Table 1. Relative importance of factors contributing to the decline of anadromous fishes in California. Subjective scores for each species range from 1 (major cause of decline) to 5 (not a cause).

Species	*Water Degradation*	*Diversions*	*Pollution*	*Overfishing*	*Hatcheries*	*Ocean Conditions*	*Precipitation*	*Predation*	*Other*
River lamprey	1	3	3	4	4	3	2	2	3
Pacific lamprey	1	2	3	4	4	3	2	2	2
White sturgeon	3	2	3	2	4	4	2	4	4
Green sturgeon	2	2	3	1	4	3	2	4	3
Delta smelt	3	1	3	4	4	4	2	3	2
Longfin smelt	2	1	3	4	4	3	2	2	2
Eulachon	2	2	4	3	4	2	3	2	4
Chinook	1	1	3	2	2	3	2	2	3
Coho	1	1	3	2	1	2	2	3	3
Pink	2	3	4	4	4	2	2	2	2
Chum	1	3	4	4	4	2	2	2	2
Steelhead	1	1	2	2	2	3	2	2	3
Cutthroat trout	1	3	4	3	3	2	2	3	3
Total points	21	25	42	44	45	43	27	33	34
Rank	1	2	6	8	9	7	3	4	5

For each species each factor was rated on a subjective 1–4 scale, where 1 indicates the factor was probably a major cause in the decline of the species; 2 a moderate contributing factor to the decline; 3 a minor cause; or 4 had no effect on the species. The scores for each factor were added and ranked from lowest to highest, with the lowest scores indicating the factors with the highest overall impact on anadromous fish populations. Watershed degradation, diversions, and variation in precipitation were ranked 1, 2, and 3, respectively (Table 1).

Decisions being made now will determine which species and stocks will become extinct in California in the near future and what segments of the original gene pools will be in existence for future use and evolution. It is possible that California stocks may be especially vulnerable if warming trends push oceanic and stream conditions to which salmonids are adapted further north. Conservation of California's anadromous fishes requires a systematic program of ecosystem protection (Moyle & Williams 1990; Moyle & Yoshiyama, 1994).

Literature Cited

Moyle, P. B., and J. E. Williams. 1990. Biodiversity loss in the temperate zone: decline of the native fish fauna of California. Conservation Biology 4:275–284.

Moyle, P. B., and R. M. Yoshiyama. 1994. A five-tiered approach to protecting aquatic biodiversity in California. Fisheries (Bethesda) **19(2)**:6–18.

Peter B. Moyle
Department of Wildlife and Fisheries Biology
University of California—Davis
Davis, CA 95616, U.S.A.

Past and Present Status of Central Valley Chinook Salmon

California's Central Valley chinook salmon populations are a fragment of their former abundance. Water development for hydroelectric production, irrigation, domestic water supplies, and flood control has restricted or eliminated much of the natural habitat formerly occupied by Central Valley salmon. Much of the species historical habitat has been replaced by hatcheries. Where certain runs are difficult to domesticate for hatchery culture, only isolated population remnants remain.

Adult chinook salmon in the ocean and juveniles in freshwater are very similar anatomically and morphologically. Only adult salmon, returning to spawn and completing their life cycle, exhibit radical differences among individuals. Therefore, Central Valley salmon runs have been vaguely defined based upon migration timing and inconsistent reports of spawning times. Stone (1874) described three runs of salmon in the Sacramento River: spring, summer (fall), and winter runs based upon their appearance in tide-water. A fourth run, late-fall, was described by Fry (1961) after large numbers of mid-winter spawning chinook salmon were trapped during Keswick operations of Coleman National Fish Hatchery. In 1967, with completion of the Red Bluff Diversion Dam and the associated fish trap, salmon migration and spawning timing at Red Bluff was determined from aerial and spawning ground surveys. Although there is considerable overlap within migration times between each run, spawning occurs at distinctly different times. Therefore each run is temporally isolated from each other, with the exceptions of overlap between fall and spring runs. Formerly fall and spring runs were spatially isolated from each other with spring run occupying the headwaters and fall run occupying the lower portions of streams near the valley floor. Cope and Slater (1957) questioned the genetic integrity of spring and fall runs after forced coexistence in the Sacramento River below Shasta Dam indicated hybridization had occurred. They concluded, from marking experiments, that each run tended to return at their appropriate time but some mixing had occurred. Slater (1963) later concluded that serious hybridization was taking place between the fall and spring runs, with fall run out-competing spring run for available spawning habitat in the Sacramento River. Other evidence based upon recent coded-wire tag returns from Feather River Hatchery indicate that current hatchery practices, using arbitrary spawning dates, leads to a significant amount of mixing between these runs.

Other unique biological characteristics further define Central Valley Chinook salmon runs (Table 1). Winter and spring runs are particularly vulnerable to catastrophic events because of the nearly singular age at maturity and because there is little contribution by older-year classes. The dominance of three-year-old females results in reduced population fecundity and places these runs at risk if changes in egg or juvenile mortality increase or excessive exploitation takes place.

All of the Central Valley salmon runs have incurred permanent habitat losses of varying amounts. In 1872 Stone (1874) observed that the absence of salmon in the American, Feather, and Yuba Rivers was due to poor water quality from intense mining activity. Although hydraulic mining was abolished in 1884, these rivers were later recolonized by salmon for only a short time before water development activities permanently cut off access to the spawning grounds. From 1900 to 1930 hydroelectric development and irrigation projects truncated large portions of the headwaters of most Central Valley rivers by dam construction. By 1928 Clark (1929) estimated 510 lineal miles remained of the original 6000 miles, an 80% reduction of principally spring-run spawning area. With completion of the Friant Dam in 1942, spring-run salmon were eliminated from the San

Table 1. Descriptive characteristics of Central Valley salmon runs.

Characteristic	*Late Fall Run*	*Winter Run*	*Spring Run*	*Fall Run*
Migration period	October–April	December–July	March–July	June–December
Peak migration	December	March	May–June	September–October
Spawning period	early January–early April	late April–early August	late August–early October	late September–December
Peak spawning	early February	early June	mid-September	late October
Average percent grilse	11%	22%	24%	20%
Percent female at:				
Age 2	2%	1%	2%	3%
Age 3	57%	91%	87%	77%
Age 4+	41%	8%	11%	20%
Average population fecundity	5806 eggs	3743 eggs	4895 eggs	5498 eggs
Juvenile emergence period	April–June	July–October	November–March	December–March
Juvenile residency	7–13 months	5–10 months	3–15 months	4–7 months
Ocean entry	October–May	November–May	March–June & November–March	March–July
Juvenile size at ocean entry	160 mm (F.L.)	120 mm (F.L.)	80 mm (F.L.)	80 mm (F.L.)
Former spawning habitat	Upper mainstem rivers	spring–fed streams	headwaters	lower rivers and tributaries

Joaquin drainage. Simultaneously, the Shasta Dam on the Sacramento River eliminated an estimated 200 miles of spring-run habitat and nearly all winter-run spawning grounds. Only Mill, Deer, and Butte Creeks remain to support remnant populations of spring run and none of the original spring-fed habitat is useable or available to winter run. Winter-run salmon were displaced into the Sacramento River downstream of the Shasta Dam where water temperatures were initially suitable for successful reproduction. However, Moffett (1949) forewarned of changes in water temperatures after the Central Valley Project became fully operational and during drought periods. Water temperatures became unfavorable for successful spawning during 1976–1977 and recent droughts.

Late-fall salmon were formerly present in the San Joaquin River (Hatton and Clark 1942) and the Sacramento River system (Hanson et al. 1940). The original late fall–run spawning grounds were apparently located at the northern and southern extremes of the valley floor where summertime water temperatures afforded suitable juvenile rearing conditions. The Friant Dam eliminated the San Joaquin habitat for late fall–run salmon and the Shasta Dam altered the Sacramento River. Of the four salmon runs, the fall run has been least affected by dam construction. The fall run is the most cosmopolitan run in the Central Valley, occupying the lower reaches of most tributary streams and valley floor rivers where suitable spawning gravel is present. Overall, most of the historical range for fall run remains except for the San Joaquin River and a portion of the Sacramento upstream of the Shasta Dam. However, conditions throughout the San Joaquin drainage have been severely altered by water projects, and salmon production is strongly related to spring flow conditions (Kjelson & Brandes 1989). Kielson and Brandes (1989) also found that habitat changes due to water development in the Sacramento–San Joaquin Delta significantly affected Sacramento River stock, with fall-run smolt survival being highly correlated to river flow, temperature, and percent of inflow diverted.

Annual landings from the Sacramento–San Joaquin gill-net fishery may provide an insight into the history of Central Valley salmon runs (Clark 1929; Clark 1940; Skinner 1962). By 1870 a gill-net fishery was already well established with markets developed for fresh salmon and an expanding canning industry. Salmon fishing initially was concentrated primarily on winter and spring runs because of their fresh appearance and excellent condition with fall run of limited value because of their advanced spawning condition (Stone 1874).

A run index, based upon limited monthly landing records and known migration characteristics for each run, was developed that indicates the relative catches for each run by decade (California Fish Commission 1882, 1900; Clark 1940). Up until 1900 spring run dominated the catches with fall run being of secondary importance. This decline in spring run closely parallels the reduction of habitat at the turn of the century and increased emphasis on fall run hatchery production (Shebley 1922). Applying the developed run index to annual landings and assuming that one half of the winter and spring runs were harvested each year provides an estimate of run size (Fulton 1968). I used a harvest rate of one third for late fall and fall runs because of their inferior quality and limited harvest by the early fishery. Using this approach, although circumspect, provides an abundance index for each of the four Central Valley runs before the twentieth century. It is possible that maximum spawning runs, including harvest, may have approached 2,000,000 fish, comprising 100,000 late fall–, 200,000 winter-, 700,000 spring-, and 900,000 fall-run salmon.

Recent population estimates for the Central Valley indicate a substantial reduction in spawning salmon taking place within the past two decades, mainly on late-fall and winter runs (Table 2). Wild spring run populations in Mill and Deer Creeks show a continuing decline with fluctuating populations present in Butte Creek. A possible listing of spring-run salmon under the Federal Endangered Species Act is imminent. Only fall-run salmon continue to maintain reasonable, although low, spawning runs that are heavily supported by hatchery production.

Table 2. Total Central Valley chinook salmon spawning stock estimates, including hatchery returns, 1967–1992.

Year	*Late-fall Run*	*Winter Run*	*Spring Run*	*Fall Run*	*Total*
1967	37,208	57,306	23,840	182,828	301,182
1968	34,733	84,414	15,360	211,371	345,878
1969	38,752	117,808	27,447	322,475	506,482
1970	25,310	40,409	7672	244,145	317,536
1971	16,741	63,089	9274	241,958	331,062
1972	32,651	37,133	8652	154,665	233,101
1973	23,010	24,079	11,967	273,880	332,936
1974	7855	21,897	8281	236,228	274,261
1975	19,659	23,430	24,044	197,789	264,922
1976	16,198	35,096	26,786	196,189	274,269
1977	10,602	17,214	13,951	185,390	227,157
1978	12,586	24,862	8358	158,198	204,004
1979	10,398	2364	2960	229,143	244,865
1980	9481	1156	11,937	175,370	197,944
1981	6807	20,041	21,784	265,752	314,384
1982	4913	1242	28,082	240,108	274,345
1983	15,190	1831	6193	220,651	243,865
1984	7163	2663	9923	264,488	284,237
1985	8436	3962	13,055	368,942	394,395
1986	8286	2464	20,329	293,399	324,478
1987	16,049	1997	12,720	276,636	307,402
1988	11,597	2094	18,486	275,576	307,753
1989	11,639	533	12,266	172,778	197,216
1990	7305	441	6630	119,832	134,208
1991	7089	191	5944	127,119	140,343
1992	10,370	1180	2997	113,948	128,495

Literature Cited

California Fish Commission. 1882. Report of the commissioners of fisheries of the state of California for the years of 1881–1882. Sacramento, California.

California Fish Commission. 1900. Fifteenth biennial report of the state board of fish commissions of the state of California for the years of 1897–1898. Sacramento, California.

Clark, F. H. 1929. Sacramento–San Joaquin salmon, *Oncorhynchus tshawytscha,* fishery of California. California Fish and Game Bulletin **17**:73.

Clark, F. H. 1940. California salmon catch records. California Fish Game **26(1)**:49–66.

Cope, O. B., and D. W. Slater. 1957. Role of Coleman Hatchery in maintaining a king salmon run. Fish and Wildlife Service Research Report **47**.

Fry, D. H. 1961. King salmon spawning stocks of the California Central Valley, 1940–1959. California Fish and Game **47(1)**:55–71.

Fulton, L. A. 1968. Spawning areas and abundance of chinook salmon, (*Oncorhynchus tshawytscha*), in Columbia River Basin—past and present. U.S. Fish and Wildlife Service, Special Science Report on Fish **571**, Washington, D.C.

Hanson, H. A., O. R. Smith, and P. R. Needham. 1940. An investigation of fish salvage problems in relation to Shasta Dam. U.S. Fish and Wildlife Service Science Report on Fish, No. **10**, Washington, D.C.

Hatton, R. S., and G. H. Clark. 1942. A second progress report on the Central Valley Fishery Investigations. California Department of Fish and Game **28(2)**:116–123.

Kjelson, M. A., and P. L. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento–San Joaquin Rivers, California. Canadian Special Publication on Fisheries Aquatic Science **105**:100–115.

Moffett, J. W. 1949. The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California. California Fish and Game **35(2)**:77–102.

Shebley, W. H. 1922. A history of fish cultural operations in California. California Fish and Game **8(2)**:61–99.

Skinner, J. E. 1962. Fish and wildlife resources of the San Francisco Bay area. California Fish and Game Water Project Branch Report **1**, Sacramento, California.

Slater, D. W. 1963. Winter-run chinook salmon in the Sacramento River, California with notes on water temperature requirements at spawning. U.S. Fish and Wildlife Special Science Report **461**, 9 pp. Washington, D.C.

Stone, L. 1874. Report of operations during 1872 at the United States salmon hatching establishment on the McCloud River. U.S. Commission on Fish and Fisheries, Report for 1872 and 1873, Part II: 168–215. Washington, D.C.

Stone, L. 1876. Report of operations in California in 1873. U.S. Fish Committee Report for 1873–1874 and 1874–1875:377–429.

Frank W. Fisher
California Department of Fish and Game
Red Bluff, CA 96080, U.S.A.

Extinction Probabilities and Delisting Criteria for Pacific Salmonids

As the number of Pacific salmon runs being considered for listing under federal and state endangered species laws increases (Nehlsen et al. 1991), there will be an increasing need for effective means of estimating probabilities of their extinction. Probabilities of extinction under various conditions can be used to: (1) assess the current status of runs, (2) plan strategies for population recovery, and (3) specify criteria for complete recovery and consequent delisting.

The models used for these calculations should be based on life history data (age-specific survivals and fecundities) and information on their density dependence as well as environmental dependence. For most species, some life history data are available, and for a few there are even time series or other information from which dependence on environment and density can be determined. In general, density dependence will be important if the population has been reduced to a low level by