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Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California

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Abstract.—The Central Valley drainage of California formerly produced immense numbers of chinook salmon *Oncorhynchus tshawytscha.* Four seasonal runs occur in this system—fall, late-fall, winter, and spring runs. Differences in life history timing and spatial distribution enabled the four runs to use the drainage to the fullest possible extent and once made it one of the richest regions in the world for chinook salmon production. Native American fishers within the Central Valley drainage harvested chinook salmon at estimated levels that reached 8.5 million pounds or more annually. Native harvests, therefore, were roughly comparable to the peak commercial harvests taken later by Euro-American fishers, but whether or not native fishing depressed the productive capacities of the salmon populations to any substantial degree is not known. The commercial chinook salmon fishery in California started about 1850 in the San Francisco Bay and Sacramento–San Joaquin Delta region, where it formed the nucleus of the first major fishery conducted by Euro-American immigrants in the state. This fishery was one of the important early industries that supported the Euro-American settlement of the Central Valley region. The salmon fishery remained centered there until the early 1900s, when ocean salmon fishing began to expand and eventually came to dominate the fishery. Annual catches by the early Sacramento–San Joaquin in-river fishery commonly reached 4–10 million pounds and generally were higher than the total statewide catches made during the most recent several decades. The historical abundances of Central Valley chinook salmon before large-scale commercial exploitation and depletion of the runs cannot be determined with certainty. However, on the basis of early commercial catch records, the maximal production levels of the Central Valley chinook salmon stocks in aggregate may be conservatively estimated to have reached approximately 1–2 million spawners annually. Although substantial investment has been made by the state of California in managing the chinook salmon resource since the early years of the commercial fishery, chinook salmon have declined over the decades to small fractions of their previous numbers. The decline of the Central Valley chinook salmon resource was caused by several factors: overfishing, blockage and degradation of streams by mining activities, and reduction of salmon habitat and streamflows by dams and water diversions. Differences between the four chinook salmon runs in life history timing and habitat requirements partly account for their different population histories; the winter run is now threatened with extinction, the spring run recently has approached a similarly imperiled state, and the late-fall run has been at moderately low population levels for the past two decades. Only the fall run, in aggregate, can be regarded as secure, but it too has undergone substantial reductions in abundance. Fall-run spawner numbers were especially low in the San Joaquin River basin in recent years, and in Sacramento River basin streams their numbers have been heavily influenced by production of hatchery fish.

The rivers draining the Great Central Valley of California and adjacent Sierra Nevada and Cascade Range once were renowned for their production of Pacific salmon *Oncorhynchus* spp., which at times reached prodigious levels (Clark 1929; Skinner 1962). The Central Valley system, encompassing the Sacramento River drainage (24,000 mi^2) in the north and the San Joaquin River drainage (13,500 mi^2) in the south, historically has been the source of most of the Pacific salmon produced in California waters (CDFG 1950, 1955; Fry and Hughes 1951; Skinner 1962; CDWR 1984). Almost 150 years ago, Captain John C. Frémont re-

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corded in his memoirs (for 30 March–5 April, 1846): ‘‘Salmon was now abundant in the Sacramento. Those which we obtained were generally between three and four feet in length, and appeared to be of two distinct kinds. It is said that as many as four different kinds ascend the river at different periods. The great abundance in which this fish is found gives it an important place among the resources of the country’’ (Frémont 1848:22). Similarly, G. M. Waseurtz af Sandels, having visited Sutter’s Fort (the site of present-day Sacramento) in 1843, noted that ‘‘the addition to my catalogue of natural history was considerable, including three different and to me unknown varieties of salmon’’ (Van Sicklen 1945:71). Yet another visitor, the pioneer Edwin Bryant, observed in 1846 that the Sacramento River ‘‘abounds in fish, the most valuable of which is the salmon. . . . I have seen salmon taken from the Sacramento five feet in length. All of its tributaries are equally rich in the finny tribe’’ (Bryant 1849:272).

Chinook salmon *Oncorhynchus tshawytscha* are, and evidently always were, the only salmon species of consequence in the Central Valley system (Eigenmann 1890; Rutter 1908), although small numbers of other salmon species—chum *O. keta,* pink *O. gorbuscha,* sockeye *O. nerka,* and coho salmon *O. kisutch*—also have occurred occasionally in its rivers (Collins 1892; Rutter 1904a, 1908; Hallock and Fry 1967; Moyle et al. 1995). Pink salmon were once said to have ascended the Sacramento River ‘‘in tolerable numbers in October’’ (CFC 1880:53), although by the 1890s they were caught only infrequently there and were called ‘‘lost salmon’’ (Jordan and Evermann 1896). Anadromous steelhead *O. mykiss* apparently were common in Central Valley tributaries (USFC 1876; Clark 1973; Latta 1977; Reynolds et al. 1993), but records for them are few and fragmented, in part because they were not sought by commercial fishers. Therefore, a historical recounting of salmonid abundance, exploitation, and decline in the Central Valley region is essentially a history of the chinook salmon runs. Hereafter, reference to ‘‘salmon’’ is to chinook salmon, unless otherwise indicated.

The once-great Central Valley salmon runs have been diminished over time. Major populations in some tributary streams have been severely reduced, and in others, they are but a long-past memory. Earlier synopses of salmon abundances and the commercial fishery they supported were given by Clark (1929) and Skinner (1962); those studies are valuable points of reference but were incomplete. Furthermore, the population status of the chinook salmon runs and the circumstances affecting them have changed over the three decades since Skinner’s summary. An updated assessment and a more comprehensive recapitulation of the history of the Central Valley chinook salmon resource are needed.

In this paper, we present a historical overview of chinook salmon in the Central Valley drainage, particularly during the period of commercial exploitation from the mid-19th century to the present. We first briefly describe the four chinook salmon runs indigenous to this drainage and present a new synthesis of the data on their historical abundance and the commercial fishery. This synthesis is necessary because much of the data on California salmon abundances are sequestered in unpublished or obscure reports and have been subjected to varied and sometimes contradictory interpretations. We then briefly discuss the major factors that are known to have contributed to the overall decline of this formerly immense resource. We note especially the different historical trajectories shown by the four runs. Finally, we close with some perspectives on the significance of the decline of the Central Valley salmon runs and on aspects of past and future salmon management. Our purpose in this work is to bring attention to the former richness of this salmon resource, to provide a clear account of chinook salmon population trends in the Central Valley drainage, and to convey an understanding of how the resource has become so diminished that segments of it, including formerly major runs, now face extinction. A clearer understanding of what has been lost should help define the goals for restoration of the depleted salmon runs by providing a historical context for those goals. Thus, our telling of the story of the Central Valley chinook salmon hopefully will clarify not only the past, but also the future.

Methods: Data Sources

We relied heavily for data sources on the serial reports of the California State Board of Fish Commissioners (the predecessor of the California Department of Fish and Game) and the United States Fish Commissioner, both of which date back to the early 1870s, particularly for data on harvests of the early commercial salmon fishery. Miscellaneous sources (e.g., newspapers, personal journals) also provided information when there were gaps in coverage by the government agency reports. Our strategy was to use the original sources whenever possible rather than the synoptic tabu-

TABLE 1.—Generalized life history timing of Central Valley chinook salmon runs (based on Fisher 1994; USFWS 1995).

Run	Migration	Peak migration	Spawning period: Total	Spawning period: Peak	Juvenile emergence	Juvenile stream residency (months)	Smolt out-migration
Sacramento River basin							
Late-fall	Oct–Apr	Dec	Early Jan–Apr	Feb–Mar	Apr–Jun	7–13	Nov–May
Winter	Dec–Jul	Mar	Late Apr–early Aug	May–Jun	Jul–Oct	5–10	Nov–May
Spring	Mar–Sep	May–Jun	Late Aug–Oct	mid-Sep	Nov–Mar	3–15	Mar–Jun and Nov–Apr
Fall	Jun–Dec	Sep–Oct	Late Sep–Dec	Oct–Nov	Dec–Mar	1–7[a]	Mar–Jul
San Joaquin River basin (Tuolumne River)							
Fall[b]	Oct–early Jan	Nov	Late Oct–Jan	Nov	Dec–Apr	1–5[a]	Mar–Jun

[a] At high streamflows, an unknown proportion of fry may emigrate downstream within a few weeks of emergence to rear in the Sacramento–San Joaquin Delta (Rutter 1904a; Kjelson et al. 1982; USFWS 1995; FERC 1996). A small fraction of fall-run juveniles (roughly, <5% of the total number) remain in freshwater for over one summer and emigrate as yearling smolts in the following Nov–Apr period (USFWS 1995).

[b] In the San Joaquin River basin, spawning migration and spawning in the tributaries may occur later than in the Sacramento River basin, depending on streamflow conditions (T. J. Ford, Turlock and Modesto Irrigation districts, personal communication). The Tuolumne River fall-run exemplifies a naturally sustained population in the San Joaquin River basin (based on FERC 1996; Ford, unpublished data).

lations of Clark (1929) and Skinner (1962). We give page numbers for quotes and for some specific points from those sources following the year of the reference (e.g., Stone 1876b:446).

Data on recent (post-1940s) spawning escapements were collected largely by the California Department of Fish and Game (CDFG) and are referenced as unpublished data. Spawning escapement data for recent decades have been regularly published by the Pacific Fishery Management Council (PFMC), and we have drawn primarily from that source for data on the fall run. We have derived our escapement numbers for the spring, late-fall, and winter runs from CDFG files because the PFMC tabulations are less complete for those runs. The numbers from the two sources generally correspond closely for the years in which they overlap.

The catch data for all years must be regarded as approximations. While we have no way of producing confidence intervals around those estimates, we believe they represent the best available information and are adequate to reflect long-term trends in abundance. It is likely that the earlier estimates, especially those before 1900, are low because of underreporting of commercial fish catches and other vagaries of the fishery.

Central Valley Chinook Salmon: The Four Runs

Four seasonal runs of chinook salmon exist in the Central Valley system. Each run is named for the season of its upstream spawning migration and is defined by the combined timing of adult migration, spawning, juvenile residency, and smolt migration periods (Table 1; Fisher 1994; USFWS 1995).

Although the designation of four Central Valley seasonal runs is biologically valid, it overlooks the wide variation in life history timing that may occur within the individual runs. For example, adult upstream migration of fall-run chinook salmon in the San Joaquin River drainage peaks later (October–November) than the fall run in the Sacramento River drainage, at least in some years (Table 1; compare USFWS 1995; FERC 1996). Also, the upstream passage of each of the four runs in the Sacramento River extends over several months (Fisher 1994; USFWS 1995). As early as 1886, successive waves of what apparently were spring-run salmon were observed arriving during May–September in the McCloud River at the northern end of the Sacramento Valley (Green 1887a). There is also variation within the runs for juvenile instream residence periods. For example, spring-run juveniles vary in duration of residence both between streams (e.g., in Butte Creek versus Deer and Mill creeks; USFWS 1995) and within streams (i.e., out-migration as either recently emerged fry, smolts that are several months old, or yearlings; USFWS 1995). This variation within runs in life history timing leads to considerable temporal overlap between the four runs (USFWS 1995).

Furthermore, it is possible that the life history timing of one or more runs has been affected to some extent by the altered flow regimes that followed dam construction and increased irrigation diversions in certain watersheds. In Deer and Mill creeks, where salmon still have access to the upstream reaches that they historically used, the egg incubation and juvenile rearing periods for spring-run salmon extend longer than for spring-run fish that use lower-elevation and warmer reaches in other Sacramento tributaries (USFWS 1995; F. W. Fisher unpublished data). Thus, fish in Mill and Deer creeks may more closely represent the original timing of spring-run fish that formerly occurred in most streams. The shorter and earlier incubation, emergence, and rearing periods now observed for spring-run fish in other nearby streams perhaps reflects their life history adjustment to being restricted to lower elevations. Such life history evolution would be expected, given the considerable adaptive plasticity of Pacific salmon species (Taylor 1991; Healey and Prince 1995), but evidence that it has in fact recently occurred in Central Valley salmon populations has yet to be rigorously documented.

Presently, all four seasonal runs occur together only in the Sacramento River in the northern Central Valley, lending that river the distinction of having adult chinook salmon in its waters throughout the year (Stone 1883a; Rutter 1904a; Healey 1991; Vogel and Marine 1991). Fish in the fall and late-fall runs spawn soon after entering the natal streams, but spring-run and winter-run fish typically hold in their streams for up to several months before spawning (Rutter 1902, 1904a; Reynolds et al. 1993). Formerly, the runs also could be differentiated to some extent on the basis of their typical spawning habitats—spring-fed headwaters for the winter run, the upper tributary streams for the spring run, upper main-stem rivers for the late-fall run, and the lower rivers and tributaries for the fall run (Rutter 1902, 1904a; Fisher 1994). Different runs, temporally staggered but still broadly overlapping in timing, often occurred in the same stream (Vogel and Marine 1991; Fisher 1994).

Before widespread Euro-American settlement of California and the concomitant alteration of the landscape, most of the major tributaries of the Sacramento and San Joaquin rivers had both spring and fall chinook salmon runs (Figure 1). Streams that lacked adequate summer flows or holding habitat to support spring-run salmon had a fall run and, in some cases, a late-fall run. The fall run undoubtedly existed in all Central Valley streams (except in the southernmost Tulare Lake basin) that had sufficient flows during November and December, even if the streams were intermittent during other parts of the year. Generally, it appears that fall-run fish historically spawned in the Central Valley and lower-foothill reaches (Rutter 1902, 1904a) up to approximately 1,000-ft elevation and were probably limited in their upstream migration by their egg-laden and somewhat deteriorated physical condition, as well as by the low water levels in the rivers at that time of year. The spring and winter runs, in contrast, ascended to the higher-elevation reaches fed by snowmelt or coldwater springs (Stone 1874a; Rutter 1904a; Van Cleve 1945a). As noted by State Superintendent of Hatcheries J. G. Woodbury more than 100 years ago: ‘‘It is a fact well known to 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 1890:33). Spring-run fish generally needed to ascend to high enough elevations to avoid the excessive summertime water temperatures of the valley floor and lower foothills—at least to about 1,500 ft in the Sacramento drainage and probably variable elevations in the San Joaquin tributaries, depending on the amount of snowmelt. Winter-run salmon required spring-fed streams that provided coldwater flows for summertime spawning, incubation, and rearing (Slater 1963)—conditions fulfilled by the snowmelt and water from melting glaciers that percolated through the volcanic terrain around Mount Shasta and Mount Lassen in the northern Sacramento River drainage.

The San Joaquin River drainage includes a number of major streams fed by snowmelt that formerly provided the requisite conditions used by spring-run salmon for over-summer holding until the fall spawning season (CFC 1900), and it was there that the spring run may well have been originally most abundant. The area near Friant (the site of present-day Friant Dam, 561-ft elevation) on the upper San Joaquin River, for example, contained large pools where the spring-run fish congregated after their upstream migration in May to early July, awaiting the fall (CFGC 1921). 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 (Kahrl 1978; Fisher, unpublished data). Winter-run chinook salmon—unique to the Central Valley (Healey 1991)—originally existed in the upper Sacramento River system (Little Sacramento, McCloud, Pit, and Fall rivers) and in nearby Battle Creek (Stone 1876b; Scofield 1900; USFC 1900; Rutter 1904a; Need-

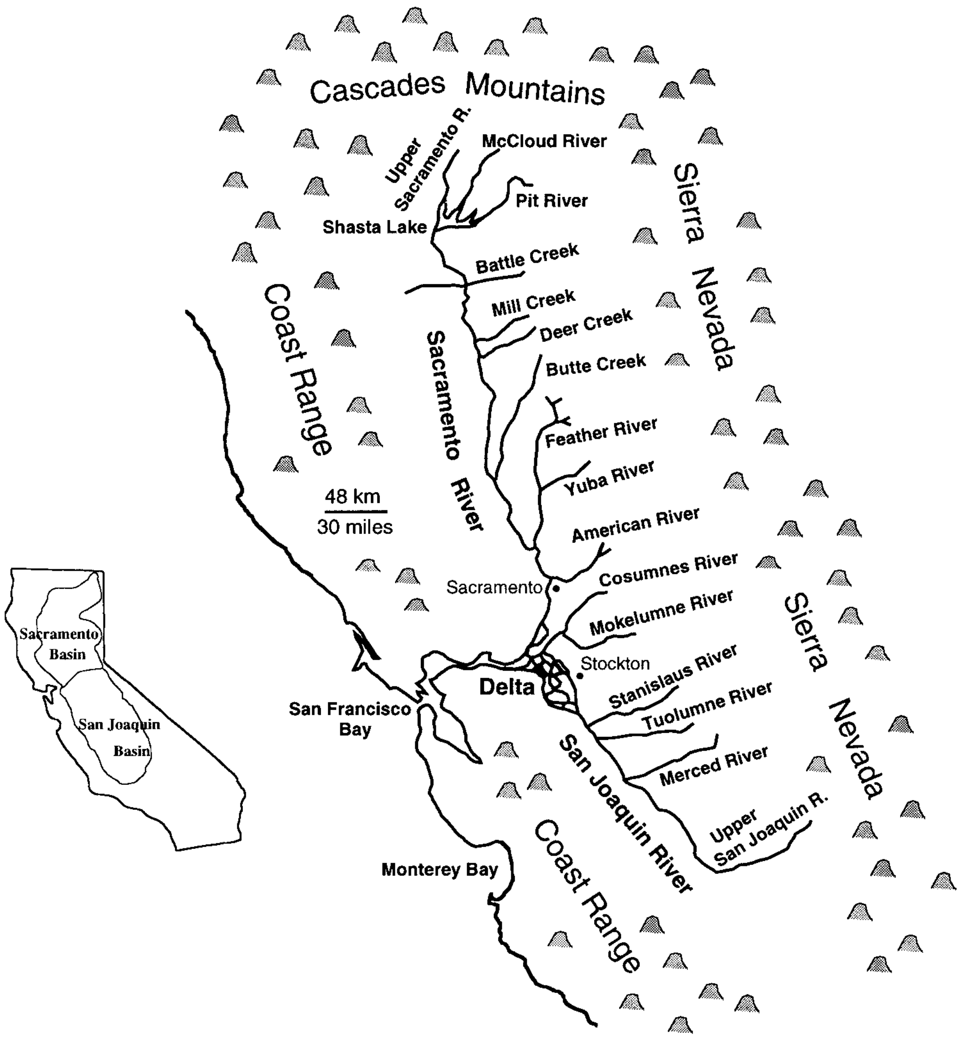

FIGURE 1.—Major historical salmon-producing streams of the California Central Valley drainage. Salmon runs are no longer extant in the McCloud, Upper Sacramento, and Pit rivers (i.e., above Shasta Lake) in the Sacramento River drainage nor in the San Joaquin River drainage upstream of the confluence of the Merced River. Only the lower main-stem reaches of the streams are shown.

ham et al. 1941), but there is no definite evidence that winter runs naturally occurred in any of the other major drainages before the development of hydroelectric and irrigation projects. The late-fall-run fish probably originally spawned in the main-stem Sacramento River and major tributary reaches now blocked by Shasta Dam and perhaps in the upper main-stem reaches of other Sacramento Valley streams (Fisher 1994), such as the American River (Clark 1929). There are also indications that late-fall chinook salmon may have migrated into the upper third of the main-stem San Joaquin River (Hatton and Clark 1942; Van Cleve 1945a; Fisher 1994).

The Salmon Resource and Fishery

Precommercial Era: Native Harvest

It is barely imaginable what salmon abundances in the Central Valley system might have been before commercial fishery records were kept and when all of the major spawning streams in the surrounding mountains were not despoiled by mining or blocked by dams. Some perspective on the magnitudes of the salmon runs before their intensive exploitation can be gained from run size estimates based on catch data for the peak decades (1870s–1880s and 1900s–1920s) of the commercial fishery. These estimates perhaps can be viewed as hypothetical lower bounds for salmon abundances in the period when only the native peoples were harvesting the runs. For the Sacramento River drainage alone, the chinook salmon runs in aggregate were estimated from commercial catch records (assuming a 1:1 catch-to-escapement ratio) to have averaged 600,000 fish a year, perhaps reaching as many as 800,000 to 1 million spawners during peak years of the commercial period before 1915 (Leidy et al. 1984). In the San Joaquin River drainage, total adult production (spawning runs plus ocean harvest) is said to have historically approached 300,000 fish (Reynolds et al. 1993). Gerstung (1971) suggested that historical run sizes in the Central Valley totaled 1–2 million spawners per year, noting that the more than 10 million pounds caught during 1880 by the commercial fishery within the delta alone amounted to roughly three-quarters of a million fish. A maximum production level approaching 2 million fish for the entire Central Valley was estimated by Fisher (1994).

Just as commercial fishers in the late 19th century slashed the population levels of salmon runs that migrated up the Sacramento and San Joaquin rivers, the native fishers before them harvested potential breeders. Hewes (1947, 1973) calculated that the harvest of Central Valley salmon by native peoples may have reached nearly 8.5 million pounds annually, based on estimated native population densities and inferred per capita consumption rates of salmon. However, that value is probably a minimal estimate because more recent determinations of Native American population sizes substantially exceed the early estimates used by Hewes (compare Cook 1955a, 1971; Hewes 1973; Ubelaker 1977; Thornton 1980), and the salmon harvests would have been correspondingly higher. Yet, did the magnitude of the native harvest have substantial impacts on the year-to-year abundance levels of the stocks? Cook (1943b:16) stated that after the decimation of Native American communities in the Central Valley by a malaria epidemic in 1832–1833, ‘‘the salmon increased because of the lack of fishing by the natives’’; however, that statement cannot be accepted literally. Cook’s inference of an increase in salmon evidently was based on the reminiscences of the pioneer George C. Yount (recorded by Reverend Orange Clark; Camp 1923). As he journeyed through the San Francisco Bay region to Sonoma in 1833, Yount observed that ‘‘the Deer, Antelope & Noble Elk held quiet & undisturbed possession of all that wide domain, from San Pablo Bay to Sutter’s Fort. . . . The wild geese, & every species of waterfowl darkened the surface of every bay, & frith, & upon the land, in flocks of millions. . . . The Rivers were literally crouded [sic] with salmon, which, since the pestilence had swept away the Indians, no one disturbed’’ (Camp 1923:52). Admittedly, the virtual absence of native fishers certainly would have allowed the spawning runs to remain in the rivers unharvested, as Yount had noted. However, it is not valid to infer from this passage alone, as Cook (1943b) evidently did, that salmon populations actually increased because of the temporary elimination of the native fishers. Yount made his observations in 1833, within a year after the epidemic (Camp 1923; Cook 1955b), but any salmon population increase resulting from the decreased fishing pressure during that year would not have been manifested for at least 3 years afterwards (the minimum generation time of chinook salmon)—1836 at the earliest. Yount remained at the Sonoma Mission until 1835 and then settled permanently in the Napa Valley in 1836, so it is unlikely that he actually saw any Central Valley salmon runs after 1833. Although the catastrophic reduction of native fishing populations in the Central Valley during the early 1830s might have led to the reported increase in salmon abundance soon afterwards (McEvoy 1986), to our knowledge there are no reliable records or testimonies that actually document any such increase.

In any event, the native peoples subsequently repopulated the Valley watercourses to various degrees (but see Cook 1955b), and they were again fishing for salmon by the time early non-Hispanic settlers, such as John Sutter, Theodor Cordua, and John Bidwell, established themselves (Wright 1880; Bidwell 1910; Gudde 1933). But the broader issue of the impact of native fishing remains. Undoubtedly, the great abundance of salmon available to immigrant fishers in the Sacramento and San Joaquin rivers during the initial period of the commercial fishery (1850s) reflected the concurrent reduction and eventual elimination of Native American fishing populations by the sudden influx of settlers and gold miners into the region. It is also possible that the high productivity of the early commercial fishery was in large part the legacy of the longer-term attrition of native peoples that started with the first Spanish inroads into the Central Valley during the late 18th century and that continued through the period of settlement by Euro-Americans from the United States (Cook 1939, 1943a, 1943b, 1943c, 1955a, 1955b, 1960; Heizer 1993). Such a sequence of events was posited to have been played out over the entire Pacific salmon region of North America following the entry of Euro-Americans (Hewes 1942, 1947, 1973). Rostlund (1952), however, strongly questioned this thesis, noting that the salmon had maintained their high productivity for 30–40 years (7–10 salmon generations), even under heavy commercial fishing, before large-scale ocean fishing and extensive disruption of spawning areas began. Rostlund contended that there was no evidence to show that Native Americans had seriously overfished western salmon streams, and he further suggested that the level of native fishing pressure probably enhanced the overall productivity of the fish resources. Chapman (1986) likewise suggested that the Columbia River chinook salmon and steelhead runs under aboriginal fishing pressure were actually larger than they otherwise would have been without native harvesting. The rationale for Chapman's suggestion was the form of the stock–recruitment relationship for Columbia River stocks—a ''hump-shaped'' Ricker curve showing density ''compensation''—in which excessive spawning escapement reduces subsequent recruitment (Ricker 1975; McFadden 1977). Furthermore, Schalk (1986) questioned whether any substantial reduction in overall harvests of Columbia River basin salmon stocks had even occurred following the decimation of resident native people along the lower Columbia River, noting that several counteracting processes may have operated to maintain the general level of native fishing pressure (e.g., movement of outlying native groups to fill the void, greater long-distance trading of dried salmon, increased harvests in the upper watershed areas).

In the California Central Valley region, where most Native American groups were characterized by a diverse diet compared with more northern and coastal salmon-dependent peoples (Kroeber 1925; Rostlund 1952; Baumhoff 1963; Jorgensen 1980), it is even less likely that they overfished and depressed the large salmon runs. It is revealing that in the McCloud River drainage, where the native McCloud Wintu people subsisted primarily on salmon and abided relatively undisturbed until the 1870s (Stone 1874a, 1878), the salmon nonetheless reportedly occurred in ''vast numbers. . . . Tens of thousands, not to say hundreds of thousands, which would perhaps be the nearer the truth'' (Stone 1876b:446). On the other hand, limited archaeological data suggest that the exploitation and availability of large anadromous fishes, relative to smaller freshwater fishes, in the upper Sacramento Valley may have decreased during the late Holocene (over approximately the past 4,000 years), possibly due to intensive resource use by indigenous human populations (Broughton 1994). On a cautionary note, however, the archaeological interpretation of salmon remains to infer time trends in salmon abundance is problematic because of the formerly widespread practice among Native American groups (both pre- and post-Contact) of pulverizing and consuming salmon backbones (e.g., among Central Valley groups: Dixon 1905; Curtis 1924; Kroeber 1925; Du Bois 1935; Aginsky 1943; Klamath River and coastal groups: Dixon 1907; Kroeber 1925; Aginsky 1943; Kroeber and Barrett 1962; other areas of North America: Rostlund 1952). Presently, neither Hewes' (1947, 1973) nor Rostlund's (1952) hypotheses can be rigorously evaluated, given the general lack of accurate information on prehistoric salmon abundances and levels of aboriginal fishing pressure. The fact remains, however, that the Central Valley system contained a tremendously productive chinook salmon resource before the 20th century, regardless of who was harvesting it.

Commercial Period: 1850 to the Present

The great abundance of salmon that formerly occurred in the Central Valley drainage is demonstrated by fishery records dating back to the late 19th century (Table 2; Clark 1929; Skinner 1962; Heimann and Carlisle 1970). The first major fishery involving non-Native Americans in California was for chinook salmon and was centered in the San Francisco Bay and Sacramento–San Joaquin Delta (Scofield 1954). The fishery was started about 1850 and was carried out initially with drift gill nets and fyke nets in the lower Sacramento and San Joaquin rivers and San Pablo Bay (CDFG 1949; Skinner 1962). State Fish Commissioner R. H. Buckingham (*Sacramento Bee,* 31 December 1885) and McEvoy (1986) credit New Englanders with initiating the salmon fishery, which thereafter came to be dominated by Mediterranean immigrants (Fisk 1905; McEvoy 1986). However, even before the Gold Rush brought a flood of immigrants—the prospective fishers among them—several non-Hispanic settlers, such as John Sutter and Theodor Cordua, were engaged in the salmon trade by the mid-1840s, the salmon being caught by Native American laborers bound (under Mexican law)

TABLE 2.—Estimated historical commercial harvests of chinook salmon in the Sacramento–San Joaquin rivers and delta and in the upper San Francisco Bay.[a] Most of the estimates (except for the years 1875–1880) are minimal values because shipments for the fresh fish market were reported only for the major dealers; generally, unknown quantities include those caught for personal consumption, amounts sold locally, and illegally harvested fish. See Table 3 for recent chinook salmon catch statistics. No data were available for years not listed.

Year[b]	Catch[c] (lb)	Year	Catch (lb)	Year	Catch (lb)	Year	Catch (lb)
1856	6,750,000	1892	3,484,049	1914[h]	>3,147,374	1936	949,179
1858	4,500,000	1893[i]	3,950,373	1915	4,547,321	1937	974,871
		1894[i]	4,494,618	1916	3,450,786	1938	1,668,376
1872	2,216,415	1895[i]	4,350,375	1917	3,975,487	1939	496,933
		1896[i]	3,276,587	1918	5,938,029	1940	1,515,588
1875[d]	5,098,781	1897[i]	3,979,397	1919	4,529,222	1941	844,963
1876[d]	5,311,423	1898	4,079,397	1920	3,860,312	1942	2,552,944
1877[d]	6,493,563	1899	6,458,959	1921	2,511,127	1943	1,295,424
1878[d]	6,520,768	1900[h]	>3,635,264	1922	1,765,066	1944	3,265,143
1879[d,e]	4,432,250	1901[h]	>6,701,824	1923	2,243,945	1945	5,467,960
1880[d]	10,837,400	1902[h]	>5,727,552	1924	2,640,110	1946	6,463,245
1881	9,600,000	1903[h]	>8,197,980	1925	2,778,846	1947	3,380,484
1882[f]	9,605,280	1904	8,233,148	1926	1,261,776	1948	1,939,801
1883[g]	10,545,672	1905[h]	>6,664,644	1927	920,786	1949[e]	899,090
1884[h]	>5,375,700	1906[h]	>5,942,996	1928	553,777	1950	1,202,890
1885[h]	>5,940,000	1907[j]	9,911,200	1929	581,497	1951	1,343,171
1886[h]	>2,593,800	1908[j]	8,801,750	1930	1,213,698	1952	738,081
1887	3,640,000	1909[j]	12,011,400	1931	941,605	1953	869,696
1888	6,622,978	1910[j]	11,056,600	1932	1,264,987	1954	900,961
1889	6,471,095	1911[h]	>2,477,428	1933	454,253	1955	2,320,746
1890	2,970,111	1912[h]	>3,588,304	1934	397,572	1956	1,139,585
1891	1,957,354	1913[h]	>5,311,444	1935	888,868	1957[k]	321,824

[a] Data are derived from the following sources for the years specified: for 1856 (Taylor 1860); 1858 (*Sacramento Union,* 1 January 1859); 1872 (Stone 1874b, 1876a); 1875–1882 (CFC 1879, 1882); 1883 (CFC 1884); 1887 (Skinner 1962); 1888, 1892 (CFC 1894); 1889–1891, 1897–1899, 1904 (Clark 1929); 1893–1896, 1907–1910 (CFGC 1910); 1915 (CFGC 1916); 1916–1957 (Heimann and Carlisle 1970).

[b] Catch records for the early years do not correspond exactly to calendar years. For the years 1875–1878, reported catches for the designated year covered the period from November 1 of the preceding year to October 31 of the designated year, and for years 1878–1879, they covered the period September 15 of the preceding year to August 1 of the designated year, reflecting the seasonal closures of the fishery (CFC 1879). Further changes in seasonal closures were instituted through the following decades (Clark 1929, 1940), thus causing variability in fishing pressure on the runs over time.

[c] Catches are of whole (ungutted) fish. ''Sacramento salmon'' were variously reported to average 12–23 lb in weight (Stone 1874a, 1883a; CFC 1880; Jordan and Gilbert 1887), but the usual weight was about 16 lb/fish (Stone 1884; Collins 1892; Jordan 1904; Cobb 1921); salmon weighing 40–50 lb, or more, were commonly caught (Stone 1874a; Jordan and Gilbert 1887).

[d] For the years 1875–1880, the reported catches were increased by 25% by the California Fish Commission to account for unreported catches upriver of Sacramento (on the Sacramento River) and Stockton (on the San Joaquin River) and for illegally harvested salmon (CFC 1879, 1880; CFGC 1910).

[e] Catches were limited in 1879 and 1949 by river fishermen's strikes (CFC 1879, 1880; CDFG 1950).

[f] Needham et al. (1941) reported a harvest of 12,000,000 lb for 1882 for the Sacramento River salmon fishery.

[g] The amount for 1883 includes 9,585,672 lb caught in the lower-river and delta fishery, plus an additional minimum of 60,000 fish caught above Sacramento City (CFC 1884) equivalent to 960,000 lb (at an average fish weight of 16 lb; Stone 1883a, 1884; Jordan 1904; Cobb 1921).

[h] Estimates are based on only the canned salmon pack (one case of 48 1-lb cans equivalent to 66 lb of whole fish [Collins 1892] or, on average, four fish [Jordan and Gilbert 1887]) and quantities (tierces) of ''mild-cured'' salmon (each tierce equivalent to 1,096 lb of whole fish; based on Collins 1892; CFC 1894; Cobb 1921). Data on the amounts of salmon sold fresh are unavailable.

[i] For the years 1893–1897, considerably higher estimates are obtained as follows. During that period, it was estimated that the San Francisco fish markets handled roughly 70% of the salmon sold fresh (CFC 1894, 1900). If the San Francisco receipts of salmon are increased to account for the additional 30% of the fresh salmon that were sold to ''interior consumers,'' and the amounts corresponding to the canned salmon pack are also added, the estimated Sacramento–San Joaquin harvests are as follows: (1893) 5,045,099 lb; (1894) 5,527,999 lb; (1895) 5,538,579 lb; (1896) 4,321,303 lb; (1897) 8,225,749 lb. These values are 23–107% (average, 43%) higher than the amounts given in the above table.

[j] Figures for 1907–1910 include the amounts of salmon packed (canned and mild-cured), sold fresh in San Francisco markets, and approximately 800,000 lb annually that were consumed locally in Sacramento and Stockton or shipped fresh to other states (CFGC 1910).

[k] The Sacramento–San Joaquin in-river fishery, which was the last commercial in-river salmon fishery in California, was terminated in September 1957 by state legislative action (CDFG 1958; Skinner 1962). The 1957 in-river salmon catch of 17,000 fish included a substantial contribution by coho salmon (which previously had not been taken in this fishery) due to returns from experimental stocking of coho salmon yearlings into the Sacramento River drainage during 1956 by the California Department of Fish and Game (CDFG 1958; Skinner 1962).

to those tutelary landowners (Gudde 1933; Hurtado 1983).

During the Gold Rush era, beach seines pulled by horses on the gravel bars of the rivers were also used, and catches were ''heavy'' (Scofield 1956). The salmon harvest for 1852 reportedly was 332,000 lb, worth US$49,800 (McEvoy 1986), and in June 1853, the first shipment of cured salmon was sent to Australia, which later became a major market for canned salmon (Bancroft 1890; Collins 1892). According to one early account (Taylor 1860:260), ''the number of salmon taken during the season of 1856 was estimated at four hundred fifty thousand, nearly four thousand per day. . . . The average weight is about fifteen pounds each, amounting in the aggregate to six million seven hundred and fifty thousand pounds.'' The fishery at that time was carried out during February–April and October–November, and the fishing grounds covered 50 mi of the Sacramento River, extending southward from a point 10 mi north of the city of Sacramento (Taylor 1860). Thus, spring, fall, and winter runs were exploited at that time. The *Sacramento Union* newspaper (1 January 1859) reported that the number of salmon ''taken in the vicinity of the city, during sixty days last Fall, was about 35,000,'' and that ''the whole number taken on the river during the present year, may be fairly set down at about 300,000.'' The article also noted that there were ''about sixty boats regularly out in the stream'' during the fishing season and ''from forty to sixty [salmon] to each boat is the yield per day in the best season. The average, throughout the seven or eight months of fishing, probably does not exceed twenty per day to each boat.'' The in-river fishery later expanded up the Sacramento River and its tributaries, as well as into the San Francisco Bay complex (primarily San Pablo and Suisun bays; Wilcox 1898; Skinner 1962). Based on the figures given by Stone (1874b:375, 1876a: 383), 94,090 fresh salmon were shipped down the Sacramento River to San Francisco in 1872 by riverboats of the Central Pacific Railroad Company, and another 19,671 fish were shipped fresh from Rio Vista. In addition, ''a large number'' of salmon were transported by sailing vessels, by steamers of other companies, and by other conveyances. Furthermore, ''about 25,000 salted salmon'' were shipped from the Sacramento River to San Francisco in the spring and ''about 9,000'' in the fall of that year (Stone 1874b:377, 1876a: 383). Thus, the number of fresh and salted salmon produced from the Sacramento River in 1872 easily exceeded 147,000 fish in aggregate from at

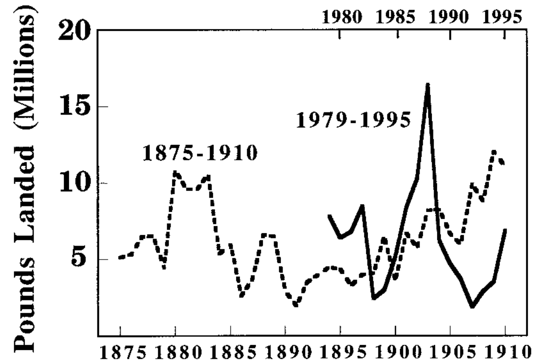

FIGURE 2.—Commercial harvests of chinook salmon for the Sacramento–San Joaquin in-river fishery during 1875–1910 and for the statewide ocean fishery in the recent period 1979–1995. Data sources are as in Tables 2 and 3.

least three of the runs—winter, spring, and fall. In March of that year, approximately 16,400 salmon (~300,000 lb) were sent fresh to San Francisco or salted locally, aside from ''other sources of outlet, which were considerable'' (Stone 1874a:180); that number would have comprised both spring-run and winter-run fish. In August 1872, at the time of year when salmon were ''cheapest and most abundant,'' 10,000 fresh (fall-run) salmon a week reportedly were sent to San Francisco from points on the San Joaquin and Sacramento rivers (Stone 1874a:197).

Records of commercial landings dating back to 1875 show that very high volumes of salmon were caught in the early documented decades of the fishery (Table 2; Figure 2). Recorded catches for the Sacramento–San Joaquin fishery during 1875–1910 were often 5–10 million pounds annually (averaging at least 7,180,000 lb) and exceeded 10 million pounds in 1880, 1883, 1909, and 1910. During 1883, in addition to the 780,405 salmon caught (amounting to 9,585,672 lb canned or sold fresh in markets), there were ''60,000 or more caught above Sacramento City'' (CFC 1884:4). A steady flow of fresh salmon went to the San Francisco fish markets; in 1893–1898, for instance, an average of 2,821,490 lb (range, 2,406,433–3,979,500 lb) of salmon were sent annually to the principal fish dealers in that city, as well as unrecorded quantities sent to the smaller dealers (CFC 1900). Collins (1892:162) reported that during the last 10 d in August 1888, the two canneries at Chipp's Island and Black Diamond (in the delta area) on some occasions ''handled as many as 18,000 salmon (more than 270,000 pounds) in a single day, and this notwithstanding they could not, on account of inadequate facilities for packing, receive many boatloads of fish that were offered.'' In later years, large quantities of salmon packed on ice were sent east or to Oregon. The California Fish Commission noted that for the fishing seasons in 1901 and 1902, ''thousands of fresh salmon are taken for cold-storage shipment, and sent to Eastern States. Tons are packed on ice and sent direct from our local dealers in San Francisco to the nearby States. It is a remarkable fact that as high as five tons per day have been sent into the State of Oregon'' (CFC 1902:15). During 1907–1910, the recorded annual salmon catch (based on the canned pack and fresh salmon shipments to San Francisco markets) ranged from 8 to 11.2 million pounds, excluding an additional volume of approximately ''800,000 pounds annually'' sent fresh to Oregon, Washington, and eastern states, or consumed locally (CFGC 1910:23).

The year-to-year rises and falls in commercial landings were not solely driven by the abundance of the salmon. Increased catches through the earlier decades of the fishery, for instance, were at least partly the result of greater fishing effort—from 100 boats and 200 fishers in 1872 to 459 boats and 907 fishers in 1899 and 842 boats and 1,490 fishers in 1909 (Clark 1929). At the height of the Sacramento–San Joaquin fishery in the early to mid-1880s, there were over 1,500 boats engaged in taking salmon and more than 3,000 salmon fishermen (CFC 1884, 1886). The low catch in 1879, conversely, was due to a fishermen's strike during which no fish were delivered to the canneries for 3 weeks during the peak of the fishing season (CFC 1880; Smiley 1884). However, the catches over the history of the in-river fishery probably largely reflected the salmon abundances because the fishermen and buyers generally sought to exploit the salmon supply to the fullest possible extent (Clark 1929; Fry and Hughes 1951).

It is noteworthy that the high catches in the early part of the commercial period (1870s and early 1880s) overlap with, or slightly postdate, the time when hydraulic gold mining in Sierra Nevada streams had already destroyed much salmon habitat (CDWR 1984). It was known by the early 1870s that the salmon runs had begun to decline. The California Fish Commission (CFC 1871:44) reported that ''formerly salmon were plenty and largely caught by the Indians in Feather River, in the Yuba, and in the American; but of late years they have ceased to visit these rivers.'' Stone (1874a:176) stated that the Upper Sacramento, McCloud, and Pit rivers were the only major salmon-producing streams in the Sacramento drainage—the salmon having ''abandoned'' the American and Feather rivers altogether. Stone (1874a: 193), also reported that ''the appearance of the white men, on the American and Feather Rivers, two great forks of the Sacramento, has been followed by the *total destruction* of the spawning beds of these once prolific streams, and the spoiling of the water, so that not a single salmon ever enters these rivers where they used to swarm by millions in the days of the aboriginal inhabitants'' (italics in original). Similarly within the San Joaquin River drainage, the California Fish Commission stated that by 1876–1877, salmon no longer entered the Mokelumne and Tuolumne rivers, where formerly, as in other rivers, they had spawned ''in vast numbers,'' and that the Merced and San Joaquin rivers constituted the remaining principal spawning streams (CFC 1877).

The high productivity of the Central Valley salmon resource is also reflected by records of the once-thriving salmon canning industry of the Sacramento River and delta (Cobb 1921; Clark 1929; Skinner 1962). The first salmon cannery in North America was founded in 1864 by Hapgood, Hume, and Company on the west shore (Yolo County) of the Sacramento River, across from the city of Sacramento (Hume 1893; Cobb 1921; Dodds 1959). Although antedated by a small salmon-canning business at Aberdeen, Scotland, and possibly another at Cork, Ireland (Carstensen 1971), the Sacramento cannery operation presaged the development of a lucrative enterprise that eventually encompassed the coastal region from Monterey, California, northward to western Alaska (Cobb 1921; Smith 1979; Newell 1989). The initial market for Sacramento canned salmon was Australia–where the first shipment netted $16 per case—because the domestic San Francisco market was not receptive to such a novel food product (Collins 1892:168). In those early years, only the high-quality spring-run (and probably winter-run) salmon were canned; the packers suspended operations in early July of each year to ensure output of ''only goods which showed a rich oil and the best food values'' (R. D. Hume, quoted in Cobb 1921:37). The reportedly poor salmon runs in 1864, 1865, and especially 1866—attributed to the degradation of the spawning beds by hydraulic mining debris (Dodds 1959)—caused the company to relocate on the Columbia River in 1866 (Collins 1892; Skinner 1962; Carstensen 1971; Smith 1979). Salmon numbers in the Sacramento River remained so low that cannery operations could not profitably operate there until the next decade (CFC 1875). The canning industry recommenced in the Sacramento region in 1874 and increased to 19–21 canneries (including 4 in San Francisco) that received salmon from the lower Sacramento and San Joaquin fishery during the early 1880s (CFC 1884; Cobb 1921; Clark 1929). However, within 3 years after its peak, the number of canneries dropped to ''five or six'' (in 1885) due to small runs and decreased catches (CFC 1886). It was the canning industry that drove the salmon fishery on the lower Sacramento–San Joaquin rivers to the limits of production and, arguably, contributed to its demise. As McEvoy (1986:117) noted, ''salmon canners processed vast quantities of California resources for export to consumers of their own ethnicity in other countries, . . . [and] the salmon industry was uncontrollable because demand for its product was simply too strong.'' Production peaked at 181,200 cases in 1881 and 200,000 cases in 1882—each case containing 48 1-lb cans (or their equivalent) and equal to about 66–75 lb of whole salmon (based on Atwater 1892; Collins 1892; CFC 1894; Carstensen 1971; Hewes 1973), amounting to a total value of roughly $1 million (at $5 per case) in each of those two years (Bancroft 1890:82). The average annual pack was 58,387 cases in the period 1880–1899 and 10,368 cases during 1900–1919 (excluding the years 1907–1912, for which separate data on the canned pack were not available; Clark 1929; Skinner 1962). Cannery production started to decline in 1884 and plummeted to 2,281 cases in 1892, but it recovered and remained fairly stable until 1906. Production thereafter was relatively low (<10,000 cases for all years except 1914), and the salmon canning industry was finally abolished after 1919 by the state legislature (Skinner 1962). During its lifetime (1864–1919), the Sacramento–San Joaquin salmon canning industry produced a documented total of 1,401,775 cases of chinook salmon (Cobb 1921), containing 67.3 million pounds of salmon meat or the equivalent of approximately 5,607,000 salmon (at four fish per case; Jordan and Gilbert 1887). The decreased cannery production in the later years, particularly after 1900, undoubtedly was due partly to the advent of the mild-curing preservation of salmon, which took 1.2–4.4 million pounds (average, 2.4 million pounds) of salmon meat in almost every year during 1901–1919 (Cobb 1921).

The Sacramento Valley salmon resource was further exploited by the early operations of the U.S. Fish Commission egg-taking station and hatchery (Baird Station) on the McCloud River in the upper Sacramento River drainage. Established in 1872 by Livingston Stone, fish culturist for the U.S. Fish Commission, it was the first salmon hatchery on the Pacific coast, and its initial purpose was to supply chinook salmon for introduction to rivers in the central and eastern United States (Stone 1878, 1883a, 1897; Clark 1929) and secondarily to other countries, including France, Germany, Netherlands, Great Britain, Italy, Norway, Canada, Mexico, Australia, New Zealand, and Japan (USFC 1878, 1880, 1882, 1893, 1894, 1899, 1900; Stone 1878, 1883a, 1897; Clark 1929). During 1873–1881, an average of 68% (range, 40–76%) of the eggs collected on the McCloud River were shipped annually to eastern states and overseas, leading one former worker (H. C. Mitchell) at the Baird Hatchery to remark that ''the McCloud River was systematically robbed of its salmon eggs'' (Clark 1929:13). After 1881, relatively few eggs and fry from the McCloud River were shipped out of the state (Clark 1929). By fate or fortuity, none of the early attempts to establish chinook salmon in the eastern watersheds were ever successful (USFC 1892; Davidson and Hutchinson 1938; Towle 1987), despite the prodigious effort to hatch and distribute young chinook salmon into streams from Maine to the Mississippi drainage, the Gulf coast, the Midwest, and a few western states (e.g., Stone 1880, 1883b). The hopeful endeavor to restore with hardy Pacific salmon the once-bountiful East Coast streams that had been dispossessed of their runs of Atlantic salmon *Salmo salar* and to establish new salmon runs in southern waters that formerly had none ended in utter failure (S. Wilmot, letter to L. Stone in Stone 1883b, 1897; USFC 1892; Towle 1987).

The ocean fishery for chinook salmon is said to have started in the early 1880s in Monterey Bay where it was carried out by a few small sailboats (Fry 1949; Fry and Hughes 1951), although Chinese fishermen at Monterey reportedly caught salmon as early as 1853 (Gunn 1910). It was not until after 1900 that salmon were fished to any significant extent in the ocean waters outside of San Francisco Bay, which was made possible by the advent in 1904–1908 of powered fishing boats that used trolling gear (CFGC 1916; Scofield 1956). Before 1914, the Monterey Bay fishery took up to 500,000 lb of chinook salmon in a good year; the catch increased to 2.5 million pounds in 1914, 3 million pounds in 1915, and over 5.2 million pounds in 1916, with a record 1-d catch of 85 tons (for about 400 fishing boats) in 1916 (CFGC 1916; Scofield 1921). By 1914, troll fishing for salmon had expanded northward to Point Reyes, and by

1916, a few trollers were operating out of Eureka and Crescent City (Fry 1949; Fry and Hughes 1951). During 1916–1926 the ocean catch of chinook salmon was roughly comparable to the in-river catch (Klamath and Sacramento rivers combined; Scofield 1921; Clark 1929), but thereafter the ocean catch dominated the fishery (CDFG 1932, 1937; Skinner 1962). The decrease in commercial landings for the Sacramento–San Joaquin in-river fishery during its later years was in large part directly due to increased ocean catches, which evidently included many immature fish (Scofield 1921; Clark 1929). Another major consequence of the ocean troll fishery was that the abundant fall-run chinook salmon were increasingly harvested (CGFC 1916), evidently because the quality of ocean-caught fish was consistently high (CFC 1900). On the other hand, a large part of the spring chinook run evaded the ocean fishery because spring-run spawners of the year had already embarked on their upriver migration by the time the spring–summer troll fishing season was underway (Skinner 1958).

The commercial ocean salmon harvest in California historically was dominated by chinook salmon, with coho salmon composing the remainder. Chinook salmon constituted 90% or more of the commercial salmon catch until at least 1960 (CDFG 1950, 1956, 1960) and, on average, 91% (range, 54–99%) of the annual catch during 1976–1992 (Brown et al. 1994). The ocean chinook salmon catch comprised mainly Central Valley stocks (approximately 70% by one estimate; Skinner 1962; compare also Fry 1949; Fry and Hughes 1951; Cope and Slater 1957), and the total exvessel value of the statewide salmon catch assessable to Central Valley fish was $1.3–$2.5 million annually (average, $1.9 million) during 1952–1956 (Skinner 1962). Chinook salmon produced in Central Valley streams also were caught in appreciable numbers by fisheries off Oregon, Washington and British Columbia (CDFG 1956; Cope and Slater 1957; Skinner 1962). Indeed, during 1952, the ocean troll fishery in those northern areas evidently took more Sacramento River chinook salmon than were caught by California ocean fishermen (CDFG 1955, 1956). The Sacramento–San Joaquin in-river salmon fishery was finally terminated in 1957 by state legislative action (CDFG 1958; Skinner 1962), although by that time various seasonal and areal closures and gear restrictions had already significantly curtailed the in-river harvest (CDFG 1953; Scofield 1956; Skinner 1958). In recent decades (1971–1995), the average statewide commercial salmon catch (~6.27 million pounds, all taken in the ocean) has been statistically no different from the average in-river catches (~6.45 million pounds) that were made during the early phase (1856–1910) of the Sacramento–San Joaquin in-river fishery ($P > 0.125$, t-test; Sokal and Rohlf 1995; Tables 2, 3; Figure 2), despite the broader areal extent of the ocean fishery and the additional production from coastal salmon streams (mainly the Klamath River system).

TABLE 3.—Estimated annual harvests of chinook salmon for the commercial ocean troll fishery in California during recent decades. Annual averages of landings are given for 5-year periods at the beginning of the table. Data are derived from PFMC (1994, 1996).

Period or year	Number of fish	Dressed fish weight (lb)	Whole fish weight[a] (lb)	Exvessel value[b] (millions US$)
1971–1975	562,700	5,743,000	6,526,100	
1976–1980	618,600	5,867,200	6,667,300	
1981–1985	462,700	4,453,600	5,060,900	16.6
1986–1990	794,700	8,097,400	9,201,600	26.6
1991–1995	332,600	3,310,800	3,762,300	7.4
1979	727,000	6,860,100	7,795,500	34.4
1980	589,000	5,612,800	6,378,200	23.1
1981	588,000	5,963,100	6,776,300	22.1
1982	765,200	7,448,600	8,464,300	29.0
1983	294,000	2,144,400	2,436,800	6.4
1984	299,800	2,621,200	2,978,600	9.8
1985	366,300	4,519,200	5,135,500	15.7
1986	825,600	7,396,800	8,405,500	19.9
1987	876,300	9,047,100	10,280,800	32.6
1988	1,317,200	14,430,800	16,398,600	51.5
1989	530,900	5,489,800	6,238,400	15.7
1990	423,400	4,122,400	4,684,500	13.1
1991	294,900	3,237,900	3,679,400	9.2
1992	163,400	1,632,100	1,854,700	4.8
1993	279,600	2,536,900	2,882,800	6.0
1994	295,600	3,103,100	3,526,300	6.6
1995	679,300	6,044,100	6,868,300	10.6

[a] Estimated poundage of whole fish was obtained by dividing the dressed weight by factor 0.12 (i.e., dressed weight [gutted fish] is 88% of whole-fish weight; Crapo et al. 1988).
[b] Value of landed catch (paid to fishermen) in 1995 dollars.

The in-river commercial catch records pertain to fish taken from the population before spawning and they represent unknown fractions of the total runs. Varying numbers of fish escaped the fishery from year to year, enabling the populations to persist, but the levels of spawning escapements were completely unknown until spawning stock assessments for specific streams were begun in the late-1930s and early-1940s (Fry 1961).

The Decline and Its Causes

The Portents

The long-term overall decline of the salmon stocks and fishery in California was first described by Clark (1929) and later by Skinner (1962). Yet, a decrease in the abundance of salmon in the Sacramento River was noticed as early as 1851: ''In the year 1849, we had no trouble whatever in procuring all the salmon we wished, by just constructing a rude barb or spear of this kind . . . wade out a few steps, and literally pick up all we desired. In 1851, we could observe a great decrease, and since that time the fish have been gradually retreating beyond their pursuing destroyers.'' (Kirkpatrick 1860). A contemporary newspaper article (*Sacramento Union,* 1 January 1859) likewise noted that before 1850, ''the waters of the river were then free of impurities, and the salmon were in great abundance, and their flavor pronounced superior to the best Eastern and Oregon varieties. . . . There has not been a heavy run of Spring salmon since 1852. . . . The principal business in salmon catching is now done in the Fall.'' By 1870, the newly appointed State Board of Fisheries Commissioners (California Fish Commission), in considering the question of whether or not salmon were decreasing in the Sacramento and San Joaquin rivers, avouched that ''the weight of the testimony is on the side of those who believe the quantity to be decreasing; and the most intelligent of the fishermen are so firmly convinced of the fact that they ask that a law be passed and enforced to prevent, for a certain period, the catching of fish while they are filled with ripe spawn'' (CFC 1871: 43). The commission further recommended that the state legislature institute more effective fishery laws, and various protective measures were enacted over the following decades (Clark 1929). However, the overall efficacy of those protective measures was questionable. Indeed, the year 1866 was especially notable for the extreme scarcity of salmon even in the lower Sacramento River—''the river being almost destitute of them''—which the fishermen attributed to ''the unusually muddy water of the river, caused by the mining of that year'' (Stone 1874a:185).

The Factors

The major causes of the reduction and, in some cases, the complete loss of salmon stocks were recognized early: overfishing; destruction of habitat by hydraulic mining, dredge mining, railroad construction, and logging; and the further loss of habitat due to construction of dams and water-diversion projects (Kirkpatrick 1860; Cobb 1921; CFGC 1924; Clark 1929; Scofield 1929). Overfishing by the river gill-net fishery was a persistent, early problem (Harkness 1890; Scofield 1919, 1929; Clark 1929; McEvoy 1986). It was reported, for example, that illegal fishing by the cannery fishermen so reduced the salmon runs in 1877 that only ''extremely small numbers'' reached the McCloud River despite ''an unusually large number running in the Sacramento'' (Stone 1879:799); and in 1878, the salmon at Baird Station on the McCloud, although present in ''vast quantities,'' were smaller than usual, evidently due to ''the innumerable driftnets [that] stopped all the large salmon'' (Stone 1880:750). In 1879, the early part of the run into the McCloud River consisted only of grilse (precocious males), and it was not until after the fishing to supply the canneries on the lower Sacramento River had stopped did large salmon appear at Baird Station about mid-August (Stone 1882; USFC 1882). In the early 1880s, the Sacramento River was at times completely blocked by gill nets (CFC 1884). The intensive fishing effort of those early times was accompanied by wastage that was, at least on occasion, enormous. One observer noted that during 15–17 September 1880, ''fully nine thousand [fall-run] fish were thown back into the river, thus wasted, for want of purchasers'' (CFC 1880:7). Even the highly valued spring-run catch was occasionally squandered; in April 1879, large shipments of salmon to the San Francisco markets resulted in an oversupply, which led to ''a great many spoiling and being thrown into the bay as unfit for any use'' (CFC 1879:6). Perhaps equally significant, juvenile salmon were also harvested, in a sense, as unscreened water diversions removed uncounted but substantial numbers of down-migranting juveniles over the decades (CFC 1890; Scofield 1929; Phillips 1931; Hanson et al. 1940; Sumner and Smith 1940), as well as ''considerable numbers'' of migrating adults (Van Cleve 1945a; compare Scofield 1913).

The profound impact of hydraulic mining in massively altering the condition of the streams impressed itself upon early observers (Kirkpatrick 1860; CFC 1871, 1880; Chamberlain and Wells 1879; Angel 1882). One account lyrically stated that ''the Salmon fish are fast decreasing from our waters—that is, upon all the streams upon which mining is carried on to any extent, and, in fact, we may say from all the streams of importance. . . . How well does the writer remember the good old days of '49 when he wished for no better mirror than the crystal waters of the 'Rio de los Americanos,' Mokelumnes, or Los Mariposas, and how the pure water sparkled and flashed from the shining sides of the merry fishes, as they hurried to their mountain retreats'' (Kirkpatrick 1860). The California Fish Commission noted that before the discovery of gold in California, ''nearly all of the tributaries of the Sacramento and San Joaquin Rivers were the spawning beds of the salmon. . . . It would be safe to estimate that one-half the streams in this state to which salmon formerly resorted for spawning have, for this purpose, been destroyed by mining'' (CFC 1877:5; see also CFC 1880:3). Ironically, the degraded water quality of the lower Sacramento River aided fishing operations: ''The water of the main Sacramento is so muddy that the fish cannot see the net till close upon them; consequently the fishing in this river can be done in the day-time, while in all other clear rivers the nets must be drawn at night'' (Stone 1874a:188; also, Collins 1892:165).

The massive influx of mining sediments covered spawning beds and filled the channels of major tributaries such as the Yuba, Feather, Bear, and American rivers, obliterating not only the salmon runs but also adjoining agricultural lands (Chamberlain and Wells 1879; Sumner and Smith 1940; Kelley 1989). Portions of the Yuba River channel, for example, reportedly were filled with mining deposits 20–30 ft deep—at one point (''Timbuctoo Ravine'') up to 80 ft deep—and the floodplains along the Yuba and Bear rivers were covered with sediments 5–10 ft thick that extended, in some places, 1.5 mi back from the streams (Chamberlain and Wells 1879). Some 39,000 acres of farmland, mostly along the Feather, Yuba and Bear rivers, were buried by mining debris, and another 14,000 acres were partially damaged, at a total cost of more than $3.4 million (Kelley 1989). An estimated 1,295 million cubic yards of mining debris were washed into the principal tributaries of the Sacramento River, and at least another 230 million cubic yards into the San Joaquin River drainage during the period of placer and hydraulic mining, the total volume equaling nearly eight times the amount of earth moved during the construction of the Panama Canal (Gilbert 1917). It was the consequent destruction wrought upon the farmlands and the widespread flooding that eventually led to a federal court injunction against hydraulic mining in 1884 (Judge Lorenzo Sawyer of the U.S. Ninth Circuit Court in San Francisco ruling in the case of *Edwards Woodruff v. North Bloomfield Gravel Mining Co. et al.*), arguably the first major federal court action on environmental protection (Kelley 1989). Furthermore, the ubiquitous diversion of water from natural stream channels by mining operations entailed the construction of innumerable ditches and flumes, as well as storage reservoirs; the aggregate length of those artificial watercourses probably reached 8,000 mi at the height of the hydraulic mining era (Coleman 1952). In Nevada County alone (978 mi^2), there were 700 mi of mining ditches and flumes in 1857 and more than 1,000 mi by 1879 (Wells 1880; Kahrl 1978).

Dams and diversions were constructed on some tributaries as early as the 1850s (e.g., Tuolumne and Merced rivers; J. B. Snyder, National Park Service, unpublished memorandum[1]). While they were usually small and temporary, the complete lack of allowance for fish passage unquestionably affected the salmon runs to some degree. The California Fish Commission noted that ''dams on the headwaters of the Stanislaus, Tuolumne, San Joaquin, and the upper Sacramento Rivers'' blocked the salmon from the spawning grounds, which mostly were above the dams, a major cause, in the opinion of the Fish Commission, for the decrease of salmon (CFC 1884:15). The dams and diversion structures on the San Joaquin Valley tributaries for the most part were emplaced relatively early during the period of Euro-American settlement in California, and as a consequence, there was very little documentation, or even anecdotal accounts, of early salmon abundances and distributions in those southern tributaries. By 1888, it was reported that ''salmon do not run into the San Joaquin in large numbers'' (Collins 1892:163), in apparent testimony to the rapid and early demise of most of the large runs in the San Joaquin River basin. The major exception was the upper San Joaquin River, where permanent obstruction of salmon migration did not occur until 1920 when Kerckhoff Dam was built. Thereafter, however, the salmon runs of the upper San Joaquin River were destroyed relatively rapidly (within three decades), and personal recollections of salmon in that river barely remain within the memories of elder Native American and Euro-American residents of the region (Rose 1992; P. Bartholomew, CDFG, personal communication). In contrast to the general pattern within the San Joaquin River drainage, the construction of dams and blockage of salmon runs in the Sacramento Valley tributaries proceeded more slowly and there was greater opportunity for records of salmon oc-

[1] J. B. Snyder, Historian, Yosemite National Park, Memorandum dated 9 May 1993 to Park Superintendent, M. Finley, ''Did salmon reach Yosemite Valley or Hetch Hetchy?'' Yosemite Research Library, Yosemite National Park, California.

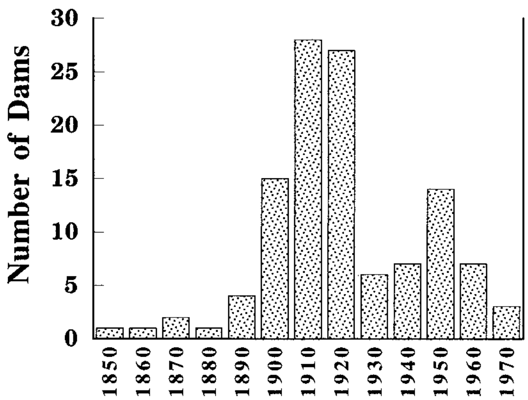

FIGURE 3.—Rate of dam construction over the decades in the California Central Valley drainage. Impoundments of the dams ranged from 40 acre-feet to 4.5 million acre-feet.

currences to be kept, even including photographic evidence (CDFG, unpublished records).

The construction of permanent dams and the corresponding loss of salmon habitat rapidly increased toward the turn of the century and peaked during the 1900s to 1920s, although it continued into the 1970s (Figure 3). In the later decades, construction of larger dams with correspondingly greater storage capacities (e.g., New Exchequer Dam [1967] on the Merced River, New Don Pedro Dam [1971] on the Tuolumne River, and New Melones Dam [1979] on the Stanislaus River) not only further eliminated salmon habitat but also has resulted in the alteration of natural flow patterns. Regulated water releases have increased flows during the spring–summer irrigation season and decreased the historically higher flows of the fall, winter, and early-spring (Reynolds et al. 1993). In addition to blocking the upstream migration of adult salmon, dams of various sizes caused significant degradation of habitat in downstream reaches by restricting streamflows, the consequences of which included elevated water temperatures, highly variable water levels, increased siltation of streambeds, net loss of gravels due to lack of replenishment from upstream sources, and the exacerbation of pollution effects (Holmberg 1972; Reynolds et al. 1993). Dams and water diversions probably substantially affected the salmon runs in westside tributaries of the Sacramento River, where precipitation was less than on the east side of the Central Valley and streamflows were inconsistent (USFWS 1995). Low streamflows continue to impede salmon access into westside streams (such as Stony, Cottonwood and Clear creeks), which historically supported salmon populations (Reynolds et al. 1993; Yoshiyama et al. 1996; Montgomery Watson et al. 1997).

Furthermore, the completion and operation of federal and state water export projects in the Sacramento–San Joaquin Delta enabled the removal of massive quantities of water, thereby disrupting the normal flow patterns in the delta and obstructing or preventing the seasonal migrations of the different salmon life stages (Herbold and Moyle 1989). Other repercussions include the actual entrainment and attendant mortalities of juvenile salmon caused by the pumping operations—an estimated 400,000–800,000 salmon annually in recent years (USFWS 1995)—despite the presence of fish screens and fish salvage efforts (Kjelson et al. 1982). Much smaller but numerous stream diversions throughout the Sacramento and San Joaquin valleys—numbering 1,497 in 1945 and more than 900 (upstream of the delta) in the mid-1950s—killed large numbers of migrating adults and juveniles (Van Cleve 1945a; Hallock and Van Woert 1959). In the Sacramento Valley, water diversions along the upper main-stem Sacramento River were found to have had relatively limited effect on juvenile salmon, at least under the normal runoff conditions and irrigation schedules observed in 1953-1954, because the majority of juveniles originating from the main-stem Sacramento River usually migrated out of the upper basin before the full onset of the irrigation operations in late April and early May (Hallock and Van Woert 1959). However, juvenile salmon losses of considerable magnitude were known to have occurred in Sacramento River basin tributaries because of the later spawning and down-migrating periods for tributary populations of the fall run and the proportionately greater diversons of streamflows (Hallock and Van Woert 1959).

Entrainment losses of juvenile salmon to irrigation diversions were particularly serious in the San Joaquin River basin, where the earlier irrigation season coincided more closely with the downstream migration period and larger portions (up to 20–40%) of the total river flow were diverted during some months (Hallock and Van Woert 1959; Holmberg 1972). A study of three major irrigation diversions conducted in the spring of 1955 indicated losses of approximately 20,000 juvenile salmon to the Banta Carbona Irrigation District diversion within a 2-month period and of more than 9,000 and 2,000 juveniles, respectively, to the El Solyo and Patterson water companies diversions within 1-month periods (Hallock and

Van Woert 1959). An important aspect of those losses was that they affected different populations to different degrees of severity. For example, juveniles from the Merced River were lost to all three diversions and were the only ones taken by the Patterson Water Company diversion, but they represented the progeny of at most about 1,000 spawners in the Merced River the previous year (Hallock and Van Woert 1959). Those three diversions, plus a fourth (West Stanislaus Irrigation District), were considered the most significant ''destroyers of young salmon,'' but there were more than 100 other smaller diversions on the lower main-stem San Joaquin River (between the city of Stockton and the mouth of the Merced River) with undetermined impacts. Additional diversions downstream within the Sacramento–San Joaquin Delta also imposed ''considerable losses'' on migrating juveniles (Hallock and Van Woert 1959).

Perhaps the most extreme example of an irrigation diversion was the impoundment of virtually the entire upper San Joaquin River by Friant Dam beginning in the mid-1940s. Thereafter, water released from Friant Dam was allocated completely to irrigation (Skinner 1958). The last significant spawning cohort to use the upper San Joaquin River—about 1,900 spring-run fish in 1948—had to be collected at the mouth of the Merced River and trucked upstream past the dry reaches of the San Joaquin River channel to the spawning beds (CDFG 1948; Warner 1991). The last year-classes of juvenile salmon ever to migrate down from the upper San Joaquin River were destroyed in 1948 and 1949 in the diversions near Mendota, where the San Joaquin River channel turns northward. For some 60 miles downstream from that point, the San Joaquin River had become essentially a dry streambed, except for irrigation runoff (Skinner 1958; Hallock and Van Woert 1959). To this day, major sections of the San Joaquin River channel above the Merced River confluence receive only irrigation drainage or are without water during much of the year (Gilliom and Clifton 1990; Reynolds et al. 1993; Jacobs et al. 1993; CALFED 1997).

There are additional factors that probably have had negative impacts on historic and present-day Central Valley salmon populations but which are poorly understood, such as the introduction of striped bass *Morone saxatilis* and other nonnative predators and the widespread and persistent presence of chemical contaminants from various sources. Striped bass are among the top predatory fishes in the Sacramento–San Joaquin Estuary, and their average population levels of 1.7 million adults during the late 1960s to early 1970s and 1.25 million adults during 1967–1991 (USFWS 1995) undoubtedly exerted considerable predation pressure on down-migrating juvenile salmon. Presently, striped bass are considered to be a primary cause of juvenile salmon mortality at the state water-export facility in the south delta (USFWS 1995). Such heavy predation, if it extends over large portions of the delta and lower rivers, may call into question current plans to restore striped bass to the high population levels of previous decades, particularly if the numerical restoration goal for striped bass (2.5–3 million adults; USFWS 1995; CALFED 1997) is more than double the number of all naturally produced Central Valley chinook salmon (990,000 adults, all runs combined; USFWS 1995). Major chemical contaminants entering the Sacramento–San Joaquin River system include toxic metals from mining deposits, effluents from pulp and paper mills, and especially pesticides and herbicides from agricultural drainage (Gilliom and Clifton 1990; USFWS 1995; Pereira et al. 1996; Domalgalski 1997; Kratzer 1997). While the population-level consequences of such contaminants are mostly unquantified, their localized impacts on salmon populations may have been substantial at times. For example, highly concentrated discharges of toxic metals in the upper main-stem Sacramento River have caused ''more than 40 documented kills of salmon and steelhead'' (USFWS 1995:2.VII.16). Although the past effects of such additional factors are ambiguous, the influence of nonnative organisms and chemical pollutants on Central Valley salmon stocks may become increasingly evident in the future as more focused studies are conducted.

The Consequences: Differential Impacts on the Runs

The overall detrimental impact of various human activities on the salmon runs is now widely recognized (Reynolds et al. 1993; Moyle et al. 1995). What has not been previously emphasized, however, is that the different factors affected the four runs in different ways over the past 150 years. For example, the spring run and probably also the winter run most likely sustained the heaviest harvest pressure from the intensive in-river fishery of the earlier years (CFGC 1916; Fisher 1994). This was because the fish of those two runs entered the rivers on their spawning migrations in prime physical condition, well before the spawning season and the deterioration that accompanies transformation into the reproductive state. Thus, spring-run fish, with their characteristically high fat content and high-quality flesh, were especially valued and heavily fished, as were winter-run fish (Jordan and Gilbert 1887; Stone 1889; Jordan 1904; Skinner 1958). As a newspaper article of that era phrased it: ''In the Spring the run is light, but the fish are choice. Their flesh is then firm and of delicate grain'' (*Sacramento Union*, 1 January 1859). Stone (1874a:180) reported a price of 18–20 cents per pound for fish caught during early November and December (winter run), compared with 3 cents per pound, or less, for fall-run salmon caught in August, noting that due to the ''very poor'' quality and great abundance of the latter, ''tons of them are thrown back into the river for want of purchasers.'' In 1883, some 451,957 ''spring salmon'' were canned and 115,004 more were sold fresh in the markets, compared with 160,542 ''Fall salmon'' canned and 52,902 sold fresh (CFC 1884:4). Nevertheless, it is well documented that the fall run was exploited intensively by the in-river fishery (Stone 1874a; Clark 1940; Skinner 1958), and increasingly so as the spring and winter runs were progressively depleted over the years (Skinner 1958; *Sacramento Union*, 1 January 1859).

Relative harvest levels for the different runs are also indicated by the commercial catch data apportioned by season for later decades of the Sacramento–San Joaquin in-river fishery. During 1916–1949, the average annual catches for the three fishing seasons were: ''fall fishery'' (August–September; taking fall-run fish), 1,436,711 lb (range, 12,975–4,837,696 lb); ''winter fishery'' (November–January; including unknown mixtures of mainly winter-run and late-fall-run fish), 44,543 lb (range, 731–235,155 lb); ''spring fishery'' (February–June; taking mainly spring-run fish), 664,979 lb (range, 61,584–2,290,083 lb; Skinner 1958). The relative catch contributions of the three fishing seasons (i.e., comparing their annual averages) over the 1916–1949 period were: fall (67%), winter (2%), and spring (31%). During the subsequent period 1950–1957, average annual catches were 1,017,278 lb (range, 283,362–2,276,410 lb) for the fall fishery, 20,376 lb (range, 104–84,734 lb) for the winter fishery, and 67,677 lb (range, 14,900–263,009 lb) for the spring fishery. The relative contributions of the three seasons during this later period were: fall (92%), winter (2%), and spring (6%). Thus, there was not only a general decrease in catches for all three fishing seasons between the two periods, 1916–1949 and 1950–1959 (Figure 4), but also a disproportionately greater reduction of the spring fishery, reflecting the precipitous decline in abundance of the spring run (Skinner 1958).

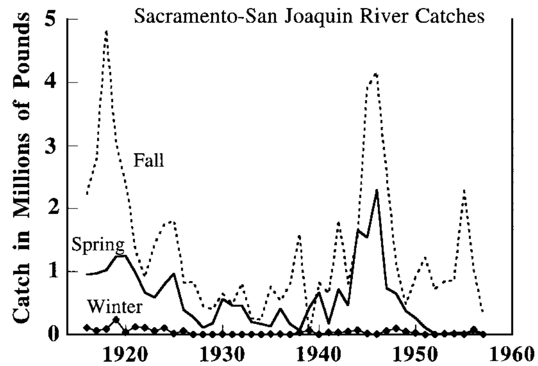

FIGURE 4.—Seasonal commerical catches for the Sacramento–San Joaquin in-river salmon fishery during 1916–1957. Based on Skinner (1958), monthly catches were grouped into three seasons: fall (August–September); winter (November–January); and spring (February–June).

It was the spring and winter salmon runs, which migrated furthest upstream, that experienced massive losses of spawning habitat in the upper watersheds when extensive construction of hydropower and irrigation diversion projects blocked off the upper streams. For example, construction of La Grange Dam on the Tuolumne River in 1893 completely barred spring-run salmon from at least 50 miles of stream above it (Yoshiyama et al. 1996). Similarly, Friant Dam blocked a considerable portion of the original spawning habitat for spring-run chinook salmon in the upper San Joaquin River and dried up the river downstream, thereby destroying the large spring run as well as the remnant fall run (Skinner 1958; Hallock and Van Woert 1959; Fry 1961; Yoshiyama et al. 1996). An even more dramatic example was Shasta Dam (completed in 1943) on the upper Sacramento River, which prevented salmon access to the entire drainages of the Little Sacramento, McCloud, and Pit rivers. Not only extensive spring-run habitat, but almost all of the known spawning areas for the winter run were removed from production (Fisher 1994). The total amount of lost spawning habitat approached 190 mi of stream (Hanson et al. 1940). Skinner (1958:4) stated that ''Shasta [Dam] eliminated access to approximately fifty percent of the existing [spawning] beds in the Sacramento system.'' However, new winter-run spawning habitat was artificially ''created'' just below Shasta Dam, where continuous coldwater releases during the summer served to replicate the necessary flow conditions previously found in the natural spawning grounds further upriver.

The fall run was less negatively affected by most major water projects (with the exception of Shasta Dam) because that run typically used the lower reaches of the rivers, which were not as extensively blocked off. Yet, the fall run also experienced habitat losses due to in-river obstacles and reductions of streamflows. Red Bluff Diversion Dam on the main-stem Sacramento River significantly altered the spawning distribution and reduced the total number of fall-run salmon, primarily by obstructing adult migration and increasing the mortality of down-migrating juveniles (Hallock 1991). Upstream diversions of water during the fall made a number of Sacramento Valley streams inhospitable to fall-run salmon until later in the year, when seasonal rainfall provided adequate streamflows; these included some streams (e.g., Mill and Deer creeks) where the spring run persisted because fish ascended during high spring flows and took refuge in cool pools at higher elevations while streamflows were low during the summer and early fall. Conversely, in some streams, the reduced streamflows due to dams and diversions degraded environmental conditions enough during the dry months to eliminate the spring run, while the fall run was not nearly as seriously affected (e.g., Stanislaus and Tuolumne rivers; CDFG 1955; Fry 1961).

Four Runs, Four Pasts—Four Fates?

Estimates of Abundance

The relative abundances of the four seasonal runs of chinook salmon in the Central Valley system before their exploitation cannot be precisely quantified because their distinct nature was not recognized by early workers. The early commercial fishermen, of course, were aware of the seasonal fluctuation in salmon abundance as the runs pulsed through the delta and lower Sacramento and San Joaquin rivers. Only two major runs, fall and spring, were recognized. One veteran fisherman described the fall run, arriving in August and September, as ‘‘the great seed run, consisting of mature fish, always on time, always urgent in their movements and purposes,’’ while the spring run, ‘‘commencing in November and ending in July, and having its greatest strength in May,’’ was somewhat indeterminate in its upriver movement, alternately impelled or checked ‘‘by the varying moods of the river in sudden rise or fall’’ (CFC 1877:8). Although not regarded as a distinct run, the relatively ‘‘scarce’’ winter-run fish were recognized by their early entry into the river and distinctive appearance: ‘‘In November and December a very few small (. . . twelve or fourteen pounds each) bright salmon appear in the river, . . . the *avant couriers* of the great spring run’’ (CFC 1877: 9). Overall salmon abundance in the Sacramento River up to the mid-1870s was described, for good years, as usually ‘‘very scarce’’ to ‘‘scarce’’ in November–February (mainly the late-fall and winter runs), ‘‘not scarce’’ in March (a mixture of runs), and ‘‘plenty’’ to ‘‘very plenty’’ in April–May (mainly spring run) and ‘‘not scarce’’ to ‘‘scarce’’ in June–July (spring run). These qualitative terms corresponded to the daily catch by two men in one boat (with one net) as follows: ‘‘very scarce’’ (2 fish/d), ‘‘scarce’’ (6 fish), ‘‘not scarce’’ (18 fish), ‘‘plenty’’ (36 fish), ‘‘very plenty’’ (72 fish); CFC 1877:10). The winter and late-fall runs, therefore, generally were much less abundant than the spring run, although there were years when the relative run sizes deviated from the norm, and both the winter and spring runs were large, resulting in a steadily increasing supply from January to May (CFC 1877).

Rough estimates of run abundances during some years after commencement of the fishery can be determined from monthly catch data (CFC 1882, 1900; Clark 1940). Fisher (unpublished data) estimated the size of the winter run in the Sacramento River drainage by summing the in-river catch data for winter months (catches for January, February, and one-half of March) and assuming a harvest rate of 20%. The resulting annual run-size estimates for 1916–1957 ranged from 200 to 91,840 fish. Estimated winter-run abundances exceeded 20,000 fish for 20 years of this 42-year period and exceeded 50,000 fish for 10 years. These estimates are subject to a number of assumptions and probably are conservative because they excluded catch data for other months (November–December and April–May) when winter-run fish were mixed with the catches of the late-fall and spring runs. The general indication is that the winter run formerly numbered in the high tens of thousands at the least and perhaps occasionally exceeded 100,000 fish. Similar estimates can be inferred from historical catch data for the spring, fall, and late-fall runs; pre-20th century run sizes, including harvest, for the entire Central Valley may have approached 900,000 fish for the fall run, 100,000 for the late-fall run, and 700,000 for the spring run (Fisher 1994). In the McCloud River alone, Stone (1880:

TABLE 4.—Chinook salmon spawning stock estimates for the Sacramento and San Joaquin drainages for the period 1940–1959 and for 1962–1963. Data are from Hatton and Clark (1942), Fry (1961), and unpublished CDFG reports; data for 1962–1963 only are from CDFG (1964). Numbers in square brackets are incomplete estimates for which data from major streams either were missing or excluded a major fraction of the spawning run; ND denotes no data available.

	Fall run[a]		Spring run	
Year	Sacramento	San Joaquin[b]	Sacramento	San Joaquin[b]
1940	[>33,000]	131,423	[>11,000]	ND
1941	[>33,000]	41,074	[>16,000]	ND
1942	[>7,000]	[>56,000]	[>4,000]	ND
1943	[>38,000]	ND	[>7,000]	35,000
1944[c]	[>76,000]	[>130,000]	[>15,000]	5,000
1945[c]	[>55,000]	ND	[>7,000]	56,000
1946[c]	[>66,000]	[>61,000]	[>35,000]	30,000
1947	107,000	[>63,000]	[>32,000]	6,000
1948	[>69,000]	[>55,000]	[>13,000]	2,000
1949	[>72,000]	[>39,000]	[>9,000]	ND
1950	[>119,000]	ND	[>23,000]	≤500
1951	[>125,000]	[>9,000]	[>9,000]	Extirpated
1952[d]	[>338,000]	[>22,000]	[>13,000]	
1953[d]	513,000	84,000	[>15,000]	
1954[d]	412,000	75,000	18,000	
1955[d]	369,000	31,000	26,000	
1956[d]	153,000	12,000	20,000	
1957[d]	102,000	15,000	ND	
1958	237,000	46,000	ND	
1959	421,000	52,000	ND	
1962	252,000	2,000	ND	
1963	301,000	2,000	ND	

[a] Includes late-fall and winter runs.

[b] For this tabulation, the San Joaquin River drainage includes the Cosumnes and Mokelumne rivers.

[c] Moffett (1949) estimated total numbers of salmon (all runs combined) in the Sacramento River upstream of Red Bluff ''conservatively'' to be 144,000 for 1944, 106,000 for 1945, and 96,900 for 1946.

[d] For 1952–1957, the following spawning stock estimates for Central Valley fall-run chinook salmon (but probably also including the late-fall run) were given by CDFG (1958): (1952) 412,000; (1953) 593,000; (1954) 521,000; (1955) 500,000; (1956) 200,000; (1957) 121,000. The average of these numbers (391,170) is 10% higher than the average (354,330) for the same period given in the above table.

763) reported examining ''one by one, nearly 200,000 salmon'' in a 40-d period preceding 5 October 1878, for egg-collecting operations; given the dates, those fish were primarily, or perhaps solely, spring-run salmon.

In the late 1930s, surveys were begun in various streams and at different seasons to assess the run sizes, although the initial counts were incomplete. Fry (1961) compiled the counts and estimates for the period 1940–1959, summarized here in Table 4. Estimates for spawning stocks were not consistently available for all streams for that period, and so many of the values in Table 4 substantially underestimate the true total run sizes. Nevertheless, those estimates that are based on complete data indicate total run sizes for the ''fall run'' of 102,000–513,000 spawners (including 1,000–13,000 fish at the Nimbus Hatchery on the American River and 1,000–13,000 fish at the Coleman National Fish Hatchery on Battle Creek) in the Sacramento River system and 12,000–131,000 fish in the San Joaquin River system (including the Cosumnes and Mokelumne rivers). Those ''fall-run'' estimates included late-fall-run and winter-run fish (Fry 1961). Totals for the entire Central Valley fall run (plus late-fall and winter runs) ranged in the hundreds of thousands during 1953–1959, with a high of 597,000 spawners in 1953. Total estimates for the Central Valley spring run were available for fewer years, but minimal estimates (based on incomplete surveys; Fry 1961) ranged from more than 15,000 to more than 65,000 spawners annually during 1943–1948.

For the more recent period of 1967–1997, separate spawning stock estimates for the four runs in the Sacramento River system were obtained as counts of fish passing the Red Bluff Diversion Dam (Table 5). Because only the fall run has existed in viable numbers in the San Joaquin River system since the late 1940s, the separate counts for the late-fall, winter, and spring runs in the Sacramento River system apply equally to the entire Central Valley and are tabulated as such.

The Fall Run

By far, the bulk of Central Valley salmon production in recent decades has been of fall-run fish. Historically, the fall-run salmon spawned predominantly in the Sacramento Valley drainages, and they still do (Fry 1961; PFMC 1994, 1998). Fall-run spawning escapements in the Sacramento River basin averaged about 218,000 fish for 1980–1989 and 162,000 fish for 1990–1995, with a recent high of 381,000 spawners in 1997. Those numbers were heavily influenced by fish produced in hatcheries on Battle Creek and the Feather and American rivers; the aggregate of all hatchery returns composed 10–22% (average, 16%) of the total Sacramento River annual escapements in 1980–1989 and 16–28% (average, 22%) in 1990–1995 (PFMC 1994, 1996). Even higher estimates of hatchery contributions to total escapements in the Sacramento River basin were given by Fisher et al. (1991): at least 10–65% (average, 34%) during 1970–1984. During 1990–1995, the annual contribution of hatchery-produced fish to spawn-

TABLE 5.—Spawning stock estimates (adults and grilse) for the four seasonal runs of Central Valley chinook salmon during the period 1967–1995, including hatchery returns. Stock estimates of the fall run are given separately for the Sacramento and San Joaquin drainages. Because the late-fall, winter, and spring runs occurred only in the Sacramento River drainage during this period, the values listed for those runs pertain equally to the entire Central Valley. Data are from Fisher (1994) and CDFG files (fall run, 1967–1969; late-fall, winter and spring runs, 1967–1992) and PFMC (1998; fall run, 1970–1997; other runs, 1993–1997). Numbers have been rounded to the nearest hundred; ND denotes no data available.

Year	Sacramento River fall run	San Joaquin River fall run[a]	Central Valley			
			Late-fall run	Winter run	Spring run[b]	Total
1967	157,600	22,800	37,200	57,300	23,800	298,700
1968	191,500	18,700	34,700	84,400	15,400	344,700
1969	268,200	52,200	38,800	117,800	27,400	504,400
1970	201,400	38,500	25,300	40,400	7,700	313,300
1971	193,400	45,100	16,700	63,100	9,300	327,600
1972	137,500	14,500	32,700	37,100	8,700	230,500
1973	262,800	8,000	23,000	24,100	12,000	329,900
1974	229,000	5,600	7,900	21,900	8,300	272,400
1975	187,100	7,700	19,700	23,400	24,000	261,900
1976	188,500	4,600	16,200	35,100	26,800	271,200
1977	185,100	1,100	10,600	17,200	14,000	228,000
1978	153,900	3,100	12,600	24,900	8,400	202,900
1979	221,000	5,300	10,400	2,400	3,000	242,100
1980	164,700	6,800	9,500	1,200	11,900	194,200
1981	230,100	25,700	6,800	20,000	21,800	304,400
1982	212,400	19,900	4,900	1,200	28,100	266,500
1983	154,500	49,700	15,200	1,800	6,200	227,400
1984	199,100	58,800	7,200	2,700	9,900	277,700
1985	283,500	77,500	8,400	4,000	13,100	386,500
1986	264,800	27,200	8,300	2,500	20,300	323,100
1987	244,700	26,400	16,000	2,000	12,700	301,800
1988	252,400	22,400	11,600	2,100	18,500	307,000
1989	174,000	3,400	11,600	500	12,300	201,800
1990	121,500	1,100	7,300	400	6,600	136,900
1991	125,500	1,200	7,100	200	5,900	140,000
1992	107,300	3,100	10,400	1,200	3,000	125,000
1993	147,200	5,700	6,000	400	9,200	168,500
1994	184,700	9,800	6,000	200	6,200	206,900
1995	285,700	6,500	ND	1,400	14,900	>308,500
1996	278,000	21,100	ND	900	8,600	>308,600
1997	381,000	28,100	ND	900	5,200	>415,200

[a] For this tabulation, the San Joaquin River drainage includes the Cosumnes and Mokelumne rivers.
[b] The spring-run numbers include spring–fall hybrids.

ing escapements in the Feather River was 17–40% (average, 27%), and in the American River, it was 9–48% (average, 31%; PFMC 1996). In the San Joaquin River system, the fall run numbered in the tens of thousands as recently as the mid-1980s, with a peak of approximately 77,500 spawners in 1985 (Table 5). The fall run of the San Joaquin River basin has shown highly variable abundances in recent decades, with year-class strength closely tied to the amount of water flow during juvenile out-migration (PFMC 1996; CDFG, unpublished data). The basinwide run size dropped to extremely low levels in 1990 and 1991, even including spawners at the hatcheries on the Merced and Mokelumne rivers. Spawning escapement (including grilse) for the entire San Joaquin River basin was only 1,100 fish in 1990 and around 920–1,200 fish in 1991, although more recent annual escapements have been much higher (>21,000 spawners in the years 1996–1997; Table 5; CDFG 1992; PFMC 1998), with hatchery spawners composing 30–60% of the fish since 1991 (PFMC 1998). During 1990–1995, the aggregate San Joaquin River basin fall run constituted, on average, only 3% of the entire Central Valley fall-run spawning escapement, compared with 6% during 1970–1979 and 12% during 1980–1989 (Table 5; PFMC 1996). However, the spectacular resurgence of the ocean salmon fishery during 1995, which provided sport fishers on the central California coast with catches unsurpassed in living memory (*Sacramento Bee,* 19 July 1995) and commercial fishers with catches not seen since the last decade (Table 3), and the concomitant large spawning runs into the Sacra-

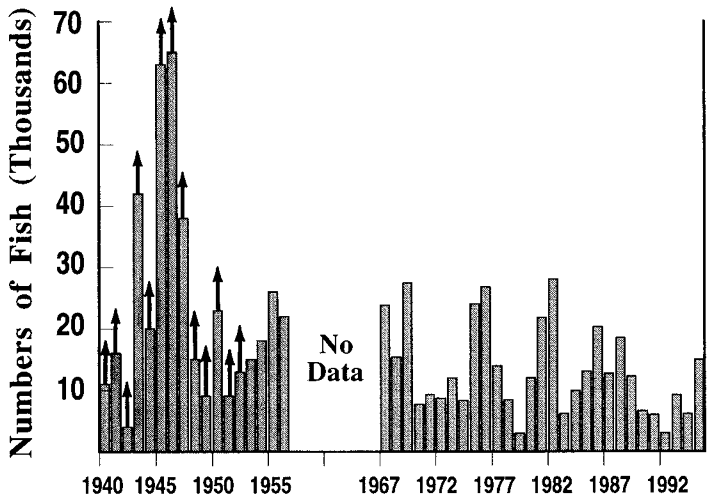

FIGURE 5.—Estimated spawning escapements for the Central Valley spring run of chinook salmon (data sources are as in Tables 4 and 5). For the earlier period, 1940–1956, only minimal estimates based on incomplete stream surveys were available. For the later period, 1967–1995, escapement estimates (including spring–fall hybrids) are for the Sacramento River drainage only because the spring run had been extirpated from the San Joaquin River drainage. By comparison with these abundances, the Sacramento–San Joaquin in-river commercial fishery harvested close to 567,000 spring-run chinook salmon during 1883 alone (CFC 1884), indicating that the spring-run salmon abundance for that earlier era was an order-of-magnitude greater.

mento River basin (PFMC 1998) suggest that recent environmental conditions have been opportune for reversing the attrition of the fall run. Increased fall-run spawning escapements since 1995 should facilitate the long-term restoration efforts currently underway to rebuild salmon stocks in the Central Valley region.

The Spring Run

Although exceedingly abundant historically, the spring run has undergone the most dramatic decline of the four chinook salmon runs in the Central Valley, as well as statewide (Figure 5; Campbell and Moyle 1991; Fisher 1994). The spring run was once the mainstay of the commercial fishery in California (Fisher 1994); 567,000 spring-run salmon (versus 213,400 fall-run fish) reportedly were caught in the Sacramento–San Joaquin commercial fishery during 1883 alone (CFC 1884). The California Fish Commission reported that during April, May, and June of 1901–1902, ''many tons of fish'' were shipped from the upper reaches of the main-stem Sacramento River: ''Small stations like Tehama and Chico, during May . . . each shipped as high as four and one half tons of fresh salmon in a single day. . . . Seldom would the shipments be less than a ton a day'' (CFC 1902:14). Nearly all of the large spring-run populations in Central Valley streams have been extirpated, and the remaining populations have been significantly reduced (Campbell and Moyle 1991). After the elimination in the late 1940s of the upper San Joaquin River spring run—the last major spring-run stock in the San Joaquin River drainage—spring-run salmon in the Central Valley system were restricted mainly to streams in the northern Sacramento Valley. Only remnants of the San Joaquin River basin spring runs were reported to have persisted through the late 1950s in the Merced River and ''to a much lesser degree'' in some other tributaries (Hallock and Van Woert 1959:246). In the Sacramento River basin, there was a spring-run population of up to a few thousand fish in the Feather River until at least the late 1950s (Fry 1961; Campbell and Moyle 1991). Although spring-run populations are purported to currently exist in a number of Sacramento Valley streams (CDFG 1990; Reynolds et al. 1993), most of them have hybridized with the fall run and are heavily introgressed with fall-run characteristics, particularly with regard to run-timing. For example, in 1988, 29% of the returning spawners to the Feather River Hatchery that were initially designated as fall-run fish based on their time of return were later determined by coded wire tag identifications to have been the offspring of ''spring-run'' parents; also, 22% of the fish with ''fall-run'' parents were initially incorrectly designated as spring-run due to their relatively early return times (CDFG, unpublished data). As early as 1963, Slater (1963) expressed concern that hybridization with the fall run may have eliminated the spring run ‘‘as a distinct race in the main-stem Sacramento River,’’ and he noted a decline in abundance of spring-run fish in the main-stem Sacramento River during the summer months. Total spring-run counts, including spring–fall hybrids, for the Sacramento River basin have been 3,000–14,900 fish (including grilse) during the period 1990–1997 (Table 5). Presently, unhybridized spring-run fish in the Central Valley system occur with certainty only in Mill, Deer and Butte creeks. During 1990–1996, the annual spring-run returns to Mill and Deer creeks collectively numbered around 330–1,620 fish. In Butte Creek (where the juvenile migration timing is different; USFWS 1995), annual run sizes were 100–750 fish during 1990–1994 and 1,180–7,480 fish during 1995–1996 (CDFG, unpublished data). Because of the generally low numbers of these unhybridized spring-run fish, the Sacramento River spring run is highly vulnerable to extirpation and, therefore, eventually may require protection under endangered species laws (Moyle et al. 1995). The spring run is presently being considered for threatened or endangered listing under both state and federal endangered species statutes. However, the increased total numbers of spring-run spawners in Mill, Deer, and Butte creeks in recent years (estimated ranges of 7,620–9,100 fish in 1995 and 2,040–2,280 fish in 1996; L. Davies, University of California, Davis, personal communication) and current efforts by private and public participants to apply flexible management measures offer hope that the decline of the spring run can be reversed in the near future, at least in those three small tributaries.

The Late-Fall Run

The late-fall run evidently ascended and spawned originally in the upper main-stem reaches of the Sacramento River above Shasta Dam and probably also in the San Joaquin River in the vicinity of Friant Dam and in several Central Valley tributaries (Clark 1929; Van Cleve 1945a; Reynolds et al. 1993; Fisher 1994). Late-fall run fish presently spawn mainly in the main-stem Sacramento River downstream from Keswick Dam to just below Red Bluff (Moyle et al. 1995). Although some ‘‘very late’’ fall-run fish were previously known to enter Central Valley streams in the winter (Fry 1961), the late-fall run was not fully recognized as a distinct run until 1966, when the completion of the Red Bluff Diversion Dam enabled monthly counts to be made of salmon passing the fish ladder. The CDFG personnel conducting the counts were astonished by the high numbers of that previously unknown run (exceeding 34,000 fish during the late 1960s) and also by the high abundance of the winter run at that time (Table 5). The late-fall run averaged approximately 25,220 fish during the first 10 years of monitoring (1967–1976), about 9,950 fish during the 1980s, and about 7,360 fish in 1990–1994 (Table 5). The relatively depressed run sizes during the past two decades led Moyle et al. (1995) to place the late-fall run within the ‘‘special concern’’ category of species population status.

The Winter Run

The winter run was first discerned as a distinct run in the early 1870s by Livingston Stone (Stone 1874a). These were the ‘‘prime salmon’’ that entered the lower Sacramento River during early November and appeared in the McCloud River beginning in March. Regarded as of the highest quality by Stone, the winter run was much less numerous than the spring and fall runs, ranging from ‘‘very scarce’’ in November to ‘‘increasing but not abundant’’ in January–February during its upriver migration (Stone 1874a:181). Yet, winter-run salmon apparently were at least occasionally numerous in the McCloud River. In 1878, Stone observed that by the time the fish weir for capturing the salmon had been completed on July 10, ‘‘vast numbers of full-grown salmon . . . had escaped the nets of the Sacramento fishermen and had already fully stocked the upper waters of the McCloud with spawning fish’’ (Stone 1880:742). Curiously, the uniqueness of the winter run was not recognized by some later fishery workers (Scofield 1900; USFC 1904), who appeared to believe that only two salmon runs—spring and fall—occurred in the Central Valley system. It was not until about 1940 that additional evidence was found and the winter run again was generally regarded as distinct from the others (Hanson 1940; Hanson et al. 1940; Slater 1963).

As with the spring run, but even more so for the winter run, the construction of in-river barriers eliminated access to spawning grounds that the winter run historically used. The winter run in California is now restricted to spawning within roughly 44 mi of the main-stem Sacramento River immediately below Keswick Dam, and the run is maintained solely by coldwater releases from Shasta Dam (Reynolds et al. 1993). The winter run seemed to thrive in that area until the late 1970s, exceeding the run sizes of both the spring and late-fall runs. Yet, the winter run remained vulnerable to various factors; run sizes of successive generations of spawning cohorts rapidly declined after the construction of Red Bluff Diversion Dam in 1966 (Williams and Williams 1991), and reproduction was further reduced in the drought years of 1976–1977 and 1987–1992 by unfavorable water temperatures below Keswick Dam during the spawning period (Fisher 1994). Current measures to remove barriers in the Battle Creek drainage upstream of Coleman National Fish Hatchery may provide winter-run salmon access to part of their historical spawning range and thus offer some insurance for the run's survival. The total winter-run population in the Sacramento River was approximately 117,800 spawners in 1969, but annual run-sizes declined dramatically thereafter (Williams and Williams 1991; Reynolds et al. 1993), numbering only 191–533 individuals during 1989–1991 (CDFG, unpublished data). Estimates of the winter-run spawning escapement in recent years have been from 200 to about 1,400 fish, and the population status is tenuous; the estimated escapement in 1995 included 1,300 adults and 100 grilse and total escapement has been about 900 fish each for 1996 and 1997 (PFMC 1998). The Sacramento winter chinook run was the first anadromous stock to gain protection under the U.S. Endangered Species Act. In 1989, the run was listed as ''threatened'' by the federal government and as ''endangered'' by the state of California, due to its unexpectedly low numbers that year (~500 spawners) and after a series of petitions and legal efforts by environmental and fisheries groups (Williams and Williams 1991). The federal listing status was changed in 1994 because of continued population decline and instability (NOAA 1994), and the winter run is currently listed as ''endangered'' under both state and federal statutes.

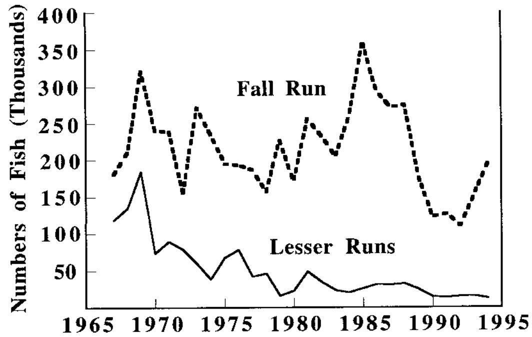

FIGURE 6.—Estimated spawning escapements during recent decades for the Central Valley fall run of chinook salmon and the aggregate lesser runs (late-fall, winter, and spring runs). Numbers of fish are approximate (probably within ±25%), but the trends are supported by other information (see text). Data are from unpublished CDFG reports and PFMC (1996).

Précis and Commentary

Status Quo

Thus, it has come to be that the two chinook salmon runs that formerly used the upper drainages of the Sierra Nevada and Cascade Range—the spring and winter runs—are now mere remnants of their past abundance. The winter run essentially no longer occurs in its original spawning range, and the spring run exists within only a fraction of its former range in perilously low numbers (Table 5; Moyle et al. 1995). Also, the lesser-known late-fall run has dropped to low levels and in recent years has numbered not much more than the beleaguered winter and spring runs. The fall run, currently by far the primary run in the Central Valley (Figure 6), is still productive, but it has shown substantial drops in some recent years (CDFG 1992) and is heavily supported by hatchery output (Fisher 1994; PFMC 1996). Using mainly the reaches or streams within the Central Valley floor and foothills, the fall run has been less dramatically affected by the loss and degradation of habitat caused by human activities in the Sierra Nevada and Cascades watersheds. Nevertheless, a continuing long-term decline of fall-run stocks could eventually lead to the complete loss of natural spawning runs in certain drainages. For example, in the San Joaquin River drainage, estimated aggregate run sizes for the Stanislaus, Tuolumne, and Merced rivers dropped to about 600 natural spawners in 1990 and 500 spawners in 1991, and total estimated annual escapements (natural plus hatchery returns) during 1992–1994 were 1,250–4,570 fish (CDFG 1996, unpublished data). These declines in the Central Valley salmon runs have been paralleled by downward trends in natural populations of chinook salmon and other salmonid species throughout California (Moyle et al. 1995; Mills et al. 1997). Further declines in spawning stocks and possible losses of entire seasonal runs will deplete the genetic diversity and seriously reduce the productivity of the chinook salmon resource of the Central Valley. In particular, the loss of adaptive genetic variation will probably have substantial negative consequences for efforts to rebuild depleted salmon stocks (CalGene 1982; Nehlsen et al. 1992; NRC 1996). Ultimately, that in turn will affect the viability of commercial and recreational fisheries that chinook salmon now support and have supported since the early years of Euro-American settlement in California.

The virtual elimination of spring-run and winter-run salmon from the upper watersheds of the Sierra Nevada and Cascades and the reduced abundance of naturally spawning fall-run fish in the lower reaches must have had a substantial, if not profound, impact on the biological productivity of those aquatic systems. Those great pulses of fish biomass decidedly affected human populations that lived along the salmon streams, and their impacts on the stream biota and ecological processes undoubtedly were no less important. The annual arrival of the spawning runs and subsequent die-off of the adults provided massive episodic influxes of organic material that fueled stream food webs and affected the richness of watercourses downstream, as well as the terrestrial fauna that foraged in and around the streams (compare Moyle 1966; Cederholm et al. 1989; Michael 1995; Willson and Halupka 1995; Bilby et al. 1996; Larkin and Slaney 1997). The young salmon life stages undoubtedly also served as important links in the stream-centered food webs, as has been observed in other regions (e.g., Reed 1967; Wood 1987a, 1987b; Willson and Halupka 1995). We cannot know in detail what effects the removal of salmon had on the stream energy flux and community dynamics, especially of the upper stream ecosystems, but it is inarguable that the face of the biological waterscape has been changed, perhaps forever.

Best Efforts or Failed Management?

Despite the history of widespread and precipitous declines of the Central Valley salmon stocks over the past century and a half, it would be inaccurate to conclude that the losses have been solely the result of avaricious intent or studied neglect. It is undoubtedly true that severe overexploitation by the in-river commercial fishery was a major factor contributing to the initial declines (CFC 1890; McEvoy 1986), but it was at least equaled by the profound effects of other activities, such as mining, irrigation, and power generation. Yet, salmon were recognized as a major natural resource early in the history of the state, as evidenced by the formation of the California Fish Commission in 1870 to manage the salmon and other fishery resources (CFC 1871). McEvoy (1986:69) noted that ''both as a highly coveted source of wealth and as a symbol of frontier abundance, the salmon fishery more than any other shaped the development of public policy for the fisheries during the nineteenth century.'' Fishing regulations for salmon were progressively introduced, starting in the early 1870s (Clark 1929, 1940), although some were admittedly ineffectual or even detrimental (Scofield 1919, 1921, 1929; Van Cleve 1945a). For example, closure of the in-river fishery during 1–2 months in the fall did nothing to protect the winter and spring runs, the prime targets of the fishery (CFGC 1916), and minimum mesh size regulations favored removal of the largest, most productive breeders and allowed the survival of smaller fish. Unfortunately, the early fishing regulations were also flagrantly violated on a massive scale (CFC 1877, 1879, 1880, 1894; Stone 1879). The California Fish Commission estimated that in 1877 alone, canneries took 50,000 salmon after the salmon fishing season had legally closed, and at least 100,000 additional fish were clandestinely salted or smoked on the banks of the sloughs (CFC 1877:21). An estimated 30,000 salmon were illegally taken and salted on the Sacramento River during the fall of 1880 (Jordan and Gilbert 1887:735). Such depredations severely curtailed the numbers of fish that reached the spawning grounds upstream, as noted by Stone (1879) for the McCloud River. Furthermore, the enforcement of fishing regulations was stultified by local sympathies for the lawbreakers (CFC 1879; Deering 1894), and political currents suffused even certain members of the California Fish Commission with a diffidence toward supporting enforcement (McEvoy 1986:111). Strong resistence by the fishing interests to salmon conservation measures continued into the early decades of the 20th century, which is reflected by the repeated failure of the state legislature to institute adequate protective laws, notwithstanding the recommendations of state fishery biologists and the California and U.S. Fish Commissioners (CFC 1873, 1888, 1890, 1894; Scofield 1919, 1921, 1929; CFGC 1923; CDFG 1937).

The longstanding investment of manpower and money into hatchery operations likewise attests to the early and continued efforts at serious management of the salmon resource (Shebley 1922a). By agreement with the California Fish Commissioners, the U.S. Fish Commission's Baird Station on the McCloud River was to hatch out and return to the water ''about one fifth of the whole yield'' of eggs (USFC 1882:30). After its temporary closure during the mid-1880s, Baird Station was reactivated in 1888 ''with the definite purpose of aiding in the maintenance of the salmon fisheries of the Sacramento River, which had been for several years rapidly deteriorating'' (USFC 1892:35; compare Shebley 1914:63). It was presumed that hatchery production enabled the periodic recovery of the salmon runs in the Sacramento River in the mid-1870s to early 1880s and in the early decades of the 20th century (CFC 1875, 1879, 1880, 1882, 1894; USFC 1882; Smiley 1884; Green 1887a; Stone 1897; Shebley 1922a). Indeed, Rutter (1904b:106) reported that the Sacramento River salmon runs were being maintained largely by artificial propagation, except for ''a considerable number'' that spawned in the main-stem Sacramento River between Redding and Tehama and that ''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.'' Yet, Clark (1929:23) cautiously noted that ''there is no evidence on either side conclusive enough to warrant making a definite statement as to the success or failure of artificial propagation.'' Skinner (1958: 2), referring to the increased catches around 1880, stated that ''present knowledge, however, indicated the runs most likely recovered on their own'' (see also Fry 1949). McEvoy (1986:87) likewise noted that the cooler and wetter coastal climatic regime during the 1880s seems to have been largely responsible for the resurgence of the salmon stocks, in consonance with the generally cooler conditions that prevailed from the mid-1870s to mid-1890s over the entire northern hemisphere, which affected other fish stocks as well (Ford 1982). At best, the contribution of the hatcheries would have been to enhance the survival of the salmon runs through the adverse periods until improved environmental conditions allowed their natural recovery. Admittedly, contemporary evaluations of the efficacy of the early hatchery operations seem to have been at times overstated. In the view of one state fish commissioner, ''if it were desirable, and the legislature made sufficient appropriation, the commissioners *could fill the river so full of salmon that it would be difficult for a steamboat to pass through them*'' (italics in original, Smiley 1884).

Presently, five hatcheries in the Central Valley are engaged in producing chinook salmon: Coleman National Fish Hatchery (on Battle Creek) and the Feather River, Nimbus (on the American River), Mokelumne River, and Merced River hatcheries. The first four were built to compensate for habitat loss stemming from water project construction, and the last was to compensate for impacts caused by irrigation diversions (Reynolds et al. 1993). Hatchery-produced fish now constitute a substantial fraction of chinook salmon production in the Central Valley. Notwithstanding the apparent benefits of hatcheries in bolstering salmon production, the potential and actual detrimental effects of hatchery-raised fish on natural (wild) stocks of salmonids have been increasingly recognized (Miller et al. 1990; Steward and Bjornn 1990; Busack and Currens 1995; Reisenbichler 1997). Those effects may include direct competitive interactions between hatchery and wild juveniles, elevation of predation pressure on juveniles, usurpation of spawning areas by hatchery-derived adults, disease transmission, and genetic dilution of wild stocks by interbreeding with hatchery fish (Steward and Bjornn 1990; Johnson et al. 1991; Brown et al. 1994). The potential genetic repercussions of hatchery operations upon wild stocks have received particular attention (Hindar et al. 1991, Waples 1991; Reisenbichler 1997). However, the significance of direct genetic effects of hatchery supplementation on naturally spawning Pacific salmon stocks remains poorly understood and controversial (Campton 1995), but undoubtedly the extensive transfers of nonnative stocks into certain watersheds and their continued artificial propagation have had substantial effects on the genetic character of native populations. One major example is the sustained massive production of hatchery coho salmon in the lower Columbia River for over three decades that evidently has effaced, presumably through genetic mixing, whatever genetic distinctiveness may have existed in the original coho salmon populations of that region (Johnson et al. 1991; NOAA 1991; Flagg et al. 1995).

In the Central Valley region, the extent of negative effects of hatchery production on the historical abundance of natural salmon stocks is unknown. In one instance, however, the CDFG has determined that a hatchery release of 532,000 yearling fall-run salmon into the Feather River resulted in their consumption (during January–February 1972) of ''as many as 7.5 million naturally-produced salmon fingerlings'' (Sholes and Hallock 1979:254). Also, hatchery practices have blurred the distinction between fall-run and spring-run salmon by allowing (or fostering) genetic mixing of the runs (e.g., at the Feather River Hatchery; Yoshiyama et al. 1996; Fisher, unpublished data). Furthermore, it is evident that increasing numbers of hatchery-derived adults have been returning and spawning in the American and Feather rivers (Fisher et al. 1991) and in other streams that have hatcheries (Battle Creek, Mokelumne and Merced rivers; FERC 1993; PFMC 1996; Fisher, unpublished data), and these hatchery fish probably have had substantial, albeit undetermined, negative effects on whatever populations of wild fish still exist in those streams.

Large-scale levee construction in the Sacramento Valley substantially altered the natural drainage patterns of low-lying areas, enabling the transformation of floodplains to farmland by preventing the overflow of flood waters. Levee construction possibly had a positive impact on salmon by reducing stranding of the vast numbers of juvenile salmon that formerly were swept onto the floodplains (Green 1887a, 1887b; Scofield 1913). However, the floodplains also offered productive rearing areas for juveniles, the benefits of which probably outweighed the losses of young salmon that were stranded as the floodwaters receded. Furthermore, the chaotic and often conflicting levee-building efforts in the Sacramento Valley (Kelley 1989) may have exacerbated the entrapment and losses of juvenile salmon. In any event, whatever benefit might have accrued from the levees was soon negated as more dams and irrigation diversions were put into place, leading to further wholesale losses of juveniles (e.g., to the Glenn–Colusa Irrigation District pumps and the Anderson–Cottonwood Irrigation District diversion canal; Phillips 1931; Hanson et al. 1940; Hallock and Van Woert 1959; Reynolds et al. 1993), until the screening of water diversion pumps and canals was instituted. The Glenn–Colusa Canal pumps alone were known to have imposed heavy mortalities on down-migrating juvenile salmon—''estimated in excess of 10 million fish''—before the installation of fish screens (Holmberg 1972:23). Yet, even the use of fish screens on the diversion canals met with obstacles. In 1913, the California Fish and Game Commission wrote that ''there has been a screen law in California nearly twenty years and this is the first Commission that has insisted on its enforcement'' (CFGC 1913:41). Up to that year, there had been no effective design for fish screens that allowed unimpaired water flow, and in previous years, the commission had been ''loath to take any action which might possibly stop the flow of water in the canals, since not only the material prosperity but the very existence of the population of the valley depends upon the irrigating water'' (Ferguson 1914:24). Remedial actions have come slowly, for in 1984 the California Department of Water Resources reported that ''tens of millions of downstream migrants have been, and in some cases still are, trapped in improperly screened or unscreened irrigation diversions and pumping facilities on both the Sacramento River and its tributaries'' (CDWR 1984:13). As recently as 1989, there were more than 300 unscreened diversions on the Sacramento River that diverted 1.2 million acre-feet of water each year, with associated annual losses of juvenile salmon reaching perhaps 10 million fish (USFWS 1995).

A detailed recounting and critique of the management of the Central Valley salmon stocks is beyond the purview of this report, and we mainly point out that there have been successes as well as failures.[2] A testament of the successes is the continued, if tenuous, existence of all four runs of Central Valley chinook salmon, despite the overwhelmingly inimical circumstances that have operated against their survival. Yet, the survival of the runs is even more a testimony of the resilience of the salmon themselves. Indeed, it is instructive to read the assessment by CDFG concerning the mitigation measures for construction of Shasta Dam, encompassed by the Shasta Fish Salvage Plan: ''[the plan] . . . contained many other features in addition to the construction of Coleman National Fish Hatchery. Virtually all the other 'mitigation' features [besides Coleman Hatchery] of the Salvage Plan either failed or were never implemented'' (Reynolds et al. 1993:I-3). And in the case of one other major water development project—Friant Dam on the San Joaquin River—no substantial measures were taken to conserve the salmon resource, aside from the foredoomed rescue efforts of the CDFG (CDFG 1955; Warner 1991). The Friant Dam Project resulted in the com-

[2] See Clark (1940) for an early history and Black (1995) for an interpretive historical perspective. Van Cleve (1945b) enumerated the general precepts for managing anadromous salmonids in the freshwater environment, and Reynolds et al. (1993), USFWS (1995) and CALFED (1997) give comprehensive accounts of current management recommendations for Central Valley salmon stocks. A relevant discourse on the history and philosophy of salmon management in the Pacific Northwest region is given by Nehlsen et al. (1992), and a programmatic framework for restoring salmon populations within an ecosystem context is presented by Lichatowich et al. (1995). A broad-based analysis of the Pacific Northwest ''salmon problem'' and a comprehensive strategy for addressing it are given in NRC (1996). Additional management perspectives are presented in Stouder et al. (1997).

plete destruction of the salmon runs in the upper San Joaquin River (CDFG 1990), including ‘‘what may have been the largest single population of spring run king [chinook] salmon in the State’’ (Skinner 1958:3), with an annual value of ‘‘almost one million dollars’’ (Hallock and Van Woert 1959: 246). It is ironic to read the words of a biologist from an earlier era in regard to managing the San Joaquin River runs:

> as the law provides that wherever a dam over which it is impracticable to construct a fishway for the free passageway of fish, the company or individual owning the same must erect and equip a suitable hatchery and egg collecting station free of charge to the state. An amendment to this law should be made at the next session of the legislature compelling the owners or occupants of such dams to not only construct and equip the hatcheries but to furnish the necessary funds to the Fish and Game Commission to operate the same, as they destroy the natural runs of fish and give the people nothing in return for the fishing interests that they destroy. [Shebley 1922b].

From a modern perspective, the major failing in this case was not so much the lack of tangible compensation, but in allowing the extirpation of the upper San Joaquin salmon runs. Their fate was, arguably, contrary to the intent of state law (e.g., Fish and Game Code, Section 5937; CDFG 1986) and the public trust doctrine, and it might have been averted (CDFG 1955), even if primarily by hatchery sustainment.

A Thought for the Future

Looking forward, we maintain that the key to successful salmon management in the Central Valley drainage lies in the effective management of the rivers and upland streams, not merely as water conveyance channels but also as living systems (Nehlsen et al. 1992; Reynolds et al. 1993; The Wilderness Society 1993; Bottom 1995). Current programs aimed at achieving integrated restoration of chinook salmon and other aquatic species together with their natural environments are in the initial phases of development and implementation (e.g., USFWS 1995; CALFED 1997). Those programs include water management (e.g., increased streamflows), habitat restoration, and other aspects. For example, the CALFED Ecosystem Restoration Program Plan (CALFED 1997) presents ‘‘visions’’ of restoration-targeted watersheds and their component ecosystems for most of the Central Valley drainage. That plan, combined with specific restoration actions recommended by the U.S. Fish and Wildlife Service (USFWS 1995) and the Comprehensive Assessment and Monitoring Program outlined by that agency (Montgomery Watson et al. 1997), provide a possible framework for restoring salmon populations in Central Valley streams to at least double the average levels that occurred during 1967–1991, as specified by the U.S. Central Valley Improvement Act of 1992 (USFWS 1995).

In an increasingly resource-limited world, it is imperative that management of fishery resources and their habitats be fully integrated with that of water supply and of land-based resources in a balanced and rational fashion (Nehlsen et al. 1992; Pimental et al. 1997). Failure to do so will probably lead to continued dwindling of the Central Valley natural salmon stocks to commercial, and perhaps biological, extinction, and the main legacy of these stocks will be to serve as another example of societal failure to sustainably manage a major fishery. But if effective integrated management can be achieved—fully recognizing ‘‘the interdependence between ecological, economic, and social processes’’ (McEvoy 1986:257)—then the chinook salmon of the Central Valley may yet fill a critical role in supplying the future economic, recreational, and aesthetic needs of the people of California, much as they have done in the past.

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