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# Chinook Salmon in the California Central Valley: An Assessment

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# Chinook Salmon in the California Central Valley: an Assessment

By Ronald M. Yoshiyama, Eric R. Gerstung, Frank W. Fisher, and Peter B. Moyle


## ABSTRACT

This paper summarizes information on recent historical distribution and abundance of chinook salmon in the California Central Valley drainage, focusing on the period from the 1950s to today. Most of the principal Central Valley streams that historically supported salmon runs still do so, but nearly half of them have lost at least one seasonal salmon run and several major streams have had all their salmon runs extirpated. Overall abundance of chinook salmon in the Central Valley system has decreased to less than 75% of their number in the 1950s. Fall-run chinook salmon in the Sacramento River basin compose by far the most abundant Central Valley stocks, but they substantially declined between 1953–1966 and 1967–1991. Fall-run chinook salmon stocks in the San Joaquin River basin and Sacramento-San Joaquin Delta tributaries showed various changes between 1953–1966 and 1967–1991 but altogether constitute only a minor portion (now 4%) of the total Central Valley spawning escapements. Three other chinook salmon runs (winter, spring, late-fall) have shown much more pronounced reductions in recent decades. Central Valley salmon have been heavily supported by hatchery production, but the effects of hatcheries on natural stocks remain poorly understood. Major efforts are underway to restore regional chinook salmon and steelhead stocks, several of which are listed under both California and U.S. endangered species statutes.




The expansive Central Valley of California (Figure 1), laced by numerous streams draining the surrounding Sierra Nevada, Cascade and Coast Range mountains, historically supported major runs of chinook salmon (*Oncorhynchus tshawytscha*)—the southernmost populations of the species in its native range. Central Valley chinook salmon constitute the great majority of salmon produced in California and at times have accounted for 70% or more of the statewide commercial harvest (Cope and Slater 1957; Skinner 1962). Less conspicuous than chinook salmon, but probably even more widely distributed in tributary streams, were runs of steelhead rainbow trout (*O. mykiss*) which decades ago supported a popular sport fishery.

The major Central Valley rivers, once the domain of great salmon hosts, now irrigate one of the most productive agricultural regions of the world. Central Valley rivers also serve populous and diverse urban areas, the largest of which lie outside the valley (i.e., San Francisco Bay area and Los Angeles basin). Consequently, the main arteries of the Central Valley—the Sacramento and San Joaquin rivers—are among the most disrupted rivers in the world, with hundreds of dams and diversions emplaced on the mainstems and tributaries. As the rivers were increasingly altered, chinook salmon and steelhead declined to the point where all runs of both species in the region currently


**Figure 1.** A map of the historical salmon-producing streams in the Central Valley drainage of California. For clarity, only the major streams and some of the minor streams that supported chinook salmon are shown. Former Tulare Lake (now a dry lakebed) fluctuated substantially in size from year to year. The historical connection between the Kings and San Joaquin rivers occurred intermittently during wet periods, but currently there are no natural flows from the Kings River and Tulare Lake basin into the San Joaquin River. Shasta Reservoir, as it is today, is shown in the northern Sacramento River basin.

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are either listed as threatened or endangered under federal and state endangered species statutes or have been designated as candidates for listing (NMFS 1998a,b, 1999). Impelled by the combination of recent federal legislation on water management, joint federal-state ecosystem restoration programs, and endangered species listings, a comprehensive effort is now underway to rebuild anadromous salmonid runs in Central Valley rivers (Box 1).

Our purpose in this paper is to compile information on the recent and current distribution and abundance of chinook salmon in the Central Valley, augmenting in greater detail for this region the broader survey by Huntington et al. (1996) of anadromous salmonid stocks in the Pacific Northwest and California. Herein we use the term "stock" interchangeably with a population of spawners that use a single major tributary (Ricker 1972; Nehlsen et al. 1991; USFWS 1995). Comparative information on past and current stock abundances provides a frame of reference for ongoing salmonid restoration efforts and may suggest approximate goals or at least yardsticks for measuring the success of recovery efforts. Our secondary intent is to summarize selected information from the historical literature (e.g., diaries or biographies, military expedition reports, county histories; Box 2) covering the early Euro-American settlement period of California (post-1840). Those sources have been used infrequently by fisheries biologists, but if viewed judiciously they may convey highly useful information. Such information, in fact, may have substantial repercussions on the management of some watersheds. For instance, historic records can be used by citizen groups to justify efforts to restore anadromous fishes to streams from which they are now absent. Likewise, historic records can justify designation of such streams as critical habitat for endangered and threatened stocks. Because comprehensive fish survey data were not regularly collected in California until the 1940s, our knowledge of salmon and other anadromous fish distributions in the Central Valley during earlier times must rely largely on non-scientific historical writings.

This paper serves as a status review of Central Valley chinook salmon. Specifically, we (1) summarize the distribution of the four seasonal runs of chinook salmon in the Central Valley drainage, (2) compare recent and current abundances of fall-run salmon in the major watersheds, (3) summarize recent abundances of the late-fall, winter, and spring runs, (4) present historical testimonies of past salmon abundance, and (5) briefly discuss the influence of hatchery production on Central Valley salmon. The main focus of our abundance assessments is the latter half of the twentieth century, which roughly corresponds to the reference time frame used in current resource agency plans to increase anadromous fish production in central California (USFWS 1995; McEwan and Jackson 1996; CALFED 1998a).

**Box 1. The background for current salmonid restoration efforts in the California Central Valley.**

The decline of Central Valley salmon has been a concern of fisheries managers in California since the late-19th century, yet it has inexorably continued (McEvoy 1986, Yoshiyama et al. 1998). Aside from the immediate societal and environmental factors that impelled the decline (e.g., gold-mining, overfishing, dams), the problem was accentuated by the perennial inability of the state's fishing interests to influence the allocation of water supply and also by the misplaced optimism of fishers, biologists, and engineers that application of technology (e.g., fish ladders, hatcheries) would counteract the forces that were driving down the stocks (Black 1995). Only when some salmon runs verged on extinction did significant action occur. In 1988, the California state legislature passed the Salmon, Steelhead Trout, and Anadromous Fisheries Program Act which mandated a goal of doubling (from 1988 levels) all anadromous fish populations within the state, but it did not provide adequate resources to accomplish the goal. In response, the California Department of Fish and Game (CDFG) produced an action plan listing specific projects at an estimated cost of at least $343 million, augmented by several larger projects (Reynolds et al. 1993).

In 1992, the U.S. Congress passed the Central Valley Project Improvement Act (CVPIA; Public Law 102-575, Title 34), which included a directive to develop and implement "a program which makes all reasonable efforts to ensure that, by the year 2002, 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." The program is now known as the Anadromous Fish Restoration Program (AFRP) (USFWS 1995:Vol. I-i). The CVPIA was significant because it emphasized natural reproduction of the stocks and also appropriated large volumes of water from federal water storage projects to enhance streamflows for salmon and other aquatic biota. Due to the high economic value of water in the region, passage of the CVPIA was controversial and its implementation has become a highly contentious issue. In 1994, the U.S. Fish and Wildlife Service issued an action plan to restore Central Valley anadromous fishes that overlapped much of the earlier CDFG plan, but specifically excluding the upper San Joaquin River as required by the CVPIA (USFWS 1994).

Concurrent with the development of the state and federal action plans, all salmon and steelhead runs were proposed for listing under both state and federal endangered species laws, eventually resulting in the listings of Sacramento winter-run and Central Valley spring-run chinook salmon (NMFS 1994, 1999) and Central Valley steelhead (NMFS 1998a). In response to the earlier federal listing of delta smelt (*Hypomesus transpacificus*) as threatened, the USFWS in 1996 presented a blanket recovery plan for the delta smelt and seven additional native fishes, including Central Valley spring-run and late-fall-run salmon and San Joaquin River basin fall-run salmon. The strategy of the USFWS plan was to recover those imperiled stocks in order to forestall the necessity of later formally listing them. A recovery plan for Sacramento winter-run salmon was issued in 1997 by the National Marine Fisheries Service (NMFS 1997).

The Bay-Delta Accord, born of the increasingly confrontational demands for water to sustain aquatic ecosystems and species and to ensure water supply for human use, was endorsed by regional stakeholders on 15 December 1994. This formal agreement between a diverse array of state and federal agencies, regional water providers, and environmental groups was a far-reaching cooperative attempt to resolve water allocation problems. It specifically created a guiding framework in the form of the CALFED Bay-Delta Program, a loosely structured superagency comprising 15 state and federal agencies, and generated several hundred million dollars in initial program funding. A key part of CALFED's mission is ecosystem restoration, including habitats crucial to anadromous salmonids—an enormously difficult endeavor which depends on the continued cooperation of disparate parties with divergent interests (CALFED 1998a, b).

Earlier estimates of abundance and more detailed distributional information for chinook salmon are covered by Yoshiyama et al. (1996, 2000) and Yoshiyama et al. (1998).

## Background: Central Valley Anadromous Salmonids

The chinook salmon is the preeminent anadromous fish in California, whether measured by economic value, popular recognition or ecological importance (Skinner 1962, McEvoy 1986, Yoshiyama et al. 1998). Four runs of chinook salmon (fall, late-fall, winter, and spring) occur in the Central Valley drainage and are defined by the timing of adult upstream migration and other life-history events (Vogel and Marine 1991; Fisher 1994; USFWS 1995)—and, to some extent, by differences in geographical range and habitat (Yoshiyama et al. 1996, 2000; Yoshiyama et al. 1998). Winter and spring runs historically used higher-elevation stream reaches and spent up to several months in fresh water before maturing into reproductive condition, while the fall run was restricted mainly to lower-elevation rivers and larger tributaries (Rutter 1904; Fisher 1994), as was probably the late-fall run. Remarkably, the continuing existence of four chinook salmon runs means that spawners and each of the other freshwater life-stages occur virtually every month of the year in the Sacramento River basin (Hallock et al. 1957; Vogel and Marine 1991; USFWS 1995).

Other salmon species historically occurred in Central Valley streams—pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*)—but in much lower abundance than chinook salmon (Collins 1892; Rutter 1908; Hallock and Fry 1967). As late as the 1950s, low numbers of pink, chum, and sockeye salmon entered the Sacramento River basin "regularly enough to be regarded as very small runs," although coho salmon were rare (except for a brief period of experimental introductions in 1956–1958) and the few individuals observed were considered strays (Hallock and Fry 1967). However, pink and coho salmon once may have had fairly substantial natural runs in the Central Valley. During the 19th century, it was noted that pink salmon "in tolerable numbers"

**Box 2. Historical excerpts referring to salmon abundance in selected Central Valley streams (see also Yoshiyama et al. 2000).**

While anecdotal statements on long-past salmon abundances do not allow meaningful quantitative comparisons with current information, they nonetheless convey an impression of the great magnitude of salmon numbers available to early Euro-American settlers and Native Americans. Their numbers at times must have greatly exceeded the combined natural and hatchery production of salmon in the Central Valley during recent decades (average, 739,500 fish for 1967-1991; USFWS 1995).

Of special note were the Upper Sacramento and McCloud rivers in the northern Sacramento River basin and the upper San Joaquin River in the southern Central Valley—both formerly highly productive streams from which salmon were extirpated by large water development projects in the mid-20th century.

**Upper (Little) Sacramento River.** Livingston Stone, fish culturist for the U.S. Fish Commission, noted: "Above the mouth of Pit River the salmon ascend the Sacramento, now called the Little Sacramento, 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. This exception is the McCloud River" (Stone 1874:176).

**McCloud River.** The McCloud River was at one time described as "The best salmon-breeding river in the world" (CFC 1890:33). In 1872, Livingston Stone established the U.S. Fish Commission's Baird Station on the McCloud River—the first salmon hatchery on the North American Pacific coast (Stone 1876, 1897, Hedgpeth 1941). Stone's reports attest to the early plenitude of McCloud River salmon:

"[In 1874] Tens of thousands, not to say hundreds of thousands, which would perhaps be nearer the truth, passed the line of our barricade before it was completed" (Stone 1876:446). "The year 1878 was the year of the immense gathering of salmon in the McCloud" (Stone 1897:213). "Indeed they were more numerous than I have ever known them to be before at that time, ...I have never seen anything like it anywhere, not even on the tributaries of the Columbia..." (Stone 1880:748). "During this time [the 40 days up to 5 October 1878] we caught and examined, one by one, nearly 200,000 salmon. We took and impregnated at least 14,000,000 eggs." (Stone 1880:763)

**Battle Creek.** Salmon egg-collecting activities on this stream were started in September-October 1895 at the Battle Creek Hatchery. The California Fish Commission noted, "Salmon enter this stream in large numbers during the months of October and November...[and] there being almost no limit to the number of eggs which can be secured there with proper apparatus" (CFC 1896:23-24). Livingston Stone likewise averred, "This Battle Creek is the most extraordinary and prolific place for collecting salmon eggs yet known, ... The first salmon make their appearance early in the fall, ...they are found in almost incredible numbers..." (Stone 1897:218).

**Feather and Yuba rivers.** The California Fish Commission stated that during the early Gold Rush period, "the salmon resorted in vast numbers to the Feather, Yuba, American, Mokolumne, and Tuolumne Rivers for purposes of spawning," and in the Yuba River as late as 1853, "the miners obtained a large supply from this source" (CFC 1877:5). Early historians also noted that the "Bear, Yuba and Feather rivers were full of salmon, and the Indians speared them by the hundred in the clear water" (Chamberlain and Wells 1879:15). "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" (Chamberlain and Wells 1879:86).

**Tuolumne and Stanislaus rivers.** The California Fish Commission reported: "The Tuolumne, a branch of the San Joaquin, at one time was one of the best salmon streams in the State... What has been said of the Tuolumne is true of the Stanislaus" (CFC 1886:20). Earlier, the pioneer John Marsh noted, "...the river of the Towalomes; it is about the size of the Stanislaus, which it greatly resembles, ...and it particularly abounds with salmon" (Bryant 1849:277). Referring to the present century, Fry (1961:66) stated: "In some years the Tuolumne River has had fall runs which were larger that those of any Central Valley stream except the Sacramento."

**Merced River.** Recollections of early residents on the Merced River attest to "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" (Clark 1929:31). During one unfavorable summer in the last century, a local newspaper reported: "...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" (Mariposa Gazette, 26 August 1882).

**Upper San Joaquin River.** Clark (1929:31) wrote, "Fifty or sixty years ago, the salmon in the San Joaquin were very numerous and came in great hordes." The early residents of Millerton (a site now covered by Millerton Reservoir) had their sleep disturbed "by the myriads of salmon to be heard nightly splashing over the sand bars in the river" (California State Historical Association 1929:117), which "created a noise comparable to a large waterfall" (Northern California Historical Records Survey Report 1940:13).

ascended the Sacramento River during October and that "Silverside salmon, [or] Cohoe salmon...has been taken in the Sacramento" (Lockington 1880:53). Of coho salmon, Eigenmann (1890:60) further stated, "This salmon runs in the Sacramento in summer and fall; it does not exceed eight pounds in weight, and many are doubtless confounded with the young of the Quinnat [chinook salmon]." However, because of the virtual absence of other salmon species in Central Valley streams during recent decades, chinook salmon currently are the primary salmon of management concern in the region. Hereafter, reference to "salmon" is to chinook salmon.

Although steelhead trout apparently were widely distributed and at least moderately abundant in the Central Valley drainage, their historical distribution and abundance are much less clearly known than is the case for salmon and we do not consider steelhead per se in this paper.

## Chinook Salmon Occurrence in Central Valley Streams

We tabulated the known past occurrences of chinook salmon runs in the major streams of the Central Valley drainage, as indicated by various historical sources (Table 1). This list is a minimal representation of past and current salmon distribution due to the incompleteness of the source material (e.g., agency reports, historical accounts by pioneers; see Yoshiyama et al. 1996, 2000; Yoshiyama et al. 1998), but it is evident that certain seasonal runs were widely distributed throughout the drainage (i.e., spring and fall runs), that at least one run was relatively restricted (the winter run in the upper Sacramento drainage), and that many Central Valley streams supported at least two runs of chinook salmon. Of the 32 streams listed, 14 streams have lost at least one seasonal run of salmon and five major streams had their salmon runs completely extirpated—viz., McCloud, Upper Sacramento, Pit-Fall, Upper San Joaquin, and Kings rivers.

We emphasize that our tabulation indicates the streams in which different runs were present but not where the runs were absent—i.e., the absence of reports for a particular run in a stream does not constitute proof that the run was absent from it historically. The tabulated current runs for some streams include both natural and hatchery-produced fish, especially for the fall run which is heavily supported by hatcheries (i.e., on Battle Creek and American, Feather, Mokelumne, and Merced rivers).

The run-identity of salmon in some early accounts is ambiguous. Although dates are often given in the historical sources for observations of salmon, there is considerable overlap in life-history timing between the seasonal runs (Vogel and Marine 1991; Fisher 1994; USFWS 1995). In cases of overlap a subjective decision was made for the most probable run. For example, salmon in good physical condition observed in the lower mainstem or major tributary reaches in January most likely were late-fall-run salmon because they would have been too late in the season for fall-run fish (usually highly deteriorated in body condition at that month), too early in most streams for the spring run, and in the wrong place for the winter run. Furthermore, the run names applied in the past are not always congruent with current usage. For example, some early reports of a "summer run" in the lower mainstem Sacramento River referred to the currently termed fall run (Stone 1874) but in other instances corresponded to the current spring run—i.e., in the lower Sacramento River (USFC 1895), McCloud River (USFC 1896), and Battle and Mill creeks (USFC 1904). In addition, Jordan (1892:51, 1904:80) noted, "In the Sacramento and the smaller rivers southward there is a winter run, beginning in December." However, none of the Central Valley streams south of the Sacramento River had summer flows suitable for the winter-run chinook's spawning and incubation period, which in some northern Sacramento Valley streams was provided by year-round coldwater springs. Therefore, Jordan very likely was referring to the late-fall run (in which adult migration and spawning are concentrated in January-April) or perhaps to very late-running segments of the fall run. On the other hand, it is possible that additional chinook salmon runs somewhat different from those currently recognized formerly occurred in the Central Valley but were extirpated—i.e., perhaps summer runs in the San Joaquin River, where "large numbers" of spawners were reported migrating during July and August in the mid-1870s (CFC 1875; USFC 1876); summer runs in the Sacramento River basin, as indicated by the periodic arrival of spawning cohorts in the McCloud River during every month of May-October 1886 (Green 1887) and the essentially continuous, but variable, summer running of salmon in the Sacramento River during 1896–1901 (Rutter 1904).

## Chinook Salmon Abundance: 1950s-Today

### *Data sources and format*

Extensive information on the distribution and abundance of Central Valley chinook salmon and steelhead in recent historical times (i.e., latter half of the 20th century) has been compiled in government agency reports (i.e., Reynolds et al. 1993; USFWS 1995) and data files, but those sources are not readily accessible and some are ponderous documents. A concise summary of the information is desirable so that not only fisheries professionals but also broader segments of the scientific community and general public can be readily informed on the recent status of the region's anadromous salmonid stocks. In particular, complete tabulations of historical and current chinook salmon runs in the major Central Valley streams previously have not been published in the primary literature. Although overall abundance estimates for Central Valley chinook salmon runs have been published (Fisher 1994; Yoshiyama et al. 1998), salmon abundances in specific watersheds heretofore have been available only in agency reports and unpublished data files.

Our primary data sources were the California Department of Fish and Game (CDFG) data files on annual spawning escapements for Central Valley streams, the U.S. Fish and Wildlife Service "Working Paper" for the Anadromous Fish Restoration Program of the U.S. Central Valley Project Improvement Act (AFRP-CVPIA; Box 1) (USFWS 1995), and the Pacific Fishery Management Council (PFMC) annual reports. Stock escapement data in the latter two sources were originally derived from CDFG data files or earlier CDFG unpublished reports. Hereafter, we specify the source documents when presenting quantitative data, but where no citation is given, the data are from CDFG data files. More detailed information on salmon abundance trends are given in the "Working Paper" (USFWS 1995), which also contains background information on factors that have affected Central Valley anadromous salmonids and discussion on recommended management actions.

Quantitative data on the abundances of salmon in the mainstems and tributaries of the Sacramento and San Joaquin rivers are generally lacking prior to the 1940s, except as might be inferred from commercial harvest records. Conservative total estimates of 1 million to 2 million spawners annually (all seasonal runs combined) have been suggested as the peak historical abundance of chinook salmon in the entire Central Valley region (Fisher 1994; Yoshiyama et al. 1998). During the late-1930s and early-1940s CDFG and USFWS initiated spawning escapement surveys to provide at least rough estimates of spring-run and fall-run numbers for several tributaries in the Central Valley. However, it was evident

**Table 1.** Historical and current chinook salmon runs in California Central Valley streams. The listed streams support or recently supported at least one seasonal run or are known historically to have had a substantial salmon run.[a] Current runs include both natural and hatchery-produced fish, particularly for the heavily supplemented fall run. NI = no information.

| Stream | Known Past Runs (pre-1960)[b] | Current Runs[c] |
|---|---|---|
| Sacramento River Basin | | |
| Cascades and Sierra Nevada: | | |
| McCloud River | fall, winter, spring | extirpated |
| Upper (Little) Sacramento River | fall, winter, spring | extirpated |
| Pit River- Fall River[d] | fall, spring | extirpated |
| Mainstem Sacramento River | fall, spring | fall, late-fall, winter, spring |
| Cow Creek | fall, spring | fall, late-fall, spring-hybrid (few) |
| Bear Creek | fall | fall (occasional years) |
| Battle Creek | fall, winter, spring | fall*, late-fall, winter*, spring |
| Paynes Creek | NI | fall (intermittent) |
| Antelope Creek | fall, spring | fall, late-fall, spring-hybrid |
| Mill Creek | fall, spring | fall, late-fall (occasional), spring |
| Deer Creek | fall, spring | fall, late-fall, spring |
| Big Chico Creek | fall, spring | fall, late-fall, spring-hybrid |
| Butte Creek | fall, spring | fall, late-fall, spring |
| Feather River | fall, spring | fall*, late-fall (occasional), spring-hybrid* |
| Yuba River | fall, spring | fall, late-fall, spring-hybrid (remnant) |
| Bear River | fall | none (occasional fall-run fish) |
| American River | fall, spring, probable late-fall | fall* |
| Coast Range: | | |
| Clear Creek | fall, spring | fall, late-fall, spring-hybrid |
| Cottonwood Creek | fall, spring | fall, late-fall, spring-hybrid |
| Elder Creek | NI | fall (intermittent) |
| Thomes Creek | fall, spring | fall (intermittent) |
| Stony Creek | fall, spring | fall (intermittent) |
| Cache Creek | fall[e] | extirpated |
| Putah Creek | fall[e] | fall (intermittent) |
| San Joaquin River Basin and Eastside Delta | | |
| Cosumnes River | fall | fall |
| Mokelumne River | fall, spring | fall* |
| Calaveras River | probable fall[f] | fall (occasional years) |
| Stanislaus River | fall, spring | fall |
| Tuolumne River | fall, spring | fall |
| Merced River | fall, spring | fall* |
| Upper San Joaquin River | fall, spring | extirpated |
| Kings River (and Tulare Lake) | fall, spring | extirpated |

[a] Small tributaries in which few salmon have been observed are not listed (e.g., Ash, Ink, Salt, Craig creeks in the Sacramento River basin; Kano 1998).
[b] Based primarily on Clark (1929), Fry (1961), Yoshiyama et al. (2000), Kano (1998). Only runs for which documented records exist are listed. Some streams probably had more runs than indicated. For example, Fry (1961:59) stated, "In addition to the winter run fish there are some very late fall run fish which enter most of the Central Valley salmon streams in the winter and spawn almost immediately"; those latter fish possibly included both fall-run and late-fall-run fish as currently defined.
[c] Runs that were present about 1990 or later (based on Reynolds et al. (1993), Kano (1998), and R. Painter, CDFG, pers. comm.). "Spring-hybrid" denotes hybrids beween the spring and fall runs. Asterisks (*) denote stocks that have been heavily supported by hatcheries located on the respective streams.
[d] Includes Hat Creek (a formerly productive salmon stream) and other small tributaries of the Pit River.
[e] Chinook salmon apparently entered these streams in all but the driest years, sometimes in large numbers. Shapovalov (1947) reported "considerable numbers" of chinook salmon in Cache Creek during the winter of 1937-1938.
[f] An unidentified seasonal run historically existed in the Calaveras River "on an irregular basis" (Reynolds et al. 1993:VII-115)—which almost certainly was the fall run. In addition, there was an unusual "winter run" during the 1970s (Reynolds et al. 1993; USFWS 1995), which we do not regard as an indigenous natural run because the Calaveras River (a low-elevation stream) originally did not have year-round conditions suitable to support the native winter run (sensu Vogel and Marine 1991, Fisher 1994, and Yoshiyama et al. 1998). That stock probably established itself as a result of, and was maintained by, coldwater releases from New Hogan Reservoir, but it was evidently later extirpated by unfavorable environmental conditions.

that the salmon runs had been severely affected by human activities long before then (Yoshiyama et al. 1998). Large-scale physical disruptions of Sierra Nevada and Cascades watersheds and intensive commercial fishing pressure on salmon had occurred for decades prior to 1900. By the late 1920s, when the first systematic qualitative assessment of Central Valley salmon was made (Clark 1929), the salmon runs in many streams were badly depleted. Indeed, reports of both the California Fish Commission and the U.S. Fish Commission acknowledged that even by the 1870s and 1880s, the formerly large salmon runs in several major Central Valley streams (e.g., Feather, Yuba, American, Stanislaus, and Tuolumne rivers) had been essentially extirpated as a consequence of hydraulic gold mining (CFC 1871; 1877; 1880) or greatly diminished by blockage by dams (CFC 1884).

Abundance estimates from early stream surveys summarized by Fry (1961) serve as approximate points of reference to compare with recent assessments of stock abundance (Table 2).

**Table 2.** Estimates for average spawning escapements of fall-run chinook salmon in major watersheds in the California Central Valley during recent periods of the 20th century. Data are from various sources.[a] Numbers are of adult spawners, except where indicated as pooled adults and grilse (A+G).[b] The numbers include both natural and hatchery spawners.[c] ND denotes no data available.

| Watershed | Period | | | |
|---|---|---|---|---|
| | 1950-1959[d] | 1953-1966 | 1967-1991 | 1992-1997 |
| Sacramento River Basin | | | | |
| Mainstem Sacramento River | 192,300 (A+G) | 179,000 | 77,000 | 40,900 (A+G) |
| Battle Creek | 17,200 (A+G) | 17,000 | 18,000 | 55,500 (A+G) |
| Minor tributaries[e] | ND | 18,000 | 5,000 | 6,000 (A+G) |
| Clear Creek | ND | 2,500 (A+G) | 1,700 (A+G) | 4,700 (A+G) |
| Cottonwood Creek | ND | 2,000 (A+G) | 2,300 (A+G) | ND |
| Antelope Creek | ND | 400 (A+G) | 200 (A+G) | ND |
| Mill Creek | 5,800 (A+G) | 2,900 (A+G) | 1,100 (A+G) | 1,100 (A+G) |
| Deer Creek | 2,600 (A+G) | 1,300 (A+G) | 400 (A+G) | 400 (A+G) |
| Upper sub-basin totals[f] | ND | 214,000 | 100,000 | 97,200<br>111,400 (A+G) |
| Feather River | 45,400 (A+G) | 41,000 | 47,000 | 46,000<br>56,300 (A+G) |
| Yuba River | 5,300 (A+G) | 14,000 | 13,000 | 11,100<br>14,200 (A+G) |
| American River | 21,400 (A+G) | 30,000 | 41,000 | 43,900<br>48,800 (A+G) |
| Basin total[g] | 281,600 (A+G) | 299,000 | 201,000 | 198,200<br>230,700 (A+G) |
| San Joaquin River Basin | | | | |
| Mokelumne River | 2,600 (A+G) | 2,000 (A+G) | 3,500 (A+G) | 6,300 (A+G) |
| Cosumnes River | 1,800 (A+G) | 1,500 (A+G) | 800 (A+G) | ND |
| Stanislaus River | 10,800 (A+G) | 7,300 (A+G) | 4,700 (A+G) | 600 (A+G) |
| Tuolumne River | 23,300 (A+G) | 18,100 (A+G) | 8,900 (A+G) | 1,800 (A+G) |
| Merced River | <1,000 (A+G) | 500 (A+G) | 4,800 (A+G) | 3,300 (A+G) |
| Basin total[g] | 39,500 (A+G) | 29,400 (A+G) | 22,700 (A+G) | 12,000 (A+G) |
| Central Valley total[h] | 321,100 (A+G) | >328,400 (A+G) | >223,700 (A+G) | 242,700 (A+G) |

[a] All estimates for the first period (1950-1959) were from Fry (1961). For estimates during the other three periods, data sources (in addition to our CDFG data) were Sacramento River basin, 1953-1966 and 1967-1991 (USFWS 1995) and 1992-1997 (PFMC 1998); estimates for the San Joaquin River basin, 1953-1997, were from CDFG data.

[b] Grilse (fish <24 inches fork length) included both males ("jacks") and females ("jills"). Grilse constituted, on average, 18% (range, 6%-36%) of the natural (in-stream) spawning escapements in the Sacramento River basin and 21% (range, 3%-74%) in the San Joaquin River basin (including the eastside delta tributaries) during 1970-1997 (PFMC 1998).

[c] Hatcheries have been operating on Battle Creek (since 1895), American River (1955), Feather River (1967), Mokelumne River (1965), and Merced River (1971) (Shebley 1922; Reynolds et al. 1993).

[d] The average escapements are for different subsets of years within 1950-1959 for different streams due to lack of data for certain years. For this period the fall-run estimates included the late-fall run (in the Sacramento River basin) and the winter run (mainstem Sacramento River only) (Fry 1961).

[e] Minor tributaries include other small streams in addition to those individually listed, not all of which were regularly monitored. The estimates shown on the minor tributaries row are based on incomplete data (from USFWS 1995), which may partly account for the discrepancy between the actual sum of individual estimates for the upper mainstem Sacramento River, Battle Creek, and minor tributaries (102,400 adults + grilse) and the tabled value for the upper Sacramento basin subtotal (111,400 adults + grilse; based on PFMC 1998) for 1992-1997.

[f] Sum of escapements for the mainstem Sacramento River (above the Feather River confluence), Battle Creek, and minor tributaries.

[g] For simplicity the basin totals shown in the table are the sums of the tabled values for the individual watersheds within the basin for the respective time periods. Those totals should be considered as approximations of the actual basinwide averages, which would be obtained more accurately by averaging the annual basinwide escapements within time periods.

[h] Central Valley totals are the sums of Sacramento River basin and San Joaquin River basin totals (adults plus grilse). The totals for 1953-1966 and 1967-1991 exclude an unknown numbers of grilse in the Sacramento River basin.

We include only data from the 1950s and later because the earlier spawning escapements were generally considered to have been seriously underestimated, except for some "reasonably accurate" but minimal tributary counts (Fry 1961). Fry's compilation probably was based on some of the same early CDFG data we used, but the extent of overlap is unknown and inclusion of Fry's data may serve as a rough check on our pre-1967 data. Our intent was to provide a concise tabulation of relative abundances of salmon during recent periods of this century, which reflect the trends in salmon stocks in major Central Valley watersheds. These abundance estimates are best viewed as approximations with wide confidence intervals but are still useful to show any major trends over recent decades. We did not attempt to evaluate the quality of the data or to standardize them (i.e., by applying "correction factors" to adjust for differences in sampling effort or accuracy) because the information is not available in sufficient detail to carry out such a formidable task. We assume that the data are of acceptable accuracy and comparability. In fact, the methods of data collection through most of the recent decades (i.e., since 1967 to at least 1991) have been consistent and relatively reliable (Mills and Fisher 1994), so we are reasonably confident of data quality. In any event, much of the original data form the basis for recent assessments of stock condition and time-trends as well as for current fishery management (including harvest regulation) and restoration programs (USFWS 1995; PFMC 1998). Therefore, the data should be made available for further scrutiny.

It did not appear useful to systematically apply statistical tests to the entire set of escapement estimates because of variable counting methods (i.e., techniques that varied over time and between watersheds, with widely different degrees of accuracy) and the inconsistent time series among streams in the earlier period (Fry 1961; Mills and Fisher 1994). Instead, we selectively conducted statistical comparisons for specific streams in which estimated escapements were large enough so that time-trends probably were less affected by sampling vagaries, and for which sufficiently long series of annual estimates were available. Statistical analyses also were constrained by the type of available data. Specifically, because a complete series of annual escapements for only adults was unavailable, we used combined escapements of adults and grilse in conducting statistical tests to detect changes between time periods (see below).

Fall-run chinook salmon has constituted the major salmon run in the Central Valley system during the recent historical era (post-1900) and probably was the most abundant run in earlier times (Stone 1874; Jordan 1892; Yoshiyama et al. 1998). We summarized abundance data on fall-run chinook salmon primarily for three periods: 1953–1966, 1967–1991 and 1992–1997 (Table 2). The delineation of those time intervals arises from historical circumstance. The key middle period (1967–1991) corresponds to the reference period for the AFRP-CVPIA. Salmonid and other anadromous fish stocks in the Central Valley are viewed, at least implicitly, to have been at low to moderate levels during that period and restoration goals were broadly defined with reference to those baseline population levels (USFWS 1995).

### *Sacramento River basin fall run*

We describe here the pattern of abundance during 1953–1966 and 1967–1991 based on adult spawners only because adults composed the bulk of the escapement data used in the AFRP-CVPIA restoration plan (USFWS 1995), which are condensed in Table 2. However, statistical comparisons between time periods were based on the more complete series of combined adult and grilse escapements (Table 3). The estimated annual spawning escapements include both natural and hatchery spawners.

For the entire Sacramento River basin, fall-run spawning escapements averaged close to 300,000 adults annually during 1953–1966 but decreased to about 200,000 during 1967–1991 (Table 2, USFWS 1995). Average escapements in the mainstem

**Table 3.** Results from statistical tests to detect differences between two time periods for average spawning escapements (adults plus grilse) and for escapement variability in major Central Valley watersheds. Spawning escapements are for combined natural and hatchery-produced fish.

| Watershed | Time periods compared | Comparisons of escapements[a] averages | variances[b] |
|---|---|---|---|
| Sacramento River Basin | 1953-1966 vs. 1967-1991 | P<0.02 | P<0.002 |
| Upper mainstem Sacramento River[c] | 1953-1966 vs. 1967-1991 | P<0.001 | P<0.002 |
| Battle Creek | 1953-1966 vs. 1967-1991 | ns | P<0.05 |
| Feather River | 1953-1966 vs. 1967-1991 | ns | P<0.05 |
| Yuba River | 1953-1966 vs. 1967-1991 | ns | P<0.05 |
| American River | 1953-1966 vs. 1967-1991 | P<0.05 | ns |
| San Joaquin River Basin | 1953-1966 vs. 1967-1991 | ns | ns |
| Mokelumne River | 1953-1966 vs. 1967-1991 | ns | P<0.01 |
| Cosumnes River | 1953-1966 vs. 1967-1991 | ns | ns |
| Stanislaus River | 1953-1966 vs. 1967-1991 | ns | P<0.01 |
| Tuolumne River | 1953-1966 vs. 1967-1991 | ns | P=0.01 |
| Merced River | 1954-1966 vs. 1967-1991 | P< 0.01 | P<0.001 |

[a] Based on t-test for equality of means and F-test for equality of variances (Sokal and Rohlf 1995). P values are given for significant outcomes (P≤ 0.05); ns denotes nonsignificant outcomes (P> 0.05).
[b] In comparisons for which variances were significantly different between time periods: greater escapement variability occurred during the earlier time period (1953-1966) in the entire Sacramento River basin and upper mainstem Sacramento, Feather, Yuba, Stanislaus, and Tuolumne rivers; in contrast, greater escapement variability occurred in the later time period for Battle Creek and the Mokelumne and Merced rivers.
[c] Above Red Bluff Diversion Dam.

Sacramento River correspondingly dropped from 179,000 to 77,000 adults annually (Table 2; USFWS 1995), but adult escapements in the major tributaries either changed relatively little (Battle Creek, Yuba River) or even increased (American and Feather rivers) (Table 2). The increases in the major tributaries apparently were due to increased hatchery production, except possibly in the Yuba River (tributary to the lower Feather River).

In Battle Creek there was a slight shift in the proportions of adult fish spawning in the stream ("natural" spawners) and those returning to Coleman National Fish Hatchery, averaging 9,000 in-stream and 8,000 hatchery-return adult spawners annually from 1953–1966 versus 8,000 in-stream and 10,000 hatchery-return adults in 1967–1991 (USFWS 1995). In the American River, average annual numbers of in-stream adult spawners (an unknown fraction of which were hatchery-produced) increased from 19,000 to 32,000 between the two periods while adults returning to Nimbus Hatchery dropped from 11,000 to 9,000 (USFWS 1995).

We also summarized fall-run escapements for individual small tributaries in the upper Sacramento River basin (under "minor tributaries"; Table 2). Those streams are notable because despite their size they each formerly supported substantial salmon runs and, together with other small streams, may have contributed a sizable fraction of the historical salmon production in the basin. Although the minor tributaries collectively showed a drop in salmon abundance between 1953–1966 and 1967–1991, individual streams had different trends. The three eastside streams (Antelope, Mill, and Deer creeks) had considerably lower average annual escapements during the later period—ranging from 30%–50% of the levels in 1953–1966—while the two westside streams showed either a modest decrease (Clear Creek) or a slight increase (Cottonwood Creek) in average annual escapements.

Estimated escapements for the slightly earlier, overlapping period 1950–1959 (from Fry 1961) also are shown (Table 2). Those estimates presumably are for adults and grilse combined because the two stages were not distinguished in the original counts. Grilse constituted, on average, 18% of the total spawning escapements in the Sacramento River basin and 21% in the combined San Joaquin River basin and delta eastside streams during 1971–1997 (based on PFMC 1998). Discounting the contribution of grilse, Fry's earlier numbers roughly equal the average adult escapements observed during 1953–1966 in the mainstem Sacramento River, Feather River, and Battle Creek, but they appear substantially lower for the American and Yuba rivers.

For 1992–1997, we did not conduct statistical comparisons with preceding periods because of the small number of years in the recent period. However, qualitative comparisons with earlier escapement levels are instructive. Overall annual escapements during 1992–1997 in the Sacramento River basin (average, 198,200 adults) approached the 1967–1991 levels (average, 201,000 adults). Recent annual runs in the upper Sacramento River and smaller tributaries (above the Feather River confluence) collectively have averaged 97,200 adults—comparable to the 100,000 adults for 1967–1991. The major tributaries of the lower basin (American, Feather, and Yuba rivers) likewise showed relatively little change in average escapements between the two periods. However, closer examination of annual adult escapements during 1992–1997 reveals a substantial recovery from very low levels in the early 1990s—i.e., between 1992–1994 and 1995–1997 average escapements increased by 159% (from 54,200 to 140,100 adults) in the upper Sacramento River basin, 66% (34,600 to 57,400) in the Feather River, 192% (5,700 to 16,500) in the Yuba River, and 179% (23,200 to 64,600) in the American River (based on PFMC 1998). Those increases reflect in large part the transition from drought years (1988–1992) to wet years in California.

## *San Joaquin River basin fall run*

In the San Joaquin basin tributaries, including the Mokelumne and Cosumnes rivers on the eastside Sacramento-San Joaquin Delta, average annual spawning escapements of combined natural and hatchery spawners (adults plus grilse) showed various changes between 1953–1966 and 1967–1991: a 75% increase in the Mokelumne River; decreases of 35%–51% in the Cosumnes, Stanislaus, and Tuolumne rivers; and more than 780% increase in the Merced River (Table 2). However, only in the Merced River was the change in average escapements statistically significant (Table 3). The pronounced increase in the Merced River was due to extremely low in-river escapements during most of the 1950s (<500 spawners in at least 6 years of that decade; Fry 1961) and through the 1960s (average, 240 fish), which rebounded to higher levels in the 1970s–1980s. The recovery was made possible by increased streamflows (starting in 1970) for the migration and spawning periods and by Merced River Hatchery operations which contributed roughly 20% of the annual escapements during 1970–1994 (USFWS 1995). During the 1960s and early 1970s large numbers of juvenile salmon were planted in the Merced River from the Stanislaus River and Nimbus Hatchery (American River) (J. R. Goertzen and D. L. Evans, CDFG, 1965–1968 file memos; Menchen 1972; Chase 1975).

Overall, the abundance of the San Joaquin basin fall run during recent decades has markedly fluctuated in a roughly cyclical pattern (USFWS 1995; Figure 2) and the likelihood of extirpation of the stock(s) is especially great during the low phases. The apparent cyclicity does not necessarily mean that the abundances are driven by natural factors (i.e., oceanographic or weather conditions), as appears to be the case for chinook

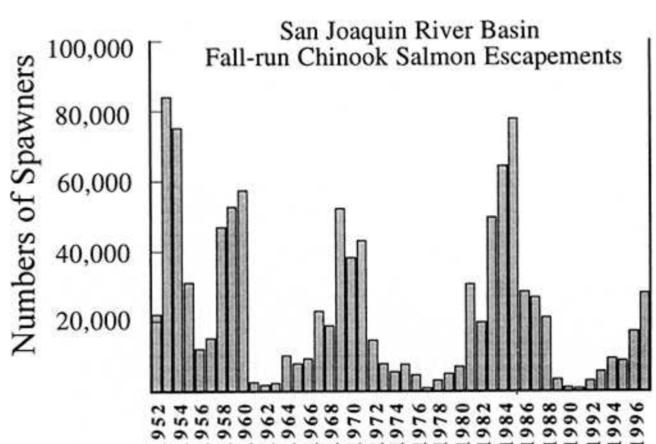



**Figure 2.** Annual spawning escapements of combined natural and hatchery fall-run chinook salmon in the San Joaquin River basin (including the Mokelumne, Cosumnes, Stanislaus, Tuolumne, and Merced rivers) during 1952-1997.

and other salmon species on a broader spatial scale (Pearcy 1992; Beamish and Bouillon 1993; Hare et al. 1999), because streamflows within the San Joaquin River basin have been highly variable and drastically affected by human activities (Clark 1929; Hallock and Van Woert 1959; Reynolds et al. 1993). Also, repeated population bottlenecks (i.e., low phases) undoubtedly have eroded the genetic diversity of fall-run salmon in this basin, and further genetic homogenization may have resulted from the increased hatchery production.

Recently, estimated annual spawning escapements in the San Joaquin basin tributaries have substantially increased, particularly since the early 1990s when there were a few hundred (in the Mokelumne and Stanislaus rivers) or even less than 100 spawners (Merced and Tuolumne rivers; USFWS 1995). Despite this upswing, average annual escapements during 1992–1997 in the San Joaquin River basin and delta eastside tributaries in aggregate have been slightly above 12,000 spawners (PFMC 1998), or about 4% of the total for the Central Valley system. In general, the percentage contribution of these tributaries to the Central Valley fall run has been relatively minor and highly variable though the last half-century: 11% (1950s), 6% (1960s), 6% (1970s), 12% (1980s), and 3% (1990s).

## *Other seasonal runs*

In sharp contrast to the fall run, which remains relatively numerous despite a general decline from pre-1967 levels, the winter, spring and late-fall Central Valley runs have precipitously declined in recent decades (Table 4; USFWS 1995; Yoshiyama et al. 1998). Reduction of the spring run from very high abundance levels in the 19th century has been especially severe (Yoshiyama et al. 1998). We mainly note here that the three less-numerous runs recently have been at such low population levels that their futures are uncertain (Moyle et al. 1995; Botsford and Brittnacher 1998; Yoshiyama et al. 1998). The winter chinook run is listed as endangered under both state and federal endangered species statutes (Williams and Williams 1991; NMFS 1994), and although the spring run seems to be in somewhat better condition, a major portion of it has been hybridized with the fall run (CDFG 1998; Yoshiyama et al. 1998). Central Valley spring-run populations that show the "true" spring-run life history timing (Fisher 1994; USFWS 1995) and that remain genetically distinct from the fall run (NMFS 1999) occur mainly in three small streams (Deer, Mill, and Butte creeks) within the Sacramento River basin. Those three sub-populations together averaged about 2,500 fish annually during 1967–1991 (USFWS 1995) and 5,616 fish during 1992–1999. Each of the sub-populations declined through much of the past half-century, but their downward trends either have leveled off or reversed during the 1990s (Table 5; NMFS 1999). In addition, there is a large hatchery-sustained "spring-run" stock in the Feather River comprising fish of mixed spring-run and fall-run ancestry (CDFG 1998; Yoshiyama et al. 1998). Even including spring-fall hybrids, the putative spring run in the Sacramento River basin altogether averaged about 14,700 adults annually during 1967–1991 (including an average 1,200 adults returning to the Feather River Hatchery) (USFWS 1995) and 9,700 adults during 1992–1998 (PFMC 1999). The Central Valley spring run was listed in 1999 as a threatened species under the federal Endangered Species Act (ESA) (NMFS 1999) and was previously listed as threatened by the California Fish and Game Commission. It is nonetheless likely that the spring run can be restored to viable naturally-sustained levels because concerted management efforts in the upper Sacramento River basin have focused on the spring run and surprisingly high numbers of spring-run spawners have occurred recently in some tributaries (i.e., in 1998, ~1,900 fish in Deer Creek and ~20,200 in Butte Creek).

The late-fall run has fared somewhat better than the winter and spring runs, numbering 5,000–9,400 adult spawners annually (average, 6,700) during 1990–1994 (PFMC 1998), although data on spawning escapements have been unavailable for the most recent years. Yet, late-fall-run escapements decreased substantially in recent decades, from an annual average of 35,000 adults in the late-1960s (USFWS 1995) to less than 10,000 adults during 1976–1990 (PFMC 1998), and the run's uncertain

**Table 4.** Average adult escapements of the late-fall, winter, and spring chinook salmon runs in the upper Sacramento River basin[a] during 1971-1997 (based on PFMC 1998). Numbers are combined natural and hatchery spawners. Ranges are given in parentheses. ND denotes data not available.

| Period | Average Adult Escapements[b,c] Late-fall run | | Winter run | | Spring run[d] | |
|---|---|---|---|---|---|---|
| 1971-1975 | 17,700 | (ND) | 22,500 | (ND) | 5,100 | (ND) |
| 1976-1980 | 10,400 | (ND) | 13,000 | (ND) | 8,500 | (ND) |
| 1981-1985 | 7,600 | (4,100-12,900) | 5,100 | (800-18,300) | 10,400 | (3,700-21,000) |
| 1986-1990 | 10,300 | (6,600-15,700) | 1,300 | (400-2,000) | 7,300 | (4,600-14,500) |
| 1991-1997[e] | 6,700 | (5,000-9,400) | 600 | (100-1,300) | 2,500 | (1,000-8,600) |

[a] The Sacramento River and tributaries upstream of Red Bluff Diversion Dam (river mile 243).
[b] In addition to the adults tabulated, grilse composed averages of 15% of the late-fall, 22% of the winter, and 23% of the spring runs during 1971-1997 (PFMC 1998).
[c] Statistical comparisons of adult spawning escapements for the three minor runs in the entire Sacramento River basin during 1967-1979 and 1980-1997 indicated significant changes in average annual escapements between those two periods for the late-fall and winter runs ($P< 0.002$, Wilcoxon test; Sokal and Rohlf 1995) but not for the spring run ($P> 0.20$). Average annual escapements were: late-fall run, 22,000 fish (1967-1979) and 9,100 fish (1980-1997); winter run, 42,200 and 2,400 fish; spring run, 14,500 and 12,000 fish.
[d] Including spring-fall hybrids, the average numbers of spring-run adults in the upper Sacramento River basin, Feather River, and minor tributaries (Mill, Deer and Butte creeks) during 1967-1991 totaled approximately 25,500 fish (USFWS 1995). Putative spring-run fish (mainly spring-fall-run hybrids) that entered the Feather River watershed spawned primarily at the Feather River Hatchery (PFMC 1998).
[e] Average estimates in the last row are for 1991-1994 for the late-fall run and 1991-1997 for the winter and spring runs.

population trend is considered "of special concern" (Moyle et al. 1995). The late-fall run was recently evaluated as part of the fall run for proposed ESA listing and it was determined that the combined Central Valley fall and late-fall runs presently did not warrant formal protection, although both runs remain under consideration as candidate species (NMFS 1999).

## Hatchery Production

Hatchery production of chinook salmon in the Central Valley region has become increasingly significant in supporting ocean harvests and in maintaining spawning escapements to some major streams (Table 6; USFWS 1995; PFMC 1998), but the effects of hatchery output on the natural sustainability of salmon and steelhead stocks is an issue of concern for salmonid conservation (Busby et al. 1996; Myers et al. 1998; NMFS 1998b). Almost all Central Valley streams with large spawning escapements during recent decades have production hatcheries located on or near them (USFWS 1995; Myers et al. 1999 (QUERY: 1998?)). Average hatchery contributions to the total estimated Central Valley salmon production (escapements plus ocean catch) have steadily increased throughout the decades: close to zero in the 1950s, less than 3% in the 1960s, 24% in the 1970s, and 38% during 1980–1985 (Fisher et al. 1991). Including in-river harvest in the production estimates, hatchery output contributed an average of 32% of the Central Valley salmon produced in the 1970s and 37% during 1980–1991 (USFWS 1995).

In the Sacramento River basin, which accounted for 92%–99% of the annual fall-run adult escapements to the Central Valley during 1990–1997, fish returning to the hatcheries constituted an average 20% of the adult spawning escapements (based on PFMC 1998). However, because hatchery-produced fish also may spawn "naturally" (i.e., in-river), the actual hatchery contributions to spawning escapements in some tributary watersheds may reach much higher levels. Based on statistical relationships between environmental and management variables and the recapture rates of hatchery-produced salmon, Dettman and Kelley (1987) estimated that an average 78% of annual escapements in the Feather River and 87% in the American River during 1978–1984 were hatchery-produced, although much lower estimates of hatchery contributions (i.e., 26%–29%) in those rivers have been suggested (Myers et al. 1998). During 1967–1991, estimated hatchery-produced portions of the fall run in individual streams reportedly were: 40% in the mainstem Sacramento River; 90% in Battle Creek; 40% each in the Feather, American, and Mokelumne rivers; and 20% in several minor tributaries (i.e., Butte, Deer, Mill, Antelope, Cottonwood, and Clear creeks) (USFWS 1995). We cannot evaluate the validity of those estimates, but the collective view of regional fisheries workers clearly indicates that hatchery production has substantially contributed to, and currently comprises a large percentage of, naturally spawning fall-run stocks in the Sacramento River basin (USFWS 1995). In the San Joaquin River basin, hatchery production of fall-run salmon in the Merced River is assumed to have been about 10% of total production in that stream for the past several decades (USFWS 1995). This is most likely a severe underestimate of the actual overall hatchery influence because of the small numbers of in-river spawners in some years and the relatively large returns to the Merced River Hatchery, particularly during the mid-1970s and early 1990s (USFWS 1995).

For the late-fall run, hatchery contributions have been relatively limited (compared to the fall run) and mainly restricted to one hatchery (Myers et al. 1998). The hatchery component of late-fall-run production during 1967–1991 is estimated to have been 90% in Battle Creek but only slightly above 8% in the mainstem Sacramento River, based on the assumption that the average number of hatchery-produced late-fall-run fish that spawned in-river was equal to the number that spawned at Coleman National Fish Hatchery (USFWS 1995). However, the validity of that assumption is unknown.

The increased reliance on hatchery production to maintain a major part of the Central Valley spring run is reflected by progressively greater spawning escapements over time in the Feather River, where the putative spring run (i.e., a spring-fall hybrid run) is composed primarily of spawners at the Feather River Hatchery (PFMC 1998). Numbers of hybrid adults returning to that hatchery averaged 400 fish during 1971–1980, 2,200 during 1981–1990, and 3,500 in 1991–1997 (PFMC 1998). However, the genetic distinctiveness of the spring run in Mill, Deer, and Butte creeks apart from the Feather River "spring run" indicates that spring-run fish in those three streams have been little influenced by Feather River Hatchery production (NMFS 1999).

Five salmon hatcheries now operate in the Central Valley system: Coleman National Fish Hatchery on Battle Creek (started in 1943), replacing the older Battle Creek Hatchery that operated during 1895–1945 (Cope and Slater 1957; Fry 1961), Feather River Hatchery (since 1967), Nimbus Fish Hatchery on the American River (1955), Mokelumne River Fish Hatchery (1965), and Merced River Fish Hatchery (1971). Even in streams where no hatcheries are located, hatchery-derived salmon may compose substantial fractions of the spawning stocks due to experimental releases of hatchery-

**Table 5.** Average spawning escapements of spring-run chinook salmon (adults plus grilse) in three small tributaries in the Sacramento River basin for periods within 1951-1999 (based on CDFG data). Those streams currently support the primary stocks of natural, unhybridized spring-run salmon remaining in the Central Valley drainage. Ranges of annual escapements are given in parentheses.

| Period | Average Escapements | | | | | |
|---|---|---|---|---|---|---|
| | Mill Creek | | Deer Creek | | Butte Creek | |
| 1951-1959 | 1,980 | (300-3,480) | 2,430 | (1,800-2,900) | 1,340 | (400-3,000) |
| 1960-1969 | 1,650 | (1,240-2,370) | 2,740 | (2,300-3,190) | 2,260 | (80-8,700) |
| 1970-1979 | 1,330 | (0-3,500) | 2,390 | (0-8,500) | 230 | (10-650) |
| 1980-1989 | 400 | (90-700) | 620 | (80-1,500) | 530 | (10-1,370) |
| 1990-1999 | 400 | (70-840) | 770 | (210-1,880) | 3,550 | (100-20,260) |

produced juveniles and natural straying of adults. In the Tuolumne River, for example, coded-wire-tagged salmon smolts (from Merced River Hatchery) released there for research purposes have returned as adults in increasing numbers since the early 1990s; those tagged adults composed roughly 14%–24% of the annual spawning escapements during 1995–1997 (when estimated escapements were 1,000–7,200 fish) and 17%–60% in prior years of very low escapements (i.e., <100 spawners in 1990–1991; 100–500 spawners in 1992–1994) (CDFG 1996; FERC 1998). Such estimated percentages for hatchery contributions to spawning escapements are minimal estimates because large numbers of unmarked hatchery salmon have been routinely released at various points within the Central Valley system; e.g., a combined total of close to a million unmarked hatchery juveniles released into the Merced River in 1995 and 1998 (T. J. Ford, Turlock and Modesto Irrigation Districts, pers. comm.). In fact, the full extent of hatchery contributions to total Central Valley spawning escapements is essentially unknown because only a small fraction (<10%) of the hatchery-produced salmon in the region are marked (A. Baracco, CDFG, pers. comm.).

Overall, salmon stocks in streams receiving large numbers of hatchery fish can be considered essentially hatchery-driven populations. Also, high levels of straying of hatchery-derived adults into non-natal streams commonly occurs. For example, large numbers of salmon produced by the Feather River and Nimbus hatcheries have contributed to the spawning run of the Mokelumne River, estimated to have averaged 37% of the spawners during 1969–1984 (FERC 1993). Straying of hatchery-produced fish into other portions of the Sacramento River basin was also considerable; during 1973–1984, on average about 38% of the returning fall-run adults originally produced by the Feather River Hatchery and 30% of those produced by Nimbus Hatchery strayed to other streams (Dettman and Kelley 1987). The high straying rate was largely attributed to planting of juveniles outside their "natal" (hatchery) streams (Dettman and Kelley 1987). Furthermore, extensive outplanting of hatchery fish was commonly conducted in Central Valley tributaries, and hatchery broodstocks often were of mixed origin; e.g., the Merced River Hachery received eggs from the American and Feather rivers (J. R. Goertzen, CDFG, 29 February 1968 file memo.; Myers et al. 1998).

Evaluations of the ecological and genetic repercussions of hatchery production in the Feather and American rivers and Battle Creek on the viability of whatever natural salmon stocks exist in neighboring streams and basinwide in the Central Valley have yet to be undertaken to any significant degree. The cumulative effects of long-term hatchery production on fitness components such as morphology, behavior and life-history traits in natural salmon populations are largely unknown and may be very difficult to determine. Indeed, Waples' (1999:18) admonitions warrant careful consideration: "...the power of even the most ambitious M&E [monitoring and evaluation] program to statistically detect a fish culture effect on traits such as these is likely to be very low ...[and] even if such an effect is detected, it will generally occur only after several (fish) generations of monitoring. This means that artificial propagation could substantially harm natural populations long before there is any reasonable expectation of being able to detect it." Furthermore, as Waples notes, "even if harm is found, there is no guarantee that effective remedial action will be taken"—e.g., the biological impacts may be irreversible, or political and fiscal constraints may preclude remediation.

An additional concern, but which is poorly understood, is that large-scale production of hatchery salmon may have deleterious effects on the ocean survival of naturally produced smolts during periods when unfavorable climate-ocean conditions limit the ocean carrying capacity for salmon (Beamish and Bouillon 1993; Beamish et al. 1997). Generally unfavorable conditions prevailed on the California-Oregon-Washington coast during 1976–1997 (Pearcy 1992; Mantua et al. 1997; Hare et al. 1999), and it would be unfortunate if the sustained high production by Central Valley hatcheries during that period inadvertently reduced the viability of natural salmon in California coastal waters.

## Conclusion

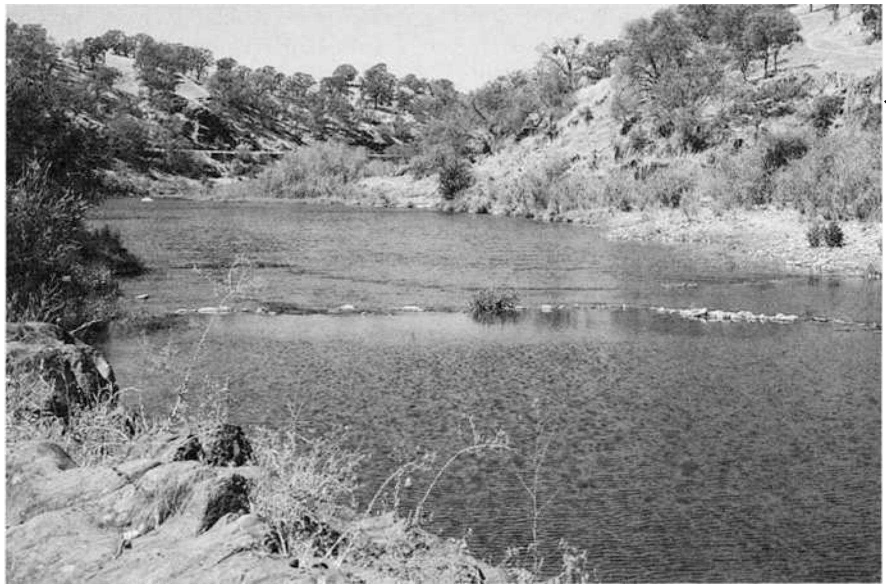
Our enumeration of past and currently extant stocks of chinook salmon in the California Central Valley shows that while

**Table 6.** Average adult spawning escapements of fall-run chinook salmon and hatchery contributions in major Central Valley watersheds during recent 5-year periods (based on PFMC 1998). Minimal hatchery contributions are shown by percentages of adult spawners that returned to local hatcheries. Hatchery-produced fish that spawned in-river are included in the numbers, so the actual percentages of hatchery fish present in each stream were higher than the tabulated values.

| Period | Upper Sacramento River basin[a] | | Feather River | | American River | | San Joaquin River basin | | Total Central Valley | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of adults | Percentage hatchery | Number of adults | Percentage hatchery | Number of adults | Percentage hatchery | Number of adults | Percentage hatchery | Number of adults | Percentage hatchery |
| 1970-1974 | 57,200 | 4 | 45,900 | 8 | 48,600 | 16 | 19,000 | 3 | 182,700 | 8 |
| 1975-1979 | 72,800 | 4 | 39,600 | 12 | 33,900 | 18 | 3,800 | 16 | 156,300 | 9 |
| 1980-1984 | 57,000 | 19 | 39,800 | 16 | 39,800 | 28 | 18,800 | 7 | 168,200 | 18 |
| 1985-1989 | 108,000 | 11 | 48,800 | 13 | 34,000 | 20 | 27,800 | 3 | 230,100 | 11 |
| 1990-1994 | 54,100 | 18 | 33,300 | 26 | 20,600 | 31 | 2,900 | 31 | 117,200 | 22 |
| 1995-1997[b] | 140,100 | 21 | 57,400 | 18 | 64,600 | 10 | 14,000 | 29 | 292,700 | 17 |

[a] Mainstem Sacramento River and minor tributaries above Red Bluff Diversion Dam.
[b] Only three years of data were available.

the majority of the principal streams that historically supported salmon runs continue to do so, almost half of them have lost one or more seasonal runs. Furthermore, several formerly highly productive streams have had all their salmon runs extirpated. We also summarized the current status of salmon stocks in major Central Valley watersheds relative to abundances during periods in the past half-century. Individual watersheds vary widely in the numbers of salmon they currently support and in the temporal trends of their stocks. The current overall abundance of chinook salmon in the Central Valley drainage is less than 75% of its level four decades ago—i.e., a drop from more than 320,000 spawners in the 1950s–1960s to ~240,000 spawners in the 1990s, counting both natural and hatchery fish. Ominously, this decrease has occurred despite large increases in regional hatchery production of salmon.



Peter B. Moyle

The Tuolumne River in the San Joaquin River basin is one of the southernmost streams in North America that supports chinook salmon. Historically highly productive, spawning escapements there reached 120,000–130,000 fish in the early-1940s (CFGC 1946; Fry 1961) and more than 40,000 spawners as recently as 1985. The great majority of spawners have been naturally produced because there is no hatchery on the Tuolumne River and, until recently, plantings of hatchery fish from other streams were intermittent.

Our assessment provides a frame of reference that reflects the former productive capacities of specific watersheds in the Central Valley. It also indicates how much more needs to be done in ongoing fishery and ecosystem management programs in order to fully revitalize the salmon stocks in the region. The broad goal mandated by the Central Valley Project Improvement Act to double natural runs of anadromous fishes over their 1967–1991 average abundances currently is far from being realized for both chinook salmon and steelhead, and that goal may remain beyond reach for the next decade or longer. With respect to the earlier goal set by the California legislature in 1988 to double salmon and steelhead runs by the year 2000, the restoration efforts to date have fallen well short—e.g., by more than 155,000 salmon spawners in 1997 in the Central Valley.

However, whether or not strict numerical targets for salmonid restoration are achieved within specified time periods may not be a true measure of success for recovery efforts because Pacific salmon populations in aggregate show considerable variability in abundance over long time-frames and broad spatial scales, much of which appears to be driven by several climate and ocean factors (Pearcy 1992; Mantua et al. 1997; Hare et al. 1999). The attainment of ambitious management goals such as doubling statewide salmon production may be stymied by unfavorable, large-scale environmental conditions (Mantua et al. 1997). Therefore, evaluations of restoration programs must consider the possible continued or recurring effects of unfavorable environmental factors within the Pacific Coast region (California-Washington) until long-term climate and ocean conditions improve, whether by a climatic "regime shift" or gradual cycling to a more productive state (Lawson 1993; Francis and Hare 1994; Hare et al. 1999).

The combined CALFED and AFRP-CVPIA programs (Box 1), in concert with local watershed efforts, represent an enormous institutional commitment to protect, restore and effectively manage Central Valley aquatic ecosystems, the more prominent elements of which include four seasonal runs of chinook salmon, a winter run of steelhead trout, and other large anadromous fishes (CALFED 1998a). This endeavor, when fully implemented, may be the most ambitious ecosystem restoration program ever initiated in the United States. A total of $880 million from state and federal sources will have been administered by CALFED since its inception up through the next several years (D. Daniel, CALFED, pers. comm.). CALFED funds already committed for 1995–1999 have equaled approximately $255 million (T. Ramirez, California Resources Agency, pers. comm.). In addition, AFRP-CVPIA expenditures exceeded $22 million during 1995–1999, to be followed by $6 million to $8 million annually thereafter (S. Spaulding, USFWS, pers. comm.). The total amount eventually spent on aquatic ecosystem restoration in the Central Valley will depend on the future availability of funds, but the costs very likely will be close to $1 billion up through year 2000.

From a simplified historical perspective, the fisheries component of the Central Valley ecosystem restoration programs may be viewed as the third concerted attempt at large-scale restoration of Pacific salmonids in North America. The first such attempt, started in the mid-1970s, was the hatchery-driven rebuilding of Alaska salmon runs which had been greatly reduced during previous decades by sustained overexploitation and other factors (Cooley 1963; Crutchfield and Pontecorvo 1969; Hare et al. 1999). That restoration attempt seemingly was a spectacular success and the means of achieving it were relatively simple—build hatcheries and, secondarily, effectively regulate harvests (Royce 1989; Holmes and Burkett 1996; Wertheimer 1997). Salmon production and harvests in the Alaska region increased to very high levels during the past two decades (Pearcy 1992; Baker et al. 1996; NMFS 1996). The overall recovery of Alaska salmon stocks undoubtedly was greatly facilitated by, if not largely the result of, improved ocean conditions (Pearcy 1992; Beamish and Bouillon 1993; Hare et al. 1999), but the effectiveness of the Alaskan restoration effort should not be summarily discounted, at least for pink and chum salmon which were the primary hatchery-produced species (Pearcy 1992; Beamish et al. 1997; Wertheimer 1997).

The second major restoration attempt, impelled with increased urgency since the mid-1980s, has been directed at the Pacific Northwest "salmon problem"—viz., the highly altered Columbia River system with its once legendary chinook, coho and sockeye salmon and steelhead runs (Netboy 1980; Chapman 1986; Schalk 1986). Considerable efforts have been expended on salmonid protection and management in that system with total costs amounting to more than $432.8 million by 1975 (Netboy 1980) and $1.3 billion during 1981–1991, 40% of which in that latter period was used for hatcheries (ISG 1996). Those efforts did not stem the overall decline of the salmonid stocks except for steelhead in the lower Snake River (Mighetto and Ebel 1994). While various elements of the restoration program are ongoing and eventually may yield substantive positive results, the aggregate outcome has been deemed an enormous failure bought at staggering cost (San Francisco Examiner and Chronicle, 17 August 1997; see also ISG 1996, 1999). Assuredly, the saga of the Columbia River salmonids has yet to be fully played out (compare Netboy 1980; Lang 1996; ISG 1999), but the recent bleak assessment of that second major restoration effort is a sobering lesson that great expenditures of money and effort do not necessarily lead to great success.

In the California Central Valley the ecological and economic backdrop to salmon and riverine management differs from that of the northern salmon realms, and it is unclear at this point how this third major restoration attempt will fare in the long run. There are multiple underlying causes for the current reduced state of Central Valley salmonid stocks which will require a multifaceted management strategy, but it certainly must employ habitat restoration, including adequate streamflows, as a cornerstone. The opportunities to restore Central Valley chinook salmon to a semblance of its former abundance and diversity have never been greater. With the rebuilding of salmon runs should come recovery of entire ecosystems and of many less-appreciated but equally endangered species—and a richer Central Valley natural environment ultimately may be a more wholesome home for humans. Given the heightened public concern and engagement in environmental issues, the large commitment of public funds and the annealing of political will to implement ecosystem and fisheries restoration in the region, and the currently imperiled status of numerous salmonid stocks, we dare not fail.

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