stated, CHAP's main goal was for the Bureau "...to offer the technical expertise, resources, and equipment which could provide immediate solutions to ongoing problems that [adversely] affected hatchery production (CHAP, as cited in USBR and Richardson 1985, p 33).

CHAP's recommendations derived from a steering committee composed of representatives from the Bureau, the Service, NMFS, DFG, and the Department of Water Resources. While most of Coleman's and Keswick Fishtrap's problems and resolutions lay well beyond CHAP's scope, interagency participants insisted that their entire priorities list be presented to the Bureau's Regional Director for identification and eventual funding consideration (USBR and Richardson 1985, p 34). At the top of their wish list was new broodstock facilities capable of handling the beleaguered winter-run chinook salmon. There was also the matter of legally obtaining Central Valley Project power at "preferred rates" to run Coleman's power-hungry chillers (USBR and Richardson 1985, p 35).⁶⁷

CHAP suggestions included increasing Bureau water releases from the Shasta-Keswick complex "...to 14,000 cubic feet per second for a 3-day period from May 13-16, 1985" (USBR and Richardson 1985, p 34). This pulse of water would help flush Coleman's 6 million salmon smolts downstream into the Delta and Suisun and San Pablo bays. To help Sacramento River fish migration, the Bureau also agreed to operate its Red Bluff Diversion Dam to minimize fish losses due to irrigation. CHAP's steering committee also recommended that the Keswick Fishtrap be modified to remain usable at flows between 16,000 and 20,000 cubic feet per second, when not yet higher water conditions (USBR and Richardson 1985, p 56).

CHAP recommendations were imbedded within two subsequent, Bureau-commissioned versions of 1992's A-6 Service document which sought to identify and resolve nagging problems at Coleman Hatchery and Keswick Fishtrap (USBR and Richardson 1985; USBR 1985). Within the first report, Richardson wrote that Sacramento River salmon declines stemmed from a variety of factors

67. As to Coleman Hatchery's eligibility for CVP power at "preferred rates," the Service sought out the Solicitor General's legal determination. On the issue of "...free mitigation water with respect to the FWS facilities in the Grasslands area, one part of the overall Central Valley Project," Donald J. Barry, the Department of the Interior's Assistant Solicitor wrote: "Agreement was reached in the Solicitor's Office among the Divisions of Conservation and Wildlife and Energy and Resources that, with respect to the Coleman National Fish Hatchery, there was ample legal authority for the Bureau of Reclamation to provide water and power to operate the Hatchery, the cost for which must be borne by the project users" (USDI and Barry 1985, p 2).

...including gravel degradation, heavy metal toxicity, unfavorable flow patterns, the Red Bluff Diversion Dam, predation, increased delta pumping, unscreened diversions and over-fishing (USBR and Richardson 1985, p 52).

From the Service's point of view, insufficient returning broodstock simply underscored the importance of improving efficiency at Coleman and the Keswick Fishtrap. A second Bureau-funded report concluded:

The [Bureau] should endorse the efforts of the [Service] and assist in securing funding for facilities modifications required to meet mitigation responsibilities at both Coleman NFH and the Keswick Fishtrap (USBR 1985, p 84).

Achieving these ends would be best obtained by revisiting the 1949 MOA between the Bureau and the Service. The report continues:

...operation and maintenance of Coleman NFH should be assessed in view of the deterioration of salmon and steelhead runs resulting from long-term impacts of Keswick and Shasta dams (USBR 1985, p 84).

The three phase resurrection of a dilapidated Coleman National Fish Hatchery carried a projected price tag of \$6,524,800 (USBR 1985, p 58).

Whirling Disease (*Myxosoma cerebralis*) at Coleman Hatchery

Coleman Hatchery's propagation activities followed somewhat predictable patterns during most of fiscal year 1985. A total of 21,543 fall chinook salmon was spawned yielding 27,814,636 green eggs (25,430,879 eyed up). A total of over 24.1 million fall-run chinook salmon was stocked. A total of 388 late fall-run chinook salmon was harvested, yielding 597,378 eggs (492,029 eyed up). Over 374,000 late fall-run salmon were stocked (CAR 1985, p 3).

Success at propagating winter-run salmon remained as elusive a goal as ever. Lack of fish prevented obtaining adequate broodstock at Keswick Fishtrap and insufficient State and federal fish personnel precluded much fish capture at Red Bluff Diversion Dam. Only one of the 32 winter-run salmon obtained survived. That lone fish was released into Battle Creek. As Coleman's Superintendent wrote: "The bottom line is that with current Coleman facilities and funding, [winter chinook salmon] holding and spawning at CNFH is impossible" (CAR 1985, p 3).

This same year 1078 steelhead were spawned yielding 2,723,830 eggs (2,281,269 eyed up). However, in June 1985, an outbreak of Whirling Disease (*Myxosoma cerebralis*) was detected among steelhead trout fingerlings. In compliance with the Service's Fish Health Protection Plan, the "Class A" infected fish were destroyed in February 1986 (CAR 1985, p 2-3; USFWS, Coleman

Files, "Whirling Disease," Decision Paper, 1987). The destruction of 1.3 million juvenile steelhead was hardly welcome news in any quarters. However, since the DFG classified the *Myxosoma cerebralis* organism as a far less catastrophic affliction than did the Service, State biologists pleaded that the fish be released into Battle Creek. The Service's Class A designation held sway, however, and Coleman Hatchery destroyed its entire steelhead production for one year, amounting to a 70 percent in-river decline among returning 1988-1989 Sacramento River runs.

Amidst a hail of criticism, Service personnel responded that Coleman's history of disease and parasitism necessitated significant facilities upgrades. The previous year, members of the Upper Sacramento River Salmon and Steelhead Advisory Committee had argued that chronic underfunding and inefficiencies produced a substandard Coleman Hatchery rife with disease problems (Payton and Coakley 1985; Frost and others 1984). Writing in August 1984, that Committee's members argued that Coleman's operation should be increased to \$1.5 million a year and "recommended operating the hatchery as part of the federal Central Valley Project, with funding from the US Bureau of Reclamation instead of [the Fish and Wildlife Service] (Payton and Coakley 1985).

Service spokesman Bill Meyer of the Portland Regional Office believed that significant Coleman funding should derive from the Bureau of Reclamation. Bureau officials, however, were more circumspect. They responded that Coleman remains the sole responsibility of the Service.

'They've assumed full jurisdiction and we've been out of it for years,' said David Houston, mid-Pacific regional director for the Bureau. Still, Houston said his agency is committed to doing what it can to rehabilitate Coleman (Payton and Coakley 1985, p A-14).

The discovery of whirling disease at Coleman Hatchery intensified discussions as to the ultimate responsibility for salmon and steelhead mitigations throughout the Sacramento River Basin. For some it was only a dress rehearsal before the Bureau accepted full financial responsibility for a failed Shasta Salmon Salvage Plan.

Coleman Hatchery's Revised Station Development Plan (1987)

In 1987, a new Coleman Station Development Plan was released "...to upgrade or develop sound, practical station development plans for future budget requests" (USFWS 1987b, p 1). The major addition to this proposal was a comprehensive, nine phase construction program which bore a total price tag of \$22,104,800 (USFWS 1987b, p 27-28). An ozone generator for water treatment topped priorities while visitor facilities closed out the list. One nagging ques-

tion remained. Who would provide the funding for such an ambitious anadromous fish recovery effort? The agency or agencies willing to fund that dramatically increased budget remained unspecified. However, it appears as though the Service pinned their hopes on the Bureau of Reclamation and a failed Shasta Salmon Salvage Plan.

It would require an additional five years before the issue of agency responsibility was resolved by an Inspector General's inquiry. Numbers of Sacramento River salmon populations requiring formal mitigation derived from Needham and others' (1943) study, which argued that a minimum of 60,000 (but probably many more) Sacramento River salmon required mitigation. Recall that Needham had called for 10,000 spring-run chinook to be hauled to Deer Creek for natural propagation; 2,000 spring-run fish to be transferred to Battle Creek for artificial propagation; 18,000 summer and early fall-chinook to be transferred for artificial propagation; and distribution of 30,000 fall-run chinook by means of instream racks (Needham and others 1943).

In a series of Service- and Bureau- commissioned reports, Thomas H. Richardson best argued that the Bureau had an outstanding unmet mitigation obligation. Time and time again he returned to historic themes to build his case (USBR and Richardson 1985). In blunt language, Richardson wrote:

...It appears that the proper [Bureau of Reclamation] mitigation goals [of the Sacramento River Migratory Fish Control Program] were not established for the loss of habitat and fish runs upstream from Keswick and Shasta Dams (USFWS and Richardson 1987a p, 32).

Using original spawning survey data, Richardson calculated that 118,048 salmon were cut off as a result of Shasta Dam (USFWS and Richardson 1987, p 12). Particularly hard hit were the spring-run for access to 187 miles of their upriver spawning habitat (consisting of 2,360,000 square feet of spawning beds) were blocked while below-dam, spring-run mitigations failed entirely (Hanson and others 1940). Richardson cited Needham's 1943 revised population estimates of 60,000 salmon as being much closer to true population size lost as a result of Shasta and Keswick dams (Needham and others 1943).

As one crude measure of what was missing, Richardson suggested the Service (and the Bureau) take current production goals and subtract them from Needham's far more plausible estimate of 60,000 fish. Since Coleman's 1984 production goals specified 18,650 return spawners, Richardson deducted this figure from Needham's preceding estimate to arrive at an unmet mitigation of 41,350 fish (USFWS and Richardson 1987, p 32). The Service biologist concluded that "...any hoped for [Bureau sponsored post-Shasta enhancement] was never realized" (USFWS and Richardson 1987, p 33).⁶⁸ Richardson advised the Bureau of Reclamation that "...the loss of anadromous fish runs (but not habitat) may be compensated by artificial propagation" (USFWS and Richardson 1987, p 31).

VIII. The Inspector General's Report and the CVPIA

Initially the Bureau of Reclamation resisted accepting Richardson's invitation to reimburse the Service for ongoing unmet mitigation obligations. Sometimes the Service funded mitigation costs which agency personnel believed "...were properly assessable to water project beneficiaries," and Coleman Hatchery was no exception (Audit Report 1991, p 3). Service policy sought to promote "cost assumption," a term connoting recovery from water project beneficiaries of unmet mitigation costs. Discussions on this and other points continued between the two agencies and culminated in a November 1988 interagency agreement (Audit Report 1991, p 3). However that MOA failed to resolve the controversial cost-assumption issue. Additional progress was also hampered by interagency bickering over who retained formal "operational control" over mitigation facilities like hatcheries. Tiring of the impasse, Service directors eventually sought and obtained a formal audit by the Office of the Inspector General. If the Service could not resolve this by means of direct negotiations with the Bureau, then they would try another approach.⁶⁹

The Auditor General's report concluded that the Service continued "...to underwrite almost \$1.5 million a year in [hatchery] mitigation costs on behalf of the beneficiaries of the two Bureau water projects [Coleman was specifically singled out]" (Audit Report 1991, p 4). Throughout the 1950-1989 period,

68. In a separate 1987 report, biologist Richard J. Hallock summarized the results of the "Shasta Salvage Plan" this way: "The plan included only mitigation for fall- and spring-run salmon, none for late fall and winter-run salmon or steelhead. Only part of the plan was ever implemented. As each element of the salvage plan failed, it was simply abandoned and those particular groups of fish to be salvaged were just "written off" (Hallock 1987, p 30).

69. Service eligibility for project power was the first in several legal steps taken to force the Bureau's hand at reinstating funding to achieve mitigation compliance.

the Service spent \$8 million in operating costs for Coleman National Fish Hatchery which should have been properly assumed by project beneficiaries.⁷⁰ Auditors also observed that a 1949 MOA between the Bureau and the Service omitted a critical "...provision for cost recovery or user assumption" as part of the project's reimbursable costs (USDI 1991, p 4). Auditors found no justification for omitting this provision upon transfer of the facility (Audit Report 1991, p 4).

The Inspector General's report helped break through an interagency logjam. The Bureau generally agreed that "...mitigation costs were legally assessable to project beneficiaries" and that they could logically recover these mitigation costs through its water service contracts (USDI 1991, p 5). The final point rested on "operation control," over who would actually run these facilities and receive assessed costs. As the chief protector and conservator of the nation's fish and wildlife resources, the Service continued insisting it was best suited to run the nation's hatcheries.

On January 11, 1991, Harold Bloom of the Inspector General's office ordered the Service to negotiate with the Bureau to establish procedures for recovering costs stemming from future CVP and other mitigations. He also advised that the Service seek a separate opinion from the Solicitor "...concerning recoverability [from the Bureau and CVP beneficiaries] of [historic] mitigation expenditures" at the Coleman Hatchery. Although Service compensation on this point was never forthcoming, a new institutional arrangement meant funding for CVP salmon and steelhead mitigations was back on track as never before.

The Central Valley Project Improvement Act (1992)

A second institutional transformation in attitudes and policies toward Western water politics, development, and its beneficiaries began in 1992. Passage of the Central Valley Project Improvement Act (CVPIA) assured that for the first time, fish and wildlife resources would have legitimate standing as a serious "beneficial use" (CVPIA 1992). The act provided specifically for the protection, restoration, and enhancement of fish, wildlife habitats in California's Central Valley and Trinity River basins (CVPIA 1992, p 1). The CVPIA included protection of both the Sacramento-San Joaquin Delta Estuary and downstream San Francisco Bay. CVPIA specified achieving a

...reasonable balance among competing demands for use of Central Valley Project water, including the requirements of fish and wildlife, agricultural, municipal and industrial and power contractors (CVPIA 1992, p 1).

70. The Service had spent \$11 million dollars funding operations at Coleman since 1950. Of this total, the Bureau advised as 76.4 percent of this total cost was reimbursable from agricultural, industrial, and municipal water users (USDI 1991, p 5).

Section 3406 of the CVPIA focuses on fish, wildlife and habitat restoration. It specifies that environmental "... mitigation, protection, and restoration of fish and wildlife" are its top priorities. This section specifies:

The mitigation for fish and wildlife losses incurred as a result of construction, operation, or maintenance of the Central Valley Project shall be based on the replacement of ecologically equivalent habitat and shall take place in accordance with the provisions of this title and concurrent with any future actions which adversely affect fish and wildlife populations or their habitat but shall have no priority over them (CVPIA 1992, p 11).

The CVPIA proposes by the year 2002, that "...natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991" (CVPIA 1992, p 12). The legislation also directs the Secretary of the Interior to "...address other identified adverse environmental impacts of the Central Valley Project..." without exactly specifying what they are (CVPIA 1992, p 12). First priority goes to "...measures which protect and restore natural channel and riparian habitat values..." through ecological restoration. To achieve this objective Central Valley Project operations like insufficient instream flows can be modified to benefit anadromous fish (CVPIA 1992, p 12).

Implementing Coleman National Fish Hatchery's Development Plan received special mention as did the Keswick Fishtrap. Additional hatchery production may mitigate for fish losses provided that it is only used to "...supplement or to re-establish natural production while avoiding adverse effects on remaining wild stocks" (CVPIA 1992, p 24). The act also calls for "...eliminating barriers to upstream and downstream migration of salmonids in the Central Valley..." including other measures deemed appropriate to "...protect, restore, and enhance natural production of salmon and steelhead trout in tributary streams of the Sacramento [River] (like Battle, Butte, Deer and Mill creeks)" (CVPIA 1992, p 25).

The intent of Central Valley Project Improvement Act legislation regarding anadromous fisheries is clear. With the recognition of fish as a legitimate interest, the act favors:

- Natural spawning over artificial propagation as a reproductive strategy.
- Restoration of certain "critical habitats" capable of supporting threatened or endangered anadromous fish stocks. (Battle, Butte, Deer and Mill creeks are singled out for their restoration promise).

- Elimination of instream fish barriers which hamper passage of returning migratory fish stocks (including Coleman Hatchery).⁷¹

Under the CVPIA's legislative umbrella, artificial propagation was relegated to last on the list of priorities. First-order priorities included restoration of riparian stream corridors capable of supporting regenerative stocks of (remaining) wild salmon. The satisfaction of "public trust" values were best accomplished by allowing nature to heal itself with minimal human interference.

Concluding Remarks

Several conclusions stem from the historical review presented within this paper.

Coleman Hatchery should seek a more balanced role in attempting to mitigate anadromous fish losses incurred above the Shasta-Keswick complex. Hanson, Needham, and Smith originally argued that a combination of artificial and natural propagation was required to achieve a balanced fish rescue strategy on the Sacramento River. These Bureau of Fisheries biologists sought a combination of reproductive paths so that each could serve as a "buffer" for the other (Hanson and others 1940, p 17). Neither Coleman Hatchery nor the Keswick Fishtrap should be faulted for becoming the sole surviving pieces of the Bureau's original fish salvage plan. Nor should we forget the hatchery's decisive failure to raise spring-run salmon. Almost by default, Coleman produced predominantly lower river fall-run chinook.

Today's CVPIA legislation calls for natural propagation within restored rivers and streams. Battle, Butte, Deer and Mill creeks, among others, should be set aside, to the greatest extent possible, as refugia for naturally propagating salmonids. Historically, spring-run and winter-run fish also spawned within some east-side Sacramento River tributaries like Battle Creek. Good faith negotiations must occur among all those affected to remove instream obstacles and "rewater" critical habitats like Battle Creek. Given the opportunity, resilient fish should be able to hold their own within surviving, remnant watersheds.

71. I recognize that Coleman's wider barrier is essential to the hatchery's broodstock collection operations (USFWS and Hamelberg 1999, p 2). However, a seasonally removable structure would provide the hatchery with their broodstock requirements while eliminating yet another obstacle for upmigrating Battle Creek stocks during most months of the year. Technologies such as weirs should be redesigned to suit the biological requirements of naturally spawning fish within restored river basins.

The idea of using tributaries as salmon refugia is hardly a recent one. In 1938, the Bureau considered designating four tributaries below Grand Coulee Dam as protected anadromous fish corridors. The Bureau sponsored considerable stream restoration on the Wenatchee, Methow, Okanogan, and Entiat rivers in the hopes of bringing newly transplanted salmon populations back up to their historic levels. The Bureau, however, soon abandoned the idea of reining-in (or buying out) competing and often harmful water development. Within the intervening decades, we have paid dearly for the Bureau's understandable but regrettable failure to set aside tributaries located downstream from dams as experimental refugia.

Water for fish is a "beneficial use". Some argue that fish conservationists can have anything they want in California, as long as it is not water. Competing riparian and appropriative water claims make salmon and steelhead restoration within their southernmost ranges all the more difficult. Salmon salvage efforts in the Sacramento River Basin are fraught with examples where biologists were required to place competing water claims above fish and wildlife habitat requirements. Under the Stillwater plan of 1940, Bureau of Fisheries biologists sought to export McCloud River water (by flume, suspended pipeline and tunnel) to a stream which was typically dry nine months of the year. There were no other competing water claims along Stillwater's dry streambed. In a second example, biologists sought to import water from the mainstem Sacramento River to supply riparian and appropriative users who seasonally dewatered Deer Creek. Money for the water substitution scheme never materialized, however, and, by 1946, the spring-run transplants to Deer Creek were abandoned. The history of fish rescue in California contains similar stories of biologists attempting to cobble together fish restoration plans with insufficient water. Sufficient, guaranteed instream flows are required to have suitable habitats for healthy runs of anadromous fish. In the end, there is no substitution for enough, clean, fresh water dedicated for fisheries.

Mitigating for salmon biodiversity on the Sacramento River. The Sacramento River (including Battle Creek) is North America's only river basin with four phenotypically unique stocks of chinook salmon. Dispersed, both temporally and spatially, one race of salmon was vacating a stretch of river just as their mature replacements (given suitable conditions) were headed upstream to spawn. This co-evolutionary example is all the more eloquent because emigrating fry and smolts feed along their downriver journey while migrating upriver salmon cease eating long before moving upstream to their natal spawning waters.

Sacramento River salmon still constitute an unequalled biodiversity treasure. With the loss of their upriver habitats, gone, too, was the opportunity for fish to mature in the upper river's high canyons. Also

missing was the possibility of over-wintering or summering in protective, upper riverine pools. After construction of the Shasta-Keswick complex, salmon stocks headed for the few remaining spawning grounds along the mainstem Sacramento. This included a stretch of river extending from Red Bluff to Keswick Reservoir. Upriver stocks remain casualties of a historically failed mitigation effort. Thus far, we have failed to mitigate for salmon biodiversity loss on a dramatically altered river, thereby placing at risk a national biodiversity treasure.

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Notes

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Lou Garlic. USFWS Washington-based Hatcheries Administrator, retired. Personal communication with retired biologist George O. Black in August 1998.

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W. L. Hobart. National Marine Fisheries Service, Seattle, Washington. Correspondence dated 28 October 28 1997 and personal communication.

Jim Lichatowitch. Sequim, Washington. Personal communication in July 1998.

William L. Sweeney. USFWS Sacramento Office Area Manager, retired. Personal communication.

Appendix A: Spawning Habitat Analysis for the Sacramento River System Affected by the Keswick Dam and Shasta Dam Projects

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Introduction

This document was prepared for the Battle Creek Technical Advisory/Work Group in an effort to understand the historic role of Coleman Hatchery.⁷²

Methods

Spawning Habitat Inventories. Spawning habitat estimates were made in 1939 as part of the Shasta Salmon Salvage Program (Hanson and others 1940). The surveyed habitat was divided into habitat considered suitable for spring-run, winter-run, or fall-run chinook salmon. The divisions were made according to recorded occurrence of spawners and available information on the suitability of temperatures in the various spawning zones. The 1939 spawning habitat surveys were compared with modern day surveys on the South Fork of Battle Creek where there have not been any habitat changes since 1939. The modern survey completed by Coots and Healey (Coots and Healey 1966) and Kondolf (Thomas R. Payne & Associates 1989) are within 10% of the 1939 surveys within this reach.

The number of available nest sites or redds available above Shasta Dam was estimated by dividing the average redd size measured in 1939 in to the available habitat. The average redd size for the reaches above Shasta Dam was 40 square feet. Reaches below Shasta Dam used a value of 50 square feet per redd (Rieser and Bjorn 1979). It was assumed the distribution of spawning efforts

72. This "Spawning Habitat Analysis" was discussed in October 1997 at a Santa Rosa meeting of the Battle Creek Technical Advisory/Work Group. The methodology of extrapolating from spawning gravel surveys to arrive at historic Sacramento River salmon populations still requires additional work.

over the three month spawning period allowed the necessary space; especially during the first and last quarter of the spawning period.

It is possible to extrapolate the available nest sites into an estimated population size. A habitat-based method may be as justified as the fish counting effort used during the late 1930s and early 1940s. The counting effort at that time was a partial count and the returning adults were from juveniles produced during the worst drought in recent recorded history. This habitat-based estimate of the population represents carrying capacity of the river system only if spawning habitat is limiting and the long-term average population is stable (1:1 spawner replacement). Each redd is assumed to represent two adults and some jacks. The percentage of jacks in 1939 was reported by the U.S. Bureau of Fisheries in 1940.

Results

Spawning sites available above Shasta Dam:

- Fall run: 24,847 nest sites representing 64,602 salmon at 2 adults per redd and 30% jacks.
- Spring run: 51,377 nest sites representing 133,580 salmon at 2 adults per nest and 30% jacks. In addition, the Pit River habitat lost to PG&E dams is estimated at 7,444 redds representing 19,354 salmon at 2 adults per redd and 30% jacks.
- Winter-run: 34,634 nest sites (including habitat lost to PG&E dams), representing 90,048 salmon at 2 adults per redd and 30% jacks.

Spawning sites available between Keswick and Shasta dams:

- Fall run: 2,286 nest sites representing 5,945 salmon at 2 adults per redd and 30% jacks.
- Spring run and winter run: None – the temperatures were too warm.

Spawning sites available between Keswick Dam and Red Bluff Dam:

- 1939 Ground Survey: 18,413 sites.
- 1964 Generalized Aerial Survey: 145,000 sites.
- 1980 Extensive Ground and Aerial Survey: 96,000 sites.

Significant differences within these surveys are attributable to the following:

- The 1939 survey was conducted during the worst drought in recent history.
- The 1964 survey was not as extensive as the 1980 survey because it only used aerial survey techniques without ground surveys.
- The 1964 and 1980 surveys incorporated aerial observations of spawning fish. The 1980 population was only one-third of the 1964 survey.
- There was less spawning gravel available in 1980 than in 1964 within the upper 15 miles of those reaches due to lost gravel recruitment caused by Shasta Dam.

Spawning sites available between Red Bluff Dam and Woodson Bridge:

- 1939 – No survey was conducted. Biologists characterized the additional 70 miles of spawning habitat to be in a “broad, slow...” and warm river.
- 1964 – Generalize Aerial Survey: 70,906 sites.

Factors Affecting Chinook Salmon Spawning in the Lower Feather River

Ted Sommer, Debbie McEwan, and Randall Brown

Abstract

We review the status of chinook salmon in the lower Feather River and examine factors affecting chinook salmon spawning since the construction of Oroville Dam. Spawning occurred in depths from 0.4 to 4 ft with the central 50% of observations in the 1.6 to 2.6 ft range. Depth used was slightly higher at increased flows. Velocities of 0.4 to 4.8 ft/s (central 50% = 1.5 to 2.7 ft/s) were used at all flows. Redds were constructed in substrate containing less than 60% fines in 0.2- to 1-inch to 6- to 9-inch gravel size classes.

Redd surveys showed that spawning occurred in twice as much area below Thermalito Afterbay Outlet than the low flow channel (LFC). However, in most recent years, about 75% of fish spawned in the LFC. Superimposition indices calculated from these results suggest that there was insufficient spawning area in the LFC to support the number of spawning pairs, but adequate area below Thermalito Afterbay Outlet. Spawning activity was highest in the upper three miles of the LFC, whereas spawning area was relatively evenly distributed below Thermalito Afterbay Outlet. Historical results suggest superimposition significantly reduces egg survival.

Statistical analysis of historical data showed that there has been a highly significant increase in the number of salmon spawning in the LFC. In-channel escapement explained a significant additional portion of the variability in spawning distribution. The significant increase in the proportion of spawners using the LFC over time may be at least partially attributable to an increasing proportion of river flow from this channel. Substrate composition based on Wolman counts and bulk samples do not explain trends in spawning distribution as LFC gravel has become progressively armored over the past 16 years, whereas downstream substrate composition has not changed detectably. Temperature trends were not significantly correlated with spawning distribution. We hypothesize that hatchery stocking location and genetic introgression between fall-run and spring-run chinook stocks also account for spawning activity in the LFC. Spawning simulations using an egg production model based on these statistical analyses yielded very different results than a PHAB-SIM instream flow model.

Introduction

The Feather River supports one of the largest runs of chinook salmon (*Onchorhynchus tshawytscha*) in California's Central Valley. Unfortunately, relatively little information has been published about the status of salmon in the lower Feather River. The river was studied intensively by Painter and others (1977), who examined the effects of the construction of Oroville Dam on Feather River fish. In 1981 the California Department of Water Resources (DWR) conducted gravel studies in the river with emphasis on chinook salmon spawning riffles (DWR 1982). Dettman and Kelly (1987) and Cramer (1992) conducted analyses of the contribution of Central Valley salmon hatcheries (including Feather River) to ocean harvest and escapement. In the mid-1990s, DWR, in cooperation with the California Department of Fish and Game (DFG), conducted several unpublished fish studies that focused on the effects of flow on salmon. These results were later used by Williams (1996) for a theoretical analysis of the effects of variability on instream flow modeling results.

The following paper summarizes our understanding about the status of chinook salmon in the Feather River including a portion of their life history, abundance trends, and physical habitat. This information is used as the basis for detailed analyses of spawning, which we believe is probably more important to in-river salmon production than either adult holding, juvenile rearing, or emigration. Specific objectives were to:

- Describe the physical conditions for chinook salmon spawning in the Feather River.
- Identify the factors that affect spawning distribution and success.
- Develop models to simulate spawning in the Feather River.

Chinook Salmon Life History in the Feather River

The lower Feather River has two runs of chinook salmon, the fall-run and spring-run. Adult fall-run typically return to the river to spawn during September through December, with a peak from mid-October through early December. Spring-run enter the Feather River from March through June and spawn the following autumn (Painter and others 1977). However, the spring-run are genetically uncertain as a result of probable in-breeding with the fall-run (Yoshiyama and others 1996; Brown and Greene 1994; Hedgecock and others, this volume). Genetic studies are presently underway to examine this issue. Fry from both races of salmon emerge from spawning gravels as early as November (Painter and others 1977; DWR unpublished data) and generally rear in the river for at least several weeks. Emigration occurs from December

to June, with a typical peak during the February through April period. The vast majority of these fish emigrates as fry (DWR unpublished data), suggesting that rearing habitat is limiting or that conditions later in the season are less suitable. Risks for late migrating salmon include higher predation rates and high temperatures. The primary location(s) where these fish rear is unknown, however in wetter years it appears that many young salmon rear for weeks to months in the Yolo Bypass floodplain immediately downstream of the Feather River before migrating to the estuary (Sommer and others 2001).

Historical distribution and abundance of chinook salmon in the Feather River is reviewed by Yoshiyama and others (this volume). They note that fall-run historically spawned primarily in the mainstem river downstream of the present site of Lake Oroville, while spring-run ascended all three upstream branches. Fry (1961) reported fall-run escapement estimates of 10,000 to 86,000 for 1940–1959, compared to 1,000 to about 4,000 for spring-run. Recent fall-run population trends continue to show annual variability, but are more stable than before Oroville Dam was completed (Figure 1). Pre-dam escapement levels have averaged approximately 41,000 compared to about 46,000 thereafter (see also Reynolds and others 1993). This increase appears to be a result of hatchery production in the system. The pre- and post-dam levels of spring-run are similar, however the genetically uncertain stock is now dominated by hatchery operations (Figure 2).

Hatchery History and Operations

Feather River Hatchery was opened in 1967 to compensate for the loss of upstream habitat by the construction of Oroville Dam. The facility is operated by the California Department of Fish and Game and typically spawns approximately 10,000 adult salmon each year (see Figure 1). Until the 1980s, the majority of the young hatchery salmon was released into the Feather River (Figure 3). However, the release location was shifted to the Bay-Delta Estuary to improve survival.

Hydrology

The Feather River drainage is located within the Central Valley of California, draining about 3,600 square miles of the western slope of the Sierra Nevada (Figure 4). The reach between Honcut Creek and Oroville Dam is of low gradient. The river has three forks, the North Fork, Middle Fork, and South Fork, which meet at Lake Oroville. Lake Oroville, created by the completion of Oroville Dam in 1967, has a capacity of about 3.5 million acre-feet (maf) of water and is used for flood control, water supply, power generation, and recreation. The Lower Feather River below the reservoir is regulated by Oroville Dam, Thermalito Diversion Dam, and Thermalito Afterbay Outlet. Under normal operations, the majority of the Feather River flow is diverted at Thermalito Diversion Dam into Thermalito Forebay. The remainder of the flow,

typically 600 cubic feet per second (cfs), flows through the historical river channel, the “low flow channel” (LFC). Water released by the forebay is used to generate power before discharge into Thermalito Afterbay. Water is returned to the Feather River through Thermalito Afterbay Outlet, then flows southward through the valley until the confluence with the Sacramento River at Verona. The Feather River is the largest tributary of the Sacramento River.

The primary area of interest for salmon spawning is the low flow channel (see Figure 4), which extends from the Fish Barrier Dam (river mile 67) to Thermalito Afterbay Outlet (river mile 59), and a lower reach from Thermalito Afterbay Outlet to Honcut Creek (river mile 44). There is little or no spawning activity in the Feather River below Honcut Creek.

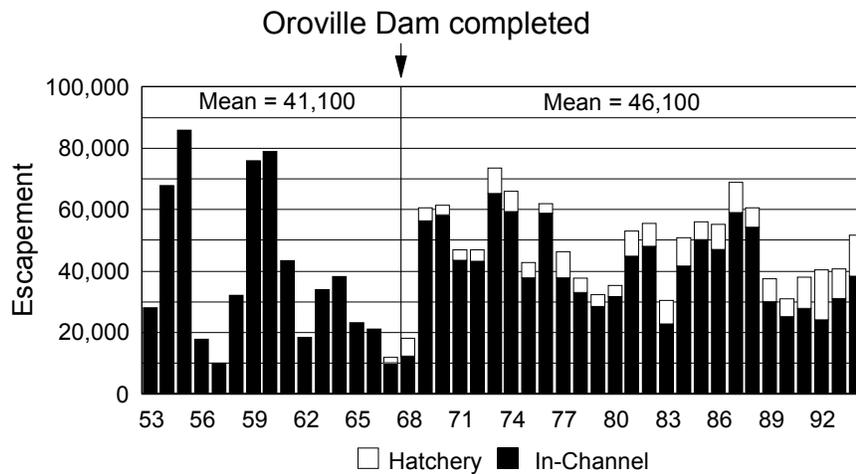


Figure 1 Escapement of fall-run chinook salmon (1953–1994) in the Feather River Hatchery and channel

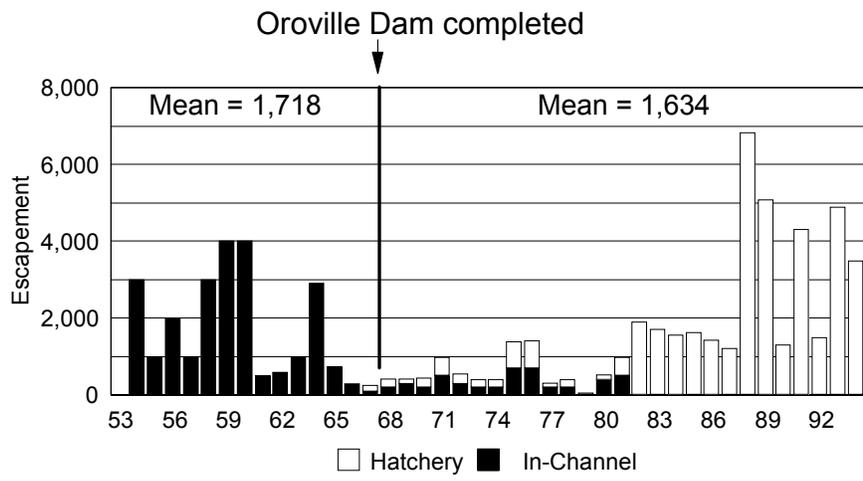


Figure 2 Escapement of spring-run chinook salmon (1953–1994) in the Feather River Hatchery and channel

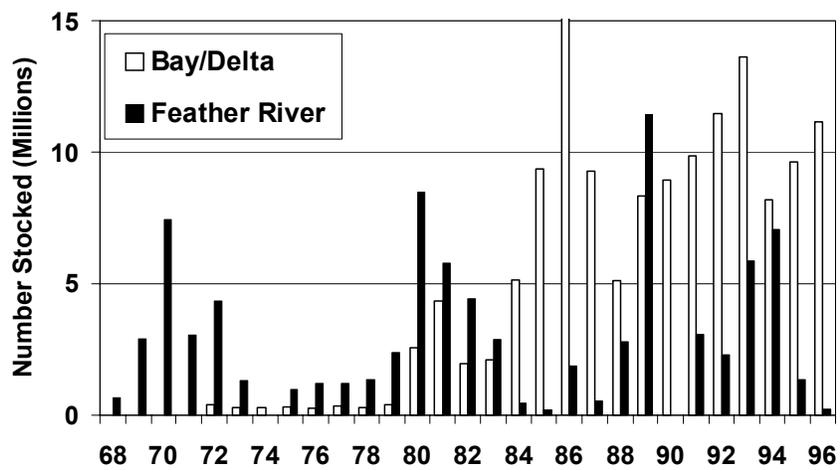


Figure 3 Stocking rates of juvenile salmon from the Feather River Hatchery into river and Bay-Delta locations

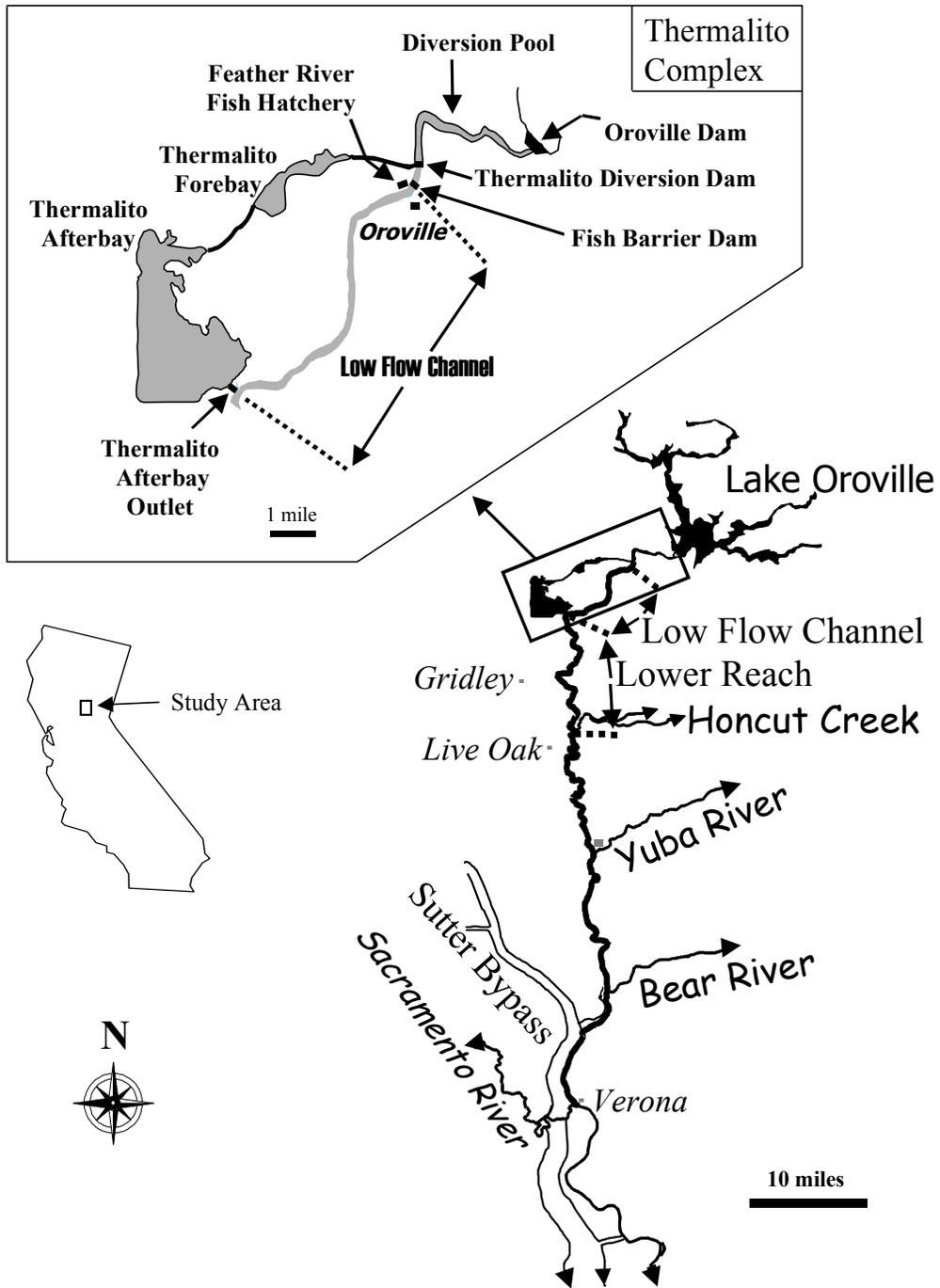


Figure 4 Feather River and vicinity

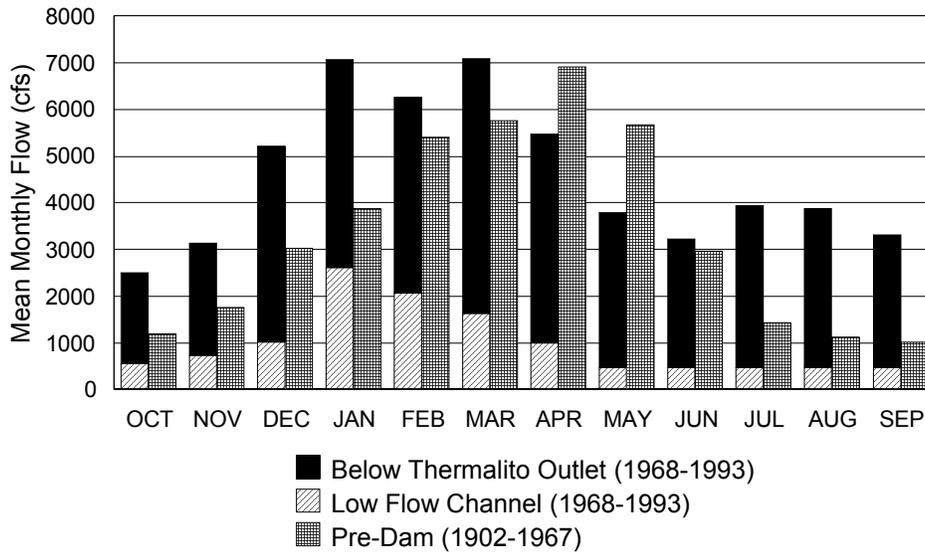


Figure 5 Mean monthly flows (cfs) in the Feather River for the pre-Oroville dam (1902–1967) and post-Oroville dam (1968–1993) periods. Total flow in the post-dam period includes the portion from the low flow channel and the portion diverted through the Thermalito complex.

The hydrology of the river has been considerably altered by the operation of the Oroville complex. The major change is that flow that historically passed through the LFC is now diverted into the Thermalito complex. Mean monthly flows through the LFC are now 5% to 38% of pre-dam levels (Figure 5). Mean total flow is presently lower than historical levels during February through June, but higher during July through January. Project operations have also changed water temperatures in the river. Compared to historical levels, mean monthly water temperatures in the LFC at Oroville are 2 to 14 °F cooler during May through October and 2 to 7 °F warmer during November through April. Pre-project temperature data are not available for the reach below Thermalito Afterbay Outlet, but releases from the broad, shallow Thermalito Afterbay reservoir probably create warmer conditions than historical levels for at least part of the spring and summer.

Methods

Data for the present study were obtained from three sources: annual carcass surveys, instream flow studies conducted during the early 1990s, and recent detailed studies on spawning. The major field measurements are summarized below.

Physical Conditions for Spawning

Our analysis of spawning conditions focused on depth, velocity, and substrate conditions. Initial field measurements were made October 1991, representing early-peak spawning activity. Sampling was concentrated in the vicinity of 36 transects selected to represent historical spawning areas (DWR 1982) and habitat types (see below). Further details about the transects are available in Williams (1996). Individual redds within approximately 100 ft of each transect were located by three field crew by wading or boat observations.

The ground level survey was verified using aerial photography of the area between Fish Barrier Dam and Honcut Creek. Photographs were taken on 16 October 1991 from an elevation of approximately 1000 ft. Comparison of color prints from the flyover with ground-level redd mapping confirmed that the field survey was reasonably comprehensive.

Field measurements of depth, substrate, and velocity were performed using wading methods. Depth and velocity were measured using a Price AA flow meter in undisturbed gravel approximately two feet upstream of each redd at an angle of 45 degrees to the direction of flow. The dominant gravel type was evaluated for the surface substrate using a modified Brusven classification (Platts and others 1983). A visual estimate of the amount of fines in the surface layer was recorded separately as a percentage of the total substrate. A single field observer was used throughout the study to minimize subjective variation.

Additional field measurements were made in 1995 based on concerns that the 1991 data were collected under unusually low flow conditions. Flows in the river during the 1995 spawning season (October to December) were experimentally increased in the low flow channel and reach below Thermalito Afterbay Outlet to 1,600 and 2,500 cfs, respectively, compared to the 600 and 1,000 cfs levels studied in 1991. Similar techniques were used in 1995 sampling, although substrate was not analyzed. Depth and velocity data from 1991 and 1995 were compared using Mann-Whitney U tests.

The quality of gravel in the major spawning riffles was examined in more detail from samples collected in 1982 and 1996. The 1996 samples were taken as close as possible to the original 1982 sites. Bulk samples weighing between 400 and 700 pounds were collected using shovels at the head of point bars adjacent to most of the major salmon spawning riffles. The surface and subsurface portions were sampled separately. Bulk samples were sieved on site and the sand to silt portion was taken to the laboratory for further analysis. The laboratory sieves ranged from 0.019 to 1.2 inches. The results were analyzed based on the geometric mean of the particle size distribution by river mile.

Surface samples were also taken at twenty riffles using a modified Wolman (1954) grid method. Although the Wolman counts do not adequately sample the finer sediments, we selected the technique because of its relative simplicity and common usage. The area sample included or was adjacent to the bulk sample site. Statistical analysis of the Wolman counts was similar to the bulk samples.

Spawning Distribution

Our basic approach to analyzing Feather River spawning distribution was to prepare a map of the available aquatic habitats, then use aerial photographs and ground-based observations to identify the spawning areas.

The major habitat types were classified using a system similar to Beak Consultants, Inc. (1989). Channel features delineated using aerial photographs (1 inch:400 feet) from October 1990 and US Geological Survey topographical maps indicated that the majority of the study area consisted of island bar complex and straight flatwater habitat. Field studies were then conducted to further refine site maps to include specific habitat components: riffles, pools and run-glide areas. Field observations were made at a flow rate of 600 cfs above Thermalito Afterbay Outlet and at approximately 4,500 cfs below the outlet.

The maps were analyzed by recording the linear distance (ft) of each habitat type. In complex areas with overlapping habitats or multiple channels, the relative abundance of each habitat type was estimated as a percentage of the total channel area. Note that actual habitat boundaries for "riffles", "pools" and "run-glide" areas changes relative to flow conditions. However, the maps we prepared provide a useful baseline to identify sampling areas and changes in spawning distribution. Another consideration is that there have been changes to some areas as a result of subsequent high flows in 1993 and 1995. However, site visits in 1995 indicated that there was no major change in the relative proportions of the different habitat types.

Aerial photographs were taken of the entire study reach in November 1995 to examine redd distribution. Ground-based observations were made within 24 hours of the date of the flight to check the accuracy of the methods. However, we were unable to identify individual redds because of the large numbers of fish spawning in relatively few areas. As an alternative, we quantified spawning activity based on the total area disturbed by spawning activity. Because some disturbed areas do not represent redds, we consider the results an estimate of the maximum amount of area used for spawning. The 1:3000 scale photographs were prepared using a yellow filter to minimize glare. The negatives were reviewed before printing to identify the sites containing redds that needed to be enlarged to a scale of 1:600. Total disturbed area, referred to as "total spawning area," was delineated on the prints relative to habitat bound-

aries from the previously described habitat map. The area estimates were calculated by digitizing these maps using AUTOCAD. The results were quantified by river mile, river reach, and habitat type.

We examined carcass count data from Painter and others (1977) to provide a historical perspective on spawning distribution. Carcass recoveries were recorded by river mile for 1971 through 1974. Although these data are biased because many carcasses would have drifted downstream of the riffle or run-glide where spawning occurred, we believe the results are a useful approximation of actual distributions.

Field observations of spawning suggested that superimposition of redds was a major problem in the Feather River. We developed indices from the 1995 data to examine superimposition rates by river reach as follows:

$$\text{Superimposition Index} = \frac{(\text{Escapement Estimate} \times 0.5)(\text{Spawning Area in ft}^2)}{55\text{ft}^2}$$

The escapement estimate is from DFG's fall carcass survey and is multiplied by 0.5 to represent the number of spawning pairs. The 55 ft² value is the average surface area for an average size fall-run chinook salmon (Bell 1986). The spawning area estimate was calculated from previously described aerial photography methods. We emphasize that the result should be considered an index rather than an actual measure of superimposition rates. As described in Healey (1991) there is considerable variability in the surface area of redds, which could have a major effect on the amount of superimposition in the Feather River.

Analysis of Factors Affecting Spawning Distribution

The superimposition and redd distribution analyses showed that there were major differences in the distribution of spawning activity between study reaches. We addressed this issue by examining the proportion of fish that spawned in the LFC relative to different environmental conditions. Historical escapement data were obtained from DFG for the LFC and from Thermalito Afterbay Outlet to Gridley. Data were available for 1969 through 1974, 1977, 1979 through 1987, 1989, and 1991 through 1996. We calculated the percentage of spawners in the low flow channel as:

$$\text{Percent Spawners in Low Flow Channel} = 100 \times \frac{\text{Escapement in Low Flow Channel}}{\text{Total Escapement Oroville to Gridley}}$$

As will be discussed in further detail, we found strong time trend in spawning distribution. We used regression analysis to determine whether total escapement, temperature, flow, and flow distribution had similar time trends that might explain the apparent changes in spawning distribution. In addition, we regressed each variable against the residuals from the spawning distribution-time relationship to determine whether the variable explained a significant additional portion of the variability. We calculated average maximum daily temperature for October and November of each year (1969–1991) using data from US Geological Survey records for Thermalito Afterbay Outlet. USGS data for 1969–1996 were obtained to estimate average October and November flow in the LFC and flow distribution, calculated as the percentage of total river flow that was released through the LFC. The normality of each variable was tested with a Shapiro-Wilks W test and log-transformed where necessary.

Modeling

Two different approaches were used to model spawning in the lower Feather River. The first was to use simulate the effect of flow on spawning using the instream flow model Physical Habitat Simulation System (PHABSIM). As an alternative, we simulated egg production using a simple mechanistic model developed from statistical relationships for factors affecting spawning distribution and egg survival.

Instream Flow Model

PHABSIM methods and models were developed by the US Fish and Wildlife Service Instream Flow Group (Bovee 1982). To summarize briefly, a habitat mapping approach (Morhardt and others 1984) was used to select and model the previously described transects. A hydraulic model was developed based on physical data collected at each transect to simulate depth, velocity, and substrate at a range of river flows for each reach. Weighted Useable Area (WUA), an index of habitat, was simulated by combining the hydraulic model results with binary suitability curves developed from data collected on conditions used for spawning. Details about the modeling approach are provided below and in Williams (1996).

Physical data collection procedures followed the methodology of Trihey and Wegner (1981). Permanent headstakes and benchmarks were established between autumn 1991 and summer 1992 at all transects following surveys of the study reach. Stage-discharge measurements were attempted at three to four different flows between autumn 1991 and spring 1993. For most lower reach transects, stage data were collected at 1,000, 2,500 and 3,000 cfs. In the LFC, stage measurements were performed at 400, 600 and 1,000 cfs.

During July 1992 cross-sectional coordinates and mean column velocity (one to three depths) were collected on at least 15 points across the wetted width of each transect. At pool and glide sites, Price AA flow measurements were made from a ten-foot aluminum boat attached to aircraft cable stretched across the channel. Similar measurements were made at riffle sites by wading using a top-setting rod.

The hydraulic data were calibrated using the methods of Milhous and others (1989). Water surface elevation and velocity data for most transects were calibrated using the IFG4 option of PHABSIM, although MANSQ was used as an alternative to calibrate elevations for some riffle and glide habitats. When at least four stage-discharge measurements were available, calibration was often improved using separate low- and high-flow range models to simulate elevations. Following calibration, water surface elevations and velocities were simulated using IFG4 within the maximum extrapolation range recommended by Stalnaker and Milhous (1983): 200 to 2,500 cfs in the LFC and 500 to 7,500 cfs in the lower reach.

Habitat suitability curves were developed using previously described data on depth, velocity, and substrate. For modeling purposes, the results were simplified into binary curves. The central 50% of observations for each depth, velocity, and dominant substrate were assigned a value of "1" and the remaining observations were assigned a value of "0." In addition, any substrate with greater than 50% fines was assigned a value of "0." Although we also considered modeling suitability based on more complex curve-fitting techniques (Bovee 1982), the resulting curves are often biologically questionable (Bovee, personal communication, see "Notes"). The binary curve approach seems reasonable for the Feather River, where spawning activity is concentrated in suitable gravel on a relatively small number of riffles and glides.

The amount of microhabitat available for different discharge rates was simulated using the PHABSIM program HABTAT (Milhous and others 1989). Habitat availability was calculated in terms of WUA by combining hydraulic simulation data and binary habitat suitability curves. The WUA in each reach was obtained by weighting transects modeled for each habitat type using habitat abundance data collected during site selection.

Egg Production Model

As further described in the results, statistical analyses suggest that flow and escapement have a significant effect on the proportion of salmon that spawn in the LFC. However, egg survival is reduced in the LFC as a result of superimposition. We developed a spreadsheet model which simulates egg survival based on flow and escapement. The basic structure of the model is that spawning distribution between the two river reaches is simulated using a

regression equation based on the proportion of flow from the LFC and escapement. Initial egg production for each reach is calculated from the number of spawning pairs. Egg survival rates are then assigned separately to the two study reaches based on historical observations.

The regression equation for spawning distribution came directly from previously-described analyses of variables affecting the proportion of LFC spawners. Other variables such as hatchery practices that may result in time trends in spawning distribution were assumed to be constant. Total flow was assumed to be constant at 2,500 cfs, which is typical for the spawning period. Total egg production was calculated for each reach by multiplying the number of spawning pairs by an assumed fecundity of 5,000 eggs.

Egg survival was simulated based on the results of Painter and others (1977), who examined the proportion of live and dead eggs for several years over different spawning densities. They found a significant inverse relationship between egg survival (S) and escapement of salmon in the LFC (L): $S = -0.00292L + 111.2$, ($r^2 = 0.575$, $P < 0.05$). We assumed that this regression relationship represented egg survival in the LFC, but set a minimum survival limit of 30%, the lowest rate observed in the Painter and others (1997) study. The upper limit was set at 100% based on maximum survival estimates from Healey (1991). There was no such relationship or strong indication of density dependence for the study reach below Thermalito, so we used the average egg survival rate for 1968 through 1972 (84%) for all simulations.

As evidence that the highest egg survival rates measured by Painter and others (1977) are reasonable, survival estimates for undisturbed chinook salmon eggs to hatching stage range from 82% (Briggs 1953) to 97% (Vronskiy 1972). We also used the method of Tappel and Bjornn (1983) to calculate "ideal" Feather River egg survival rates based on the particle size distribution of several spawning riffles. The key particle sizes needed for the model were estimated by linear interpolation from combined bulk surface and subsurface samples. The survival estimate for gravel in three spawning riffles using the Tappel and Bjornn (1983) method was 83% (SD = 5), close to the 84% average (SD = 8) for below Thermalito Afterbay Outlet, but lower than the highest survival rate observed in the LFC (93%). Although these results suggest that the highest Feather River survival rates measured by Painter and others (1977) are reasonable, we were unable to verify the shape of the inverse relationship with LFC escapement. The Painter and others (1977) results were from observations of eggs pumped from redds using a McNeil sampler, which does not measure mortality of eggs lost to the water column through superimposition. However, Fukushima and others (1998) found that the number of pink salmon eggs lost into the channel was roughly proportional to spawner abundance, indicating that water column losses can at least be expected to follow the same trend as intergravel mortality. For modeling purposes, we assumed that the

slope of the Painter and others (1977) relationship would not change substantially if water column losses were included.

Results

Physical Conditions for Spawning

A total of 205 depth measurements and 198 velocity measurements was made in riffles, pools and glides in the low flow channel. Spawning occurred in depths from 0.4 to 4.0 ft with the central 50% of observations ranging from 1.6 to 2.6 ft (Figure 6). Salmon spawned at velocities of 0.4 to 4.8 ft/s with a range of 1.5 to 2.7 ft/s for the central 50% of observations (Figure 7). The data suggest that the velocities used in 1992 were similar to 1995, but spawning occurred at somewhat greater depths in 1995 (see Figure 6). These hypotheses were confirmed using a Mann-Whitney U test, which showed that there were no significant differences for velocities, but highly significant differences for depth ($P < 0.0001$).

The dominant substrate used by spawners ranged from the 0.2- to 1-inch size class to the 6- to 9-inch class (Figure 8). Spawning was not observed in substrate with greater than 50% fines. The Wolman samples show that the largest substrate was at the top of the LFC, with a trend towards smaller material to Thermalito Afterbay Outlet (Figure 9). Gravel size increased at most sampling sites in the LFC from 1982 to 1996, but decreased below Thermalito Afterbay Outlet, suggesting armoring of the LFC as smaller gravel was transported downstream. Armoring is also evident in the surface bulk samples, with similar spatial trends and changes between the two years in the samples (Figure 10). Subsurface gravel size was somewhat larger in the LFC and showed an increase in size in the uppermost riffles.

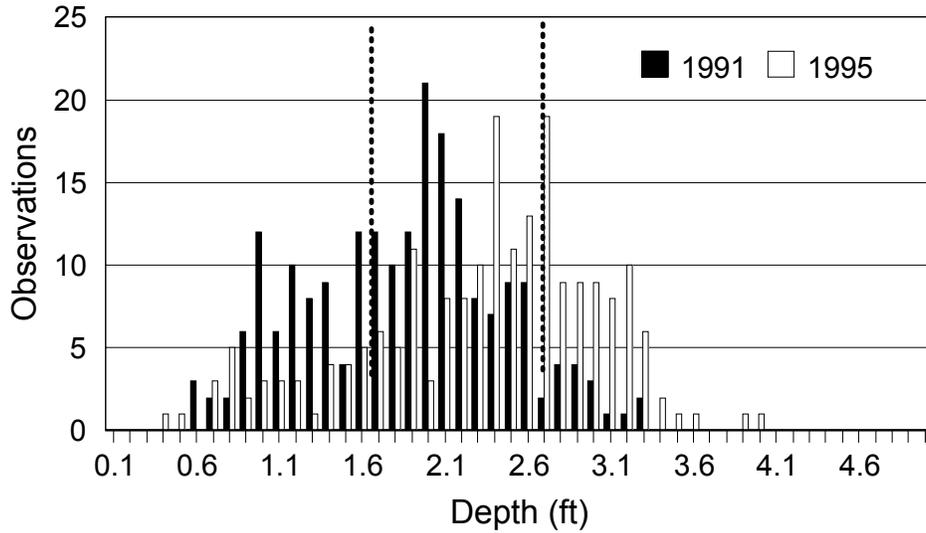


Figure 6 Histogram of spawning observations at different depths for 1991 and 1995, when flows were higher. The central 50% of observations are bracketed by dashed lines.

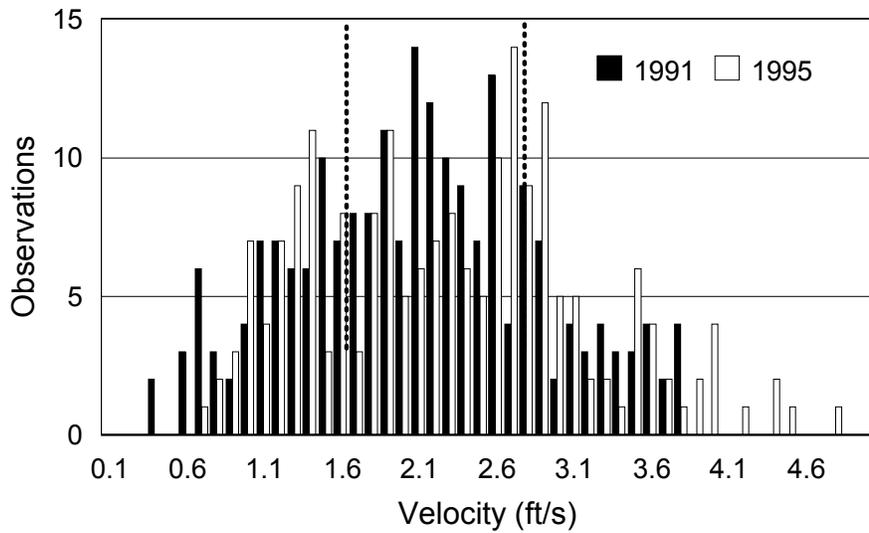


Figure 7 Histogram of spawning observations at different velocities for 1991 and 1995, when flows were higher. The central 50% of observations are bracketed by dashed lines.

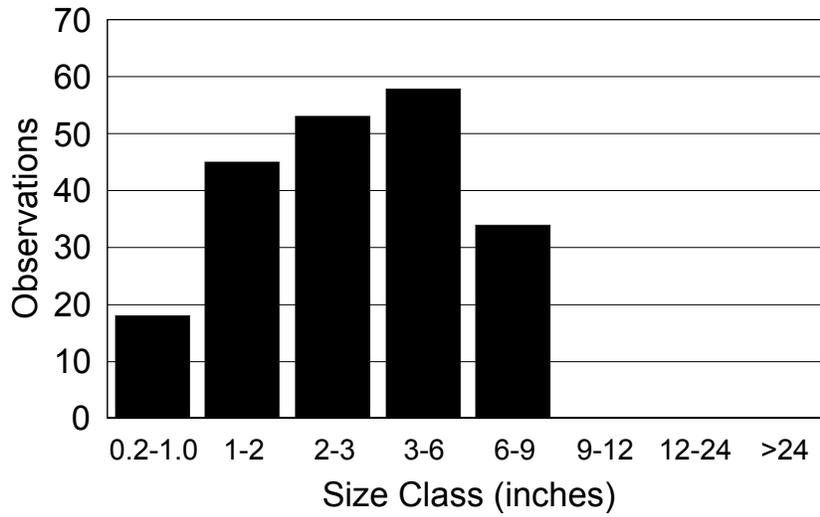


Figure 8 Size classes of spawning gravel used by Feather River salmon

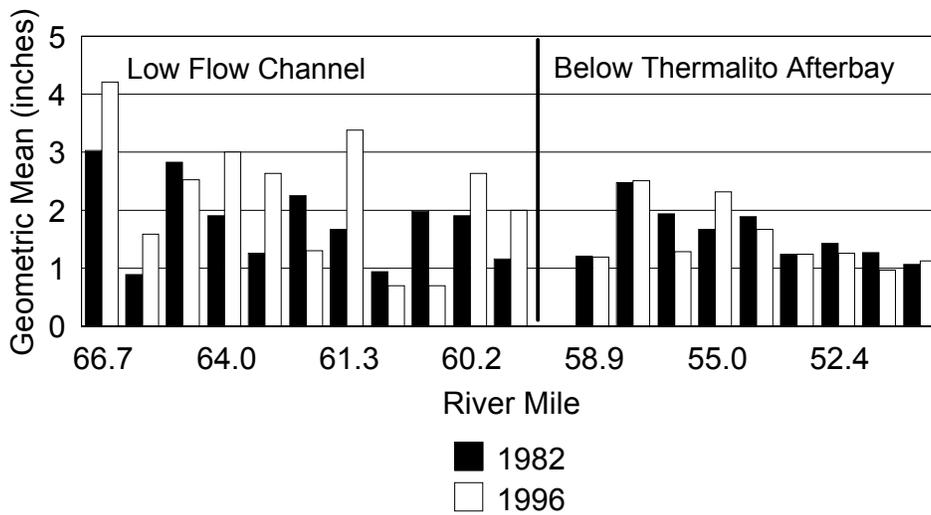


Figure 9 The geometric mean (inches) of Wolman gravel samples collected by river mile for 1982 and 1996

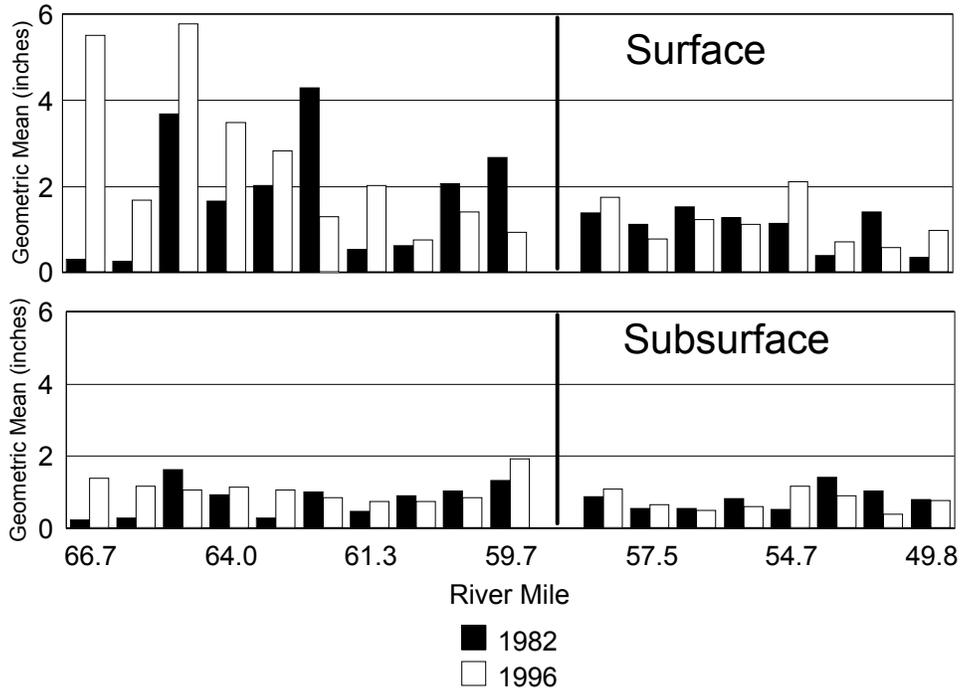


Figure 10 The geometric mean (inches) of bulk surface and subsurface gravel samples collected by river mile for 1982 and 1996

Spawning Distribution: In 1995 a total of 773,732 ft² of the LFC was used for spawning, with the greatest area concentrated in upper few kilometers of the reach (Figure 11). The majority of spawning occurred in the “riffle” and “glide” areas (Table 1). The upper three miles contained more than 60% of the total spawning area. A similar trend for the LFC is also evident in the historical data (Figure 12).

The estimate of total spawning area for the reach below Thermalito Afterbay was 1,480,085 ft² (see Figure 11). The “glide” areas showed the greatest amount of spawning activity and the “riffle” and “pool” areas had approximately equal levels (see Table 1). In contrast to the LFC, spawning area below Thermalito showed no obvious trend by river mile—spawning areas were relatively evenly distributed across the reach. The historical data below Thermalito Afterbay suggest a similar pattern, although there is some indication of increased spawning activity near river mile 57 at the upper end of the reach (see Figure 12).

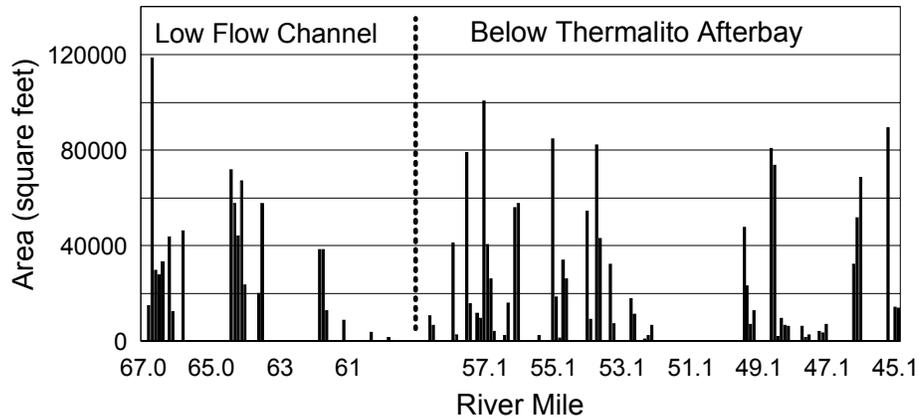


Figure 11 Spawning area (ft²) by river mile for 1995

Table 1 Spawning areas relative to boundaries set in a baseline habitat map

<i>Habitat</i>	<i>Area (ft²)</i>	<i>Percent</i>
Low Flow Channel		
“Riffle”	276,078	40
“Glide”	141,486	20
“Pool”	280,845	40
Total	698,409	100
Below Thermalito Afterbay		
“Riffle”	508,607	34
“Glide”	517,340	35
“Pool”	468,531	31
Total	1,494,478	100

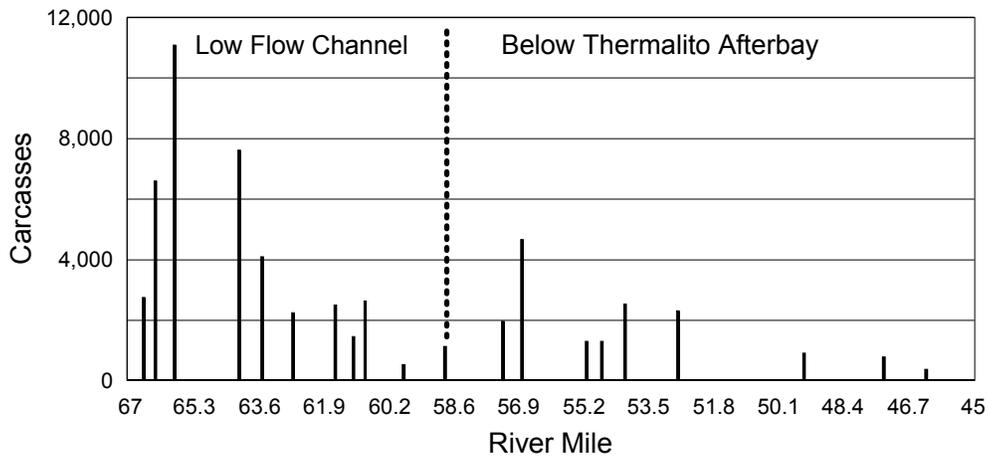


Figure 12 Salmon carcass numbers collected by river mile for 1971–1974

The 1995 DFG carcass surveys estimated that the total number of spawners for the low flow channel and the reach from Thermalito Afterbay Outlet to Gridley (see Figure 1) was 44,111 and 15,572, respectively. However, spawning area showed the opposite trend with estimates of 773,732 ft² and 915,089 ft², respectively. Based on these results, the estimated superimposition index for the LFC was 1.57 and the index for the lower reach was 0.47.

Factors Affecting Spawning Distribution

Time had a highly significant effect on the percentage of fish spawning in the LFC, explaining 72% of the variability (Figure 13). LFC flow ($r^2 = 0.02$, $P > 0.05$), October water temperature ($r^2 = 0.12$, $P > 0.05$), November water temperature ($r^2 = 0.02$, $P > 0.05$) and annual escapement ($r^2 = 0.09$, $P > 0.05$) showed no such time trend. However, flow distribution had a similar significant but weaker trend ($r^2 = 0.33$, $P < 0.001$) (Figure 14). Flow distribution ($r^2 = 0.10$, $P > 0.05$), total LFC flow ($r^2 = 0.02$, $P > 0.05$), October water temperature ($r^2 = 0.15$, $P > 0.05$) and November water temperature ($r^2 = 0.02$, $P > 0.05$) were not significantly related to the residuals from the spawning distribution-time relationship, but escapement had a weak significant relationship ($r^2 = 0.19$, $P < 0.05$) (Figure 15).

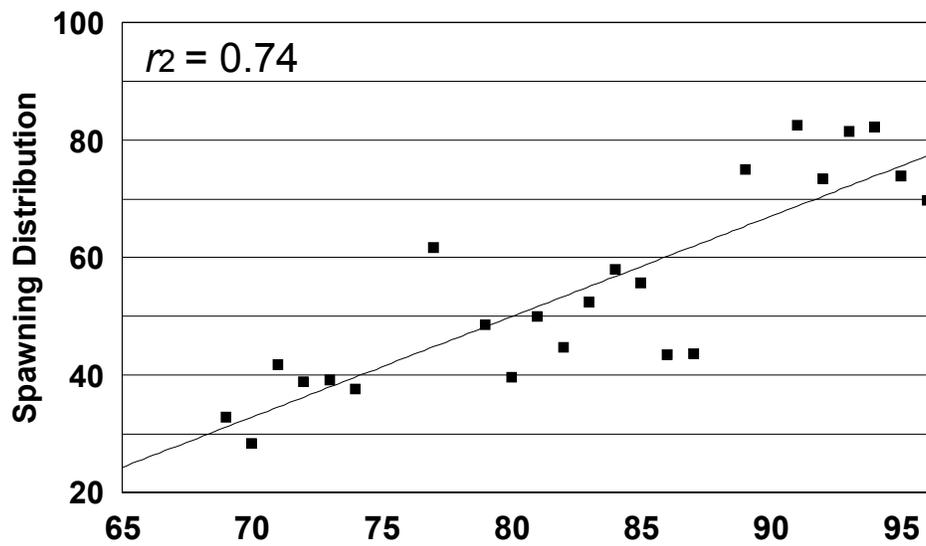


Figure 13 The percentage of salmon spawning in the LFC for 1969–1996. The increase is significant at the $P < 0.001$ level.

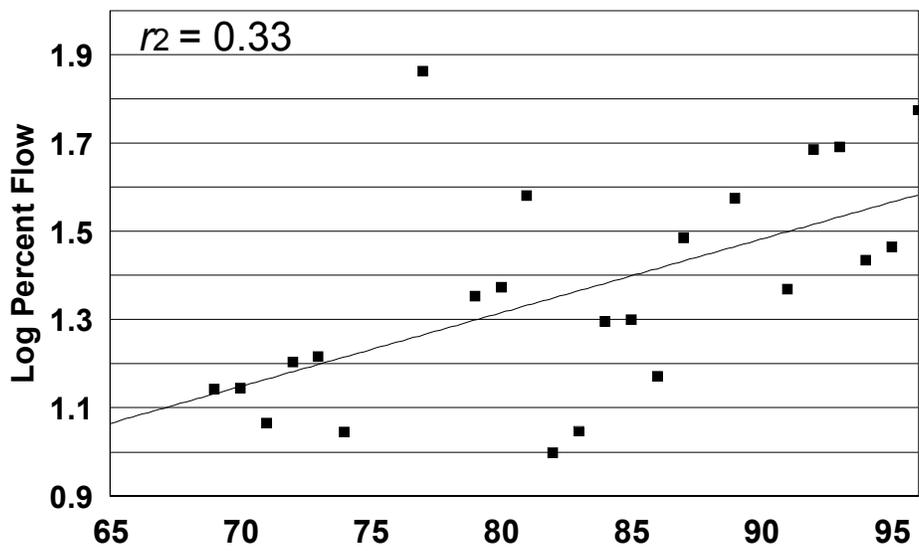


Figure 14 Log percentage of river flow from the LFC for 1969–1996. The increase is significant at the $P < 0.05$ level.

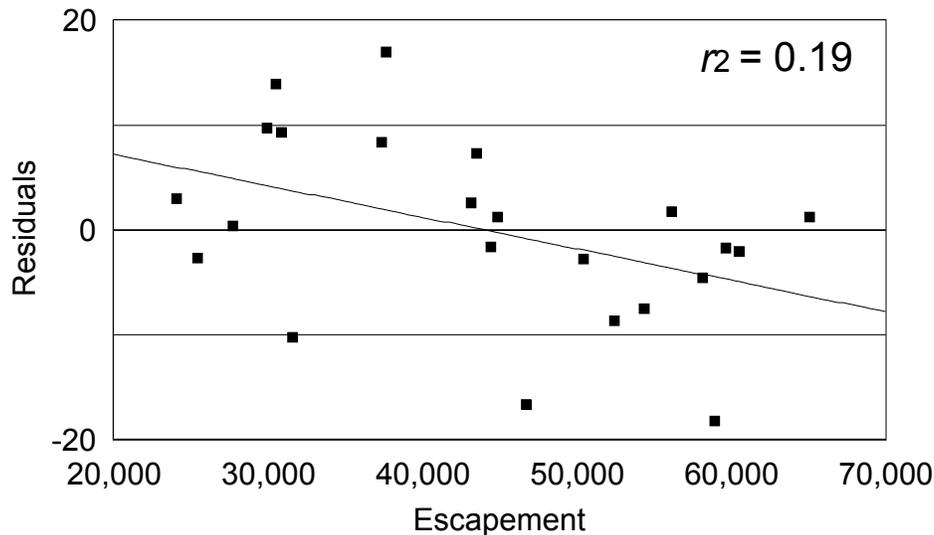


Figure 15 Relationship between in-channel escapement and the residuals from the time-LFC flow distribution relationship (see Figure 11). The decrease is significant at the $P < 0.01$ level.

These results suggested that escapement in the river and flow distribution were the key variables analyzed that could explain trends in spawning distribution. The two variables were combined in a multiple regression analysis, which showed that total escapement in the river and flow distribution explained about 47% of the variability in the percentage of salmon spawning in the LFC. However, the combined effects of flow and escapement explain less variability in spawning distribution than a model using time and escapement (multiple $r^2 = 0.77$, $P < 0.001$).

Modeling

The PHABSIM model predicted that WUA would be maximized in the LFC at 1,000 cfs and at 3,250 cfs in the reach below Thermalito Afterbay Outlet (Figure 16). The results for the egg survival model were quite different (Figure 17). Egg production increased roughly in proportion to the number of spawners. Flow had relatively little effect on predicted egg production at low escapement levels (20,000), but at higher escapement levels total egg production improved with decreasing flow.

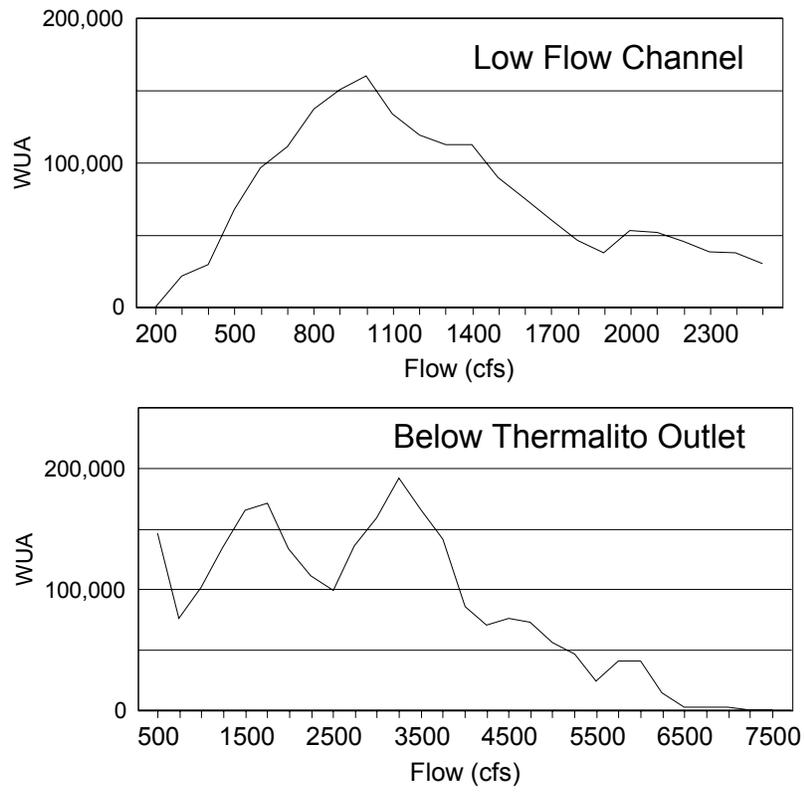


Figure 16 Simulation of spawning Weighted Useable Area (WUA) against flow (cfs) for two reaches of the lower Feather River using a PHABSIM model

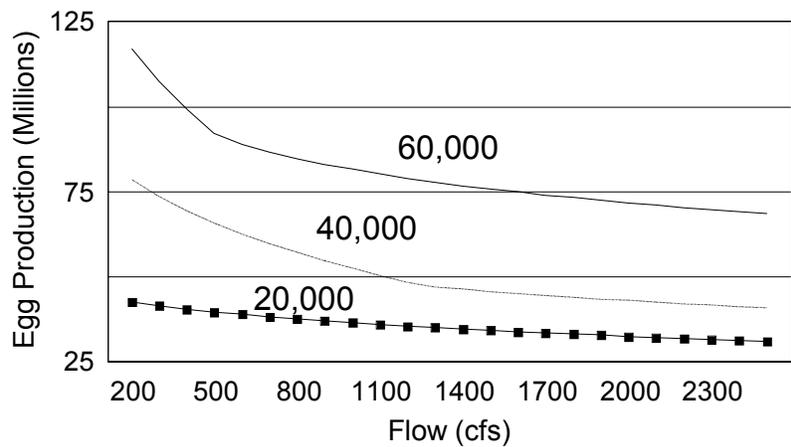


Figure 17 Simulation of egg production against flow (cfs) for three different levels of in-channel escapement

Discussion

This study documents a marked shift in the spawning distribution of chinook salmon in the lower Feather River. Since the construction of Oroville Dam and Feather River Hatchery, salmon have shifted their spawning activity from predominantly in the reach below Thermalito Afterbay Outlet to the LFC (see Figure 13). An average of 75% of spawning activity now occurs in the LFC with the greatest portion crowded in the upper three miles of the LFC (see Figure 11). While there is evidence that this upper section of the LFC was also intensively used after the construction of the dam and hatchery, the shift in the spawning distribution has undoubtedly increased spawning densities. The high superimposition indices we calculated for the LFC suggest that spawning habitat in this reach is limiting. Moreover, the results of Painter and others (1977) indicate that increased escapement will result in high egg mortality from superimposition.

The combined effects of time and escapement explained the greatest proportion of variability in spawning distribution. The effect of run size is biologically reasonable because spawning adults are highly territorial. Increased escapement levels could be expected to “push” more fish into the reach below Thermalito Afterbay Outlet.

Possible factors responsible for the time trend in spawning distribution include changes in total LFC flow, flow distribution, temperature, substrate, escapement, and hatchery practices. Of the first three variables, only flow distribution had a significant time trend. Three reasons may account for the increase in the proportion of flow from the LFC over the past three decades: (1) the minimum required LFC flow increased from 400 to 600 cfs in 1983; (2) drought conditions during 1987–1992, when total river flows were low; and (3) LFC high flow tests in 1995 and 1996. It is biologically reasonable that increasing percentage of flow from the LFC resulted in higher spawning activity in that reach—there is a well documented effect of “attraction flows” on the movements of salmon (Banks 1969).

Although changes in flow distribution explain much of the time trend in spawning distribution, it is likely that other changes may be of equal or greater importance. The combined effects of time and escapement explain 77% of the variability in spawning distribution, whereas flow distribution and escapement explain only 47%. Other potential explanations for increased use of the LFC over time include changes in gravel quality and hatchery operations. If substrate were responsible we would expect to see the greatest decline in gravel quality below Thermalito Afterbay Outlet. Yet our Wolman counts and bulk samples show that the gravel quality has deteriorated to the greatest extent in the LFC, not downstream. The increase in the gravel size at

the surface of the upstream riffles in the LFC shows that substantial armoring has occurred (see Figure 10) as smaller material has been transported downstream. Note, however, that our analyses do not account for possible changes in gravel permeability. It is possible that reduced use of the lower reach is a result of decreased gravel permeability.

Spawners seem most attracted to the heavily armored riffles at the upstream end of the reach, suggesting that hatchery operations may be at least partially responsible. We suggest two possible mechanisms for hatchery effects: (1) changes in stocking location of hatchery salmon and (2) genetic introgression between fall-run and spring-run chinook stocks.

Before 1983, most hatchery fish were stocked in the river, but after most were released downstream in the Sacramento-San Joaquin Estuary (see Figure 3). This change in operations probably increased survival rates of the hatchery fish (Cramer 1992), perhaps increasing the proportion of hatchery salmon in the stock. Salmon of hatchery origin are likely to have a stronger behavioral attraction to the LFC riffles closest to the hatchery than wild fish. Juvenile tagging studies initiated in the 1970s and more intensively in the 1990s may help to address this issue. As an indication that the proportion of hatchery fish has increased in the population, the mean escapement of fall-run at Feather River Hatchery was 4,600 adults during the first ten years of the operation of the hatchery as compared to a mean of 9,200 adults for 1983–1994 (see Figure 1). There is also evidence from other locations that hatchery salmon can displace natural stocks. Unwin and Glova (1997) found that the proportion of naturally produced chinook salmon steadily declined after the construction of a hatchery on a New Zealand stream. Like the Feather River fall-run (see Figure 1), operation of the hatchery resulted in no major change in total run strength. There is also good local evidence that operation of a hatchery can cause major changes in the distribution of chinook salmon stocks. Coleman National Fish Hatchery was built in 1942 on Battle Creek, a small tributary of the Sacramento River, to mitigate for the construction of Shasta Dam (Leitritz 1970; Black, this volume). Data for 1967–1991 show that there has been a major increase in the number of spawners using Battle Creek, while escapement in the mainstem Sacramento River had no obvious trend (Figure 18). The likely cause is that the Battle Creek population has been augmented by, or perhaps even replaced by, salmon from Coleman Fish Hatchery.

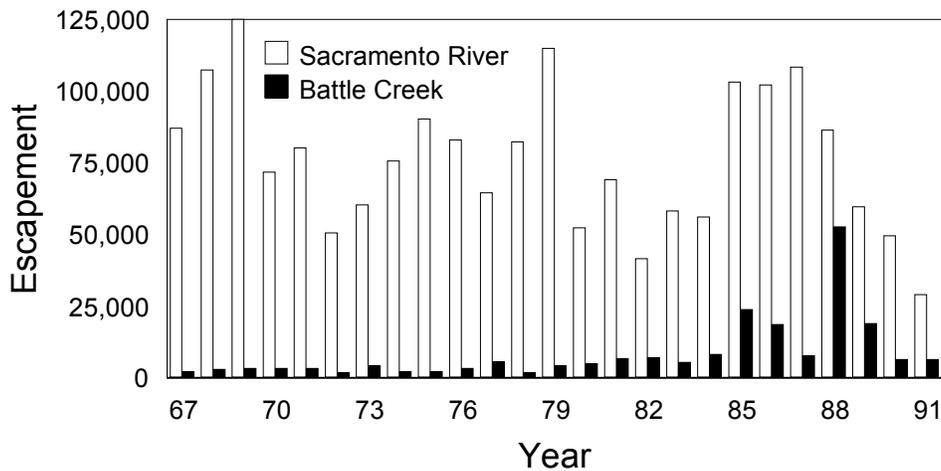


Figure 18 Salmon escapement trends in the Sacramento River compared with Battle Creek, a small tributary where Coleman National Fish Hatchery was constructed

An alternative hypothesis is that genetic introgression between fall-run and spring-run chinook salmon increased spawning in the LFC. The spawning periods for these two races historically overlapped in late summer and early fall. Genetic integrity was maintained by differences in spawning location; fall-run spawned on the valley floor, while spring-run migrated into higher gradient reaches and tributaries (Yoshiyama and others 1996). However, the construction of several dams on the Feather River blocked spring-run access to historical spawning areas. Since the construction of Oroville Dam, DFG staff at the Feather River Hatchery attempted to maintain the genetic integrity of the two races by designating the earliest-arriving spawners as spring-run. Unfortunately, this approach does not appear to have been successful. Brown and Greene (1994) describe coded-wire-tag studies on the progeny of hatchery fish identified as “fall-run” and “spring-run” and found evidence of substantial introgression. They report that significant portions of the offspring of each hatchery race returned as adults during the wrong period. For example, many of the “spring-run” group returned during months when hatchery operators designated all spawners as “fall-run.” Based on historical spawning behavior, gradual introgression of spring-run traits into the Feather River population would be expected to result in an increasing preference for the uppermost riffles of the LFC.

The PHABSIM and egg survival models yielded dramatically different results. Whether either model is a useful management tool is open to debate. The PHABSIM model is based on instream flow methodology, which is the most widely used system to develop flow recommendations (Reiser and others 1989). It predicts that increasing minimum flows in the LFC by 50% should

result in the maximum amount of spawning area (see Figure 16). However, the egg survival model indicates that increasing flow to the LFC could make conditions worse by attracting more spawners, resulting in high egg mortality through superimposition (see Figure 17). Another concern is the PHABSIM model for the reach below Thermalito Afterbay Outlet produced polymodal results, which is biologically questionable (see Figure 16). An advantage of the egg survival model is that it is based on field data collected over many years in the Feather River. While superimposition has been shown to be a major source of mortality in other locations (Fukushima and others 1998), additional studies are needed to determine whether egg supply is actually a limiting factor in the Feather River and to verify the shape of the egg survival-escapement relationship developed by Painter and others (1977). The egg survival model also does not incorporate potentially important effects of hatchery operations and is particularly questionable at low flows in the LFC, when river temperature and egg aeration could result in egg mortality.

We do not recommend either model to manage river flows at this time. Although the models yielded different results, both may reflect actual processes in the river. Given the many additional factors that could affect salmon survival in the river, we recommend the development of a more comprehensive life history model which may include aspects of the PHABSIM and egg survival models, as well as features to describe the effect of hatchery operations. In the absence of a quantitative model of salmon production in the Feather River, the results of this study could still be used as the basis for a conceptual model to test different hypotheses in the river. For example, it is possible that superimposition problems could be reduced by shifting more of the spawning activity to the reach below Thermalito Afterbay, where armoring is low and spawning habitat is more abundant. Testable alternatives to achieve this include varying the proportion of flow from the LFC or reducing the hatchery component of the stock, which are more likely to spawn in the uppermost reach of the LFC close to Feather River Hatchery.

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Notes

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