D. W. KELLEY & Associates aquatic biology

THE INFLUENCE OF FLOW ON CENTRAL VALLEY SALMON

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Prepared for the

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PREFACE AND ACKNOWLEDGMENTS

This report was first issued in March 1986 as a Sacramento River analysis. This edition has been updated in response to the many readers who offered comments and criticism and in response to some additional information we have obtained. The principal change has been to modify the estimates of historical catches supported by Central Valley chinook in Chapter III. There is so much known and to learn about salmon of the Central Valley that a report of this kind can never be called complete.

We are grateful to the many biologists and managers who have shared their knowledge with us. We can present this as our, not necessarily their, present understanding, with a renewed request for criticiscm and comment.

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THE INFLUENCE OF FLOW ON CENTRAL VALLEY SALMON

EXECUTIVE SUMMARY

The US Fish & Wildlife Service (USF&WS)/California Department of Fish and Game (CF&G) Program in Stockton has been conducting experiments to assess the survival rates of juvenile salmon as they move down the Sacramento River through the Delta and the Bay. Our review of those experiments leads us to believe that both of their estimates of survival, one based on Chipps Island trawl capture rates of coded wire tagged juveniles planted in the North Delta, and the other based on coded wire tag returns from these same groups of planted fish captured as adults in the ocean, are valid. Both estimates provide evidence that survival rates increase in direct proportion to Sacramento River flow up to levels of about 30,000 cfs at I Street. The experiments continue with modification to identify the effects of spring water temperatures and the fraction of river flow being diverted.

As a check on the USF&WS/CF&G experiments, we compared the return of these coded wire tags retrieved from spawning escapements with Sacramento River flow and Delta outflow. We found a positive correlation between an index of spawning returns, based on these coded wire tags, and June flow in the Sacramento River, and with both June and July outflow from the Delta.

Have these flow/survival relationships been reflected in historical records of catch? The long-term historical record of salmon catches from the Sacramento-San Joaquin system provides annual estimates of catch in the gill net fisheries from 1864 to 1957, the ocean commercial troll fisheries since 1915, the ocean sport fisheries since 1960, and estimates of the spawning escapements since 1953. Our analysis of these data describes how the Sacramento Basin-produced salmon population fell to low levels in the 1930s, recovered in the 1940s, and has fluctuated around 650,000 fish ever since. There has been a major reduction in the upper Sacramento River spawning runs, but the Feather and American rivers runs have increased, probably due to hatchery operations. Those increases are probably supporting much of the ocean fishery. Total landings have fluctuated around one-half million fish the last three decades.

The changes in spawning escapements have been accompanied by a reduction in the number of large older fish. In most years almost 90 percent of the salmon returning to the Sacramento River Basin are less than 4 years old. Most are 3 years old.

To assess the effect of environmental conditions, when the juveniles are emigrating down the Sacramento River and through the estuary, on adult populations, we used age composition information to estimate how many of each year's production of juveniles reached adulthood and returned to spawn. These "return indexes" should be correlated with spring environmental conditions which affect survival rates, but we found no correlation between the mainstem

Sacramento and American rivers "return indexes" and the Sacramento River flow or Delta outflow. There was a significant positive correlation between the Feather River indexes and June Sacramento River flow and July Delta outflow. For lack of more age composition data, the return indexes could only include 12 of the 30 years of escapement estimates in the Sacramento River Basin. The data may not be adequate to define relationships even if they exist.

We conducted a second analysis of the relationship between adult returns from each spring's juvenile production and environmental factors by using 2-year moving averages of spawning escapements, Sacramento flows, and Delta outflow. The resulting analysis provides evidence that through 1967 there was a positive relationship between upper Sacramento River salmon production and spring Sacramento River flow and Delta outflow, but that since 1968 no such relationships are observable. Similar correlations exist for Feather River production, but we found none at all for the American River since 1969.

The various analyses described in this report are evidence that both juvenile salmon survival and adult population size has been related to Sacramento River flows and Delta outflow. Our analysis suggests that the relationship between those flow parameters and adult population size has broken down in recent years. It is reasonable to suspect this to result from the CF&G policy of planting large numbers of salmon smolts directly into the estuary, thus avoiding the risks of the Sacramento River and the Delta. This may be why low flows during the 1976-77 drought were not reflected in either catch or spawning escapement several years later. Additional analysis of the role of planted fish should shed more light on this matter.

The major assumption required in concluding that Sacramento River flow and Delta outflows are related to the survival of emigrating juveniles is that those fish reared in hatcheries will, when stocked in the rivers, behave and survive like the progeny of river spawners. The need now is to evaluate the performance of hatchery fish relative to wild fish to assess the relative contribution of hatchery and naturally produced fish to adult populations.

CHAPTER I. FACTORS ASSOCIATED WITH THE SURVIVAL OF FALL RUN JUVENILE SALMON IN THE SACRAMENTO RIVER.

This report describes our efforts to define how Sacramento River streamflow and Delta outflow have influenced the survival and abundance of fall run juvenile chinook salmon. Obviously, many factors affect these young fish and their subsequent return as adults. These factors include floods, changes in food production, stream temperatures, water quality, predation, unscreened agricultural diversions, the combined effects of the State and Federal pumping plants, and the increased harvest of the adult population in the ocean. All act in unison and tend to obscure the effect of any one.

To illustrate the relative importance of different phases in the life cycle of the fall run chinook salmon, we constructed Figure I-1, illustrating the hypothetical fate of 5000 eggs produced from a spawning female. Survival of eggs to returning adults varies between years but in a stable population over the long-term, survival will equal about 0.04 percent. This is based on a fecundity of 5000 eggs per female and the need for one male and one female to return and spawn. From 1953 through 1983, the ratio between catch and escapement has varied from about 1.5 to 6. Using these ratios we estimate there will be 3-12 fish caught in the ocean fishery for every 5000 eggs laid. Therefore, survival from the 5000 eggs to adults in the ocean will vary from 0.1 to 0.3 percent. In tributaries of the Sacramento River, Gangmark and Broad (1956) and Wales and Coots (1954) found that the survival rate from deposited eggs to fry emigrant ranged from 7 to 60 percent depending upon the amount of scour and stability of the flow when the eggs were incubating. Using these estimates, we calculate that the original cohort of 5000 eggs can be reduced to 350 to 3000 young swim-up fry (Figure I-1). After smolts have migrated through the lower river and estuary, their survival improves considerably. Using tag return data for postsmolt Columbia River salmon, Van Hyning (1973) estimated the return of 12-20 inch smolts to range from 39 to 75 percent. Since outmigrants from the Sacramento-San Joaquin are typically smaller than 12 inches, survival rates are probably lower. If 30 percent is used, we calculate that 17 to 47 outmigrant smolts would have been required to produce 5 to 14 returning adults (Figure I-1). This example requires a survival rate from swim-up fry to first summer outmigrants of 0.6 percent to 13.4 percent. Obviously, even small changes in these survival rates will have large effects on the return of adults to the fishery and spawning escapement groups. Thus, conditions in the stream environment during egg incubation, feeding, and emigration are important. In the mainstem of the Sacramento River, releases above Red Bluff and in the Feather River below Oroville Dam tend to stabilize flow during the spawning and incubation periods and we believe that the emergence from eggs to fry is usually high. This may mean that survival during the downstream migration and smolting phases are of major importance as a determinant of adult returns.

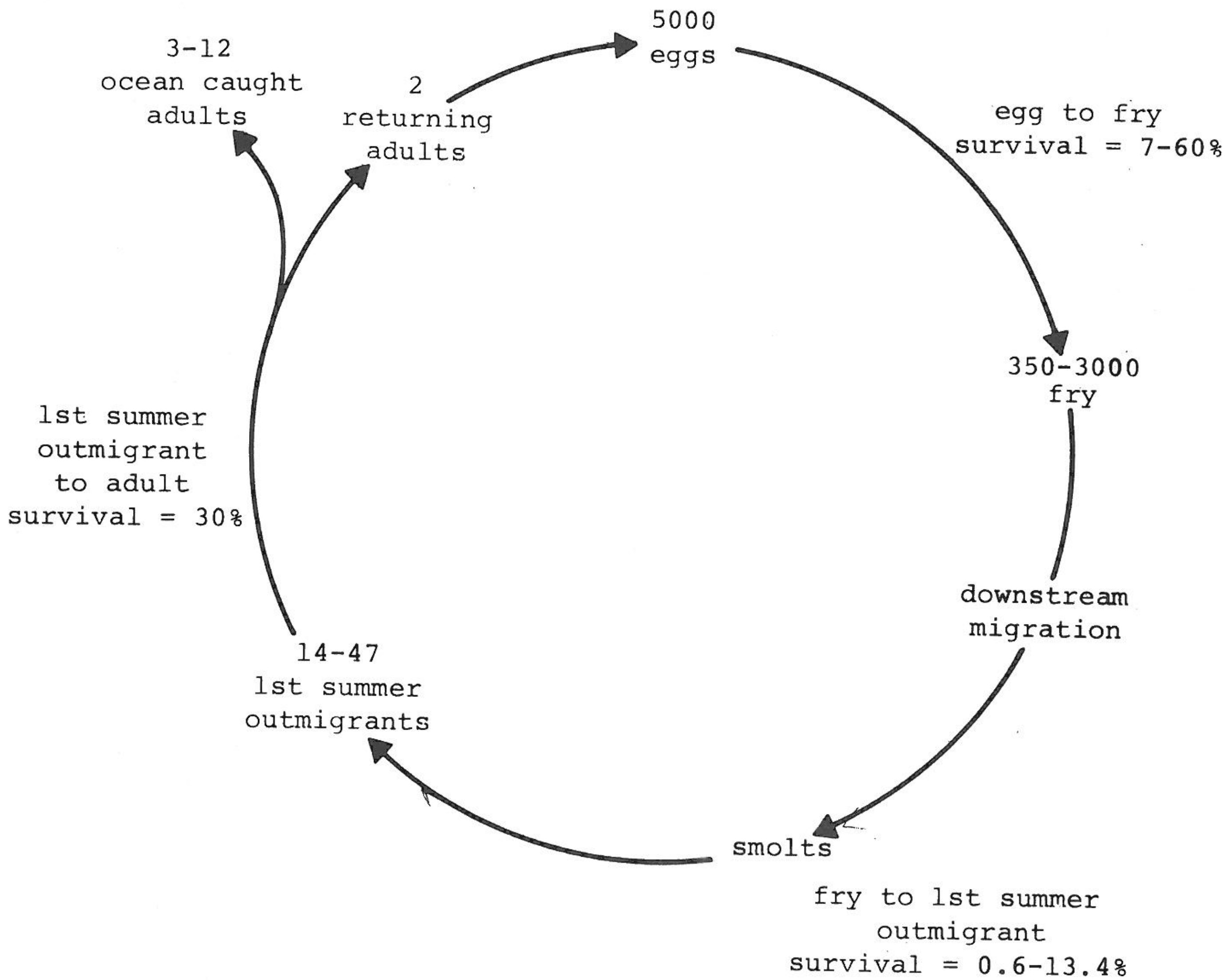

Figure I-1. Hypothetical model of chinook salmon life cycle showing the fate of 5000 eggs produced by a pair of spawning adults.

TIMING OF DOWNSTREAM MOVEMENT OF FRY AND JUVENILE SALMON

Accurate knowledge of timing of downstream fry movements and smolt migration is important for determining when streamflow may exert an effect on the survival of young salmon. Based upon our review of the historical association between downstream migration and winter and spring flows, we believe it is most appropriate to correlate the survival and abundance of fry to Sacramento River streamflow from December through April and to correlate survival of smolts to flows of April through June. Delta outflow may be important to smolt survival during June and July.

Timing of Fry Movement

Downstream movement of fry is influenced by the timing of the upstream adult migration and the water temperature which influences the length of the incubation period. In reviewing historical adult upstream migration, Hallock and Fry (1967) summarized findings of Rutter (1903) who found that most fall run fish moved into the river between the first of September and December, and most spawning occurred in November and December. Records from recent carcass counts on the Feather River (Reavis 1983) show that spawning now begins about October 15, peaks in the week before November 15, and is completed by December 10. Similarly, records of adult migration at the Red Bluff Diversion Dam show peak migration there occurs between October 4 and 10. Most spawning in the upper Sacramento River is completed by early or mid-November.

The duration of incubation and timing of emergence depend primarily upon water temperature. The time between fertilization and hatching varies from 6 weeks at 12^{o} C to 13 weeks at 5^{o} C (Godin 1982). After hatching, the sac-fry remain in the gravel for a period of time depending upon temperature. Rutter (1903) found that this period of time ranged from 2 to 3 weeks.

After emergence, young salmon fry begin to disperse downstream into their initial feeding areas. At this time streamflow apparently begins to exert an influence upon their distribution. Kjelson et al. (1982) reported that fry abundance was usually greatest in the Delta between February and March following major storms, and that in wet years, such as 1982 and 1983, high flows dispersed young as far down as San Pablo and San Francisco Bays. Kjelson, using numbers and minimum size of fry caught in seine hauls, estimated that dispersal of fry occurs through the end of March.

Timing of Smolt Migration

Beginning in late March, the average size of juvenile chinook salmon in the Delta begins to increase, indicating that the fish are growing and that larger individuals are beginning to move downstream from upstream rearing areas. By April, young salmon that have reached the length of about 70 mm are classified as smolts and they begin to migrate to the ocean.

Smolt downstream migration coincides with historical flow increases caused by the melting snowpack in the Sierras. Wickwire and Stevens (1971) found migrating salmon smolts passing Collinsville in three discrete groups with peak movement occurring between April 3 and May 4, May 16 and May 22, and May 26 and June 5. Messersmith (1966) and Sasaki (1966) sampled young salmon smolts at Carquinez Straits and in the Delta, and found the peak catch occurred in May 1962 and June 1964. Records of salmon caught at the State pumping plant at Tracy (California Department of Fish and Game 1981) document similar seasonal movement of young salmon smolts (Figure I-2). With the exception of 1977 and 1978, most juvenile salmon were caught in April, May, and June, usually with a peak in May.

Because of the coincidental timing of increased streamflow and the outmigration of young smolts, the USF&WS and CF&G hypothesized that high flows at this time of the year benefit the outmigration and survival of smolts. They have used correlations between streamflows in May and June and the survival of marked and planted fish to test this hypothesis.

The influence of Delta outflow on the abundance and survival of juvenile salmon smolts in San Pablo and San Francisco Bays is unknown. The Bay-Delta Study group began sampling in San Francisco Bay at Golden Gate Bridge in 1983, and preliminary results indicate that smolts are in the Bay through July. Trawl catches increased to a peak in June with four to five times as many smolts caught in May and June as in April and July. However, this catch index cannot be directly linked to abundance in the Bay, because large smolts in June and July are probably not caught as efficiently as the small smolts in May and June.

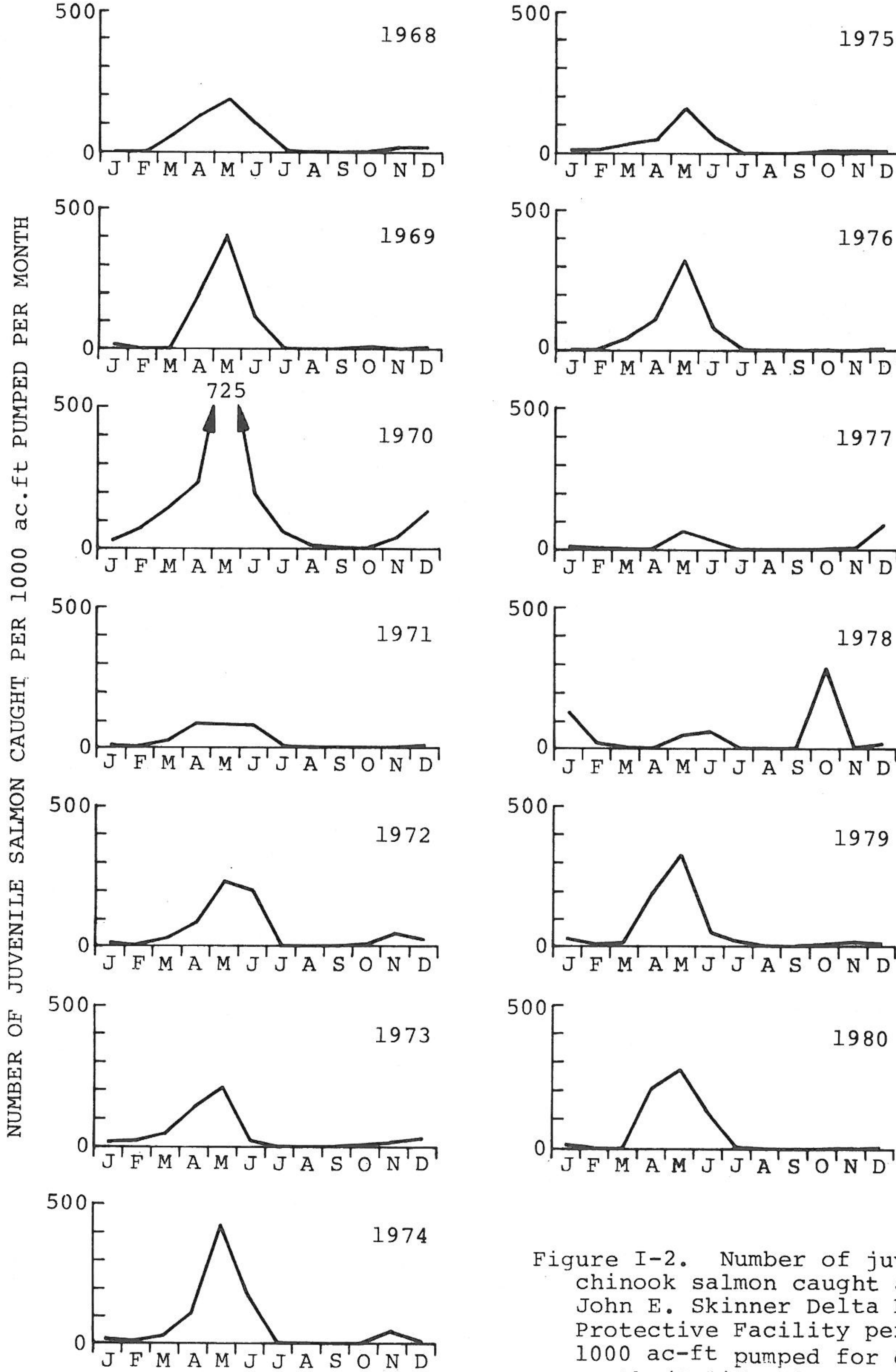

Figure I-2. Number of juvenile chinook salmon caught at the John E. Skinner Delta Fish Protective Facility per 1000 ac-ft pumped for each month (California Department of Fish and Game 1981).

CHAPTER II. REVIEW OF THE CFG/USF&WS COMPARISON OF JUVENILE SALMON SURVIVAL WITH STREAMFLOW IN THE SACRAMENTO RIVER

Biologists Donald Stevens, CF&G, and Martin Kjelson and Patricia Brandes, USF&WS, (1984; 1985) have developed both indices and estimates of the rates at which juvenile salmon survive as they emigrate down the Sacramento River. Their comparison of these with the streamflows at I Street leads them to conclude that, when flows were 30,000 to 35,000 cfs, the survival of these young salmon swimming down this reach of the river was 6 to 10 times as high as when flows were 10,000 cfs (Figures II-1 and II-2). Their estimate of survival is based upon the ratio of tags returned from juvenile salmon planted at Sacramento (or in one case, Knight's Landing above Sacramento) and downstream at Port Chicago and Rio Vista. The percentage of tags that are recovered is small ranging from 0.03 to 2.7, but the ratio between the recovery rate of tags planted at the upstream and the downstream station, adjusted for numbers planted and for the different distances between the stations, seems a valid estimate of the survival in this reach of river. This estimate is called the "ocean index".

The "trawl index" is based upon the number of marked fish planted upstream and then captured by trawling near Chipps Island. This index is adjusted to consider the fraction of the migration period that the trawl was fishing and the fraction of the stream channel that was sampled. Unlike the "ocean index", the "trawl index" is not an estimate but an index of survival.

VALIDITY OF THE SURVIVAL ESTIMATE AND THE SURVIVAL INDEX

We have had a number of useful discussions and written exchanges with Don Stevens, Marty Kjelson, and Pat Brandes, about the validity and biases involved in these indexes, and they have drafted a report which addresses potential biases. It is important to distinguish between any biased results of these particular studies and inappropriate interpretation of those results, which we will cover in the next section.

We were all concerned that there might have been higher planting mortality at Sacramento but we could find no evidence of it. We were also concerned that the planting of different size fish might have injected an important bias. Stevens, Kjelson, and Brandes have examined the problem that fish were of different size and concluded that size did not cause the correlations between salmon survival and river flow.

The "trawl index" is probably biased low during a period of high flow and high during a period of low flow. This is because it assumes that the fish are moving downstream past the trawl site at about the same rate in all flows--and they probably are not. If corrected, this bias would probably cause the line describing the trawl survival index versus flow to be even steeper than it is.

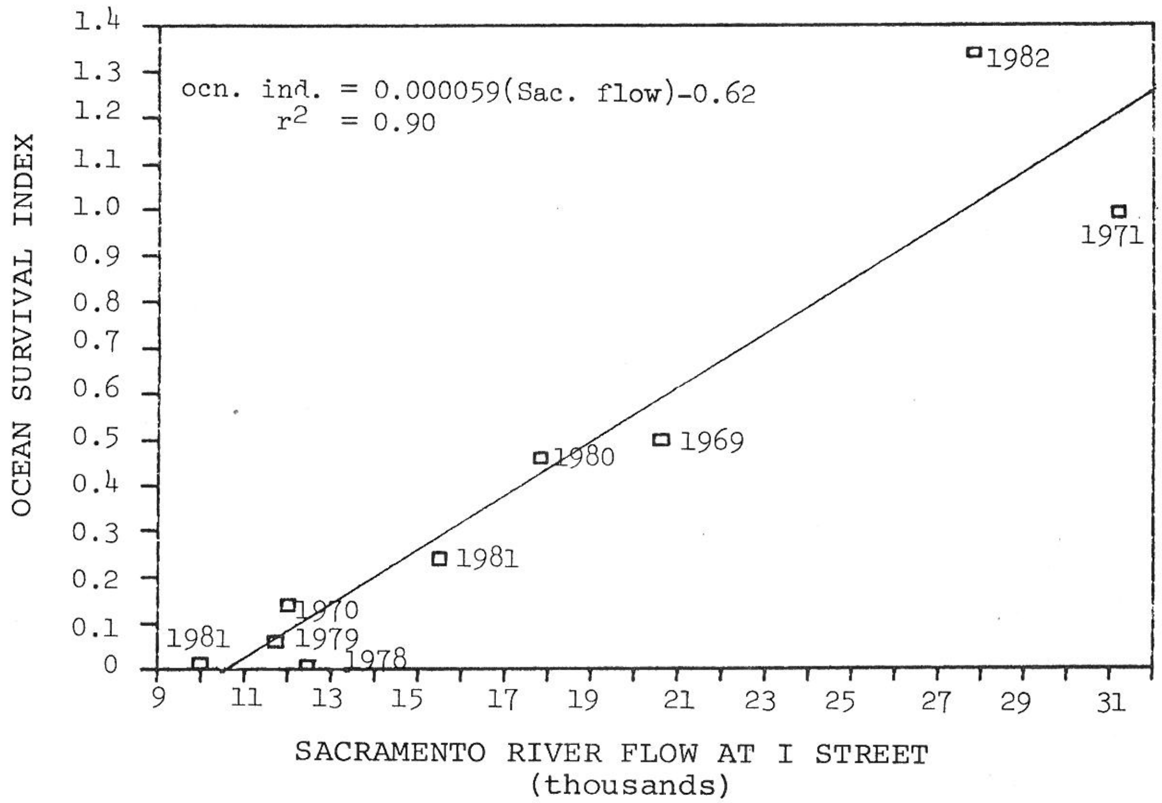

Figure II-1. Relationship between ocean survival index of late May and June plants of chinook salmon from Sacramento to Chipps Island and flow in the Sacramento River at I Street. Survival rate estimates based on ocean tag recoveries (Stevens et al. 1984).

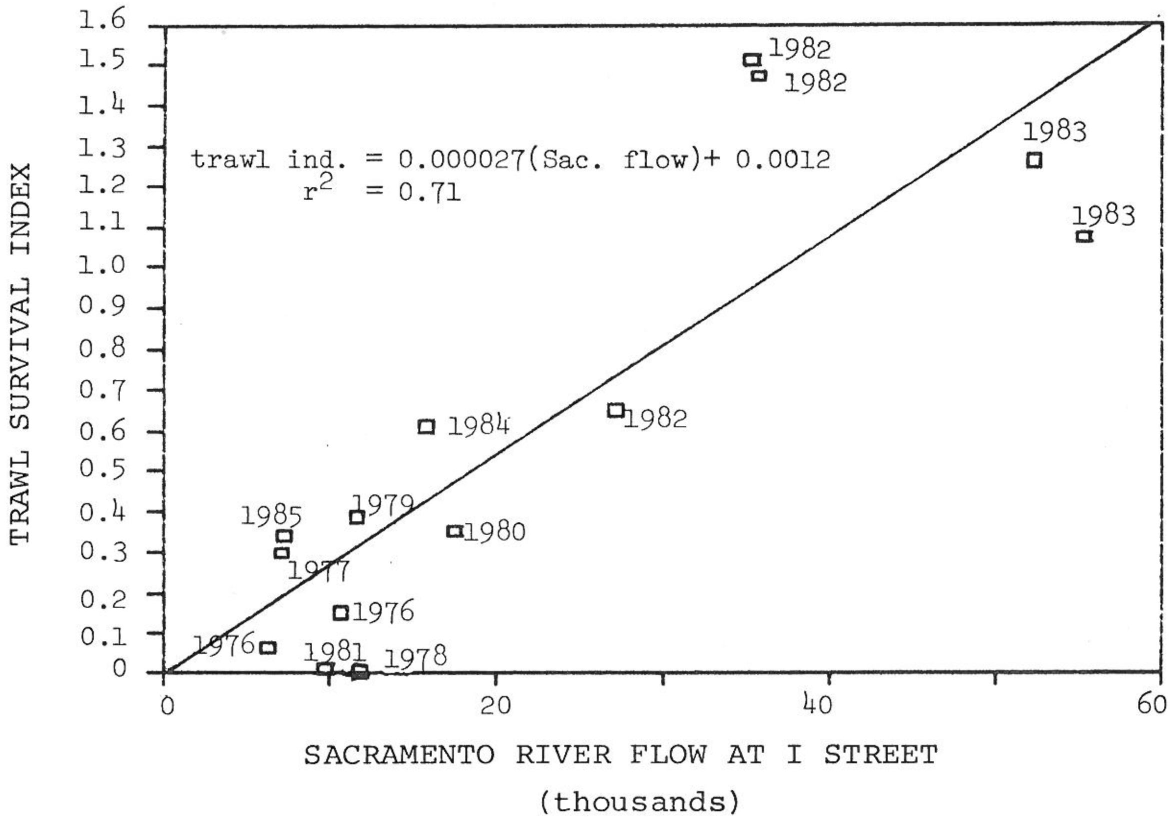

Figure II-2. Relationship between trawl survival index of late May and June plants of chinook salmon and flow in the Sacramento River at I Street. Survival index based on trawl catches near Chipps Island (Stevens et al. 1985).

As a further check on Stevens, Kjelson, and Brandes' evidence that the survival of juvenile salmon released into the Sacramento River above the Delta is related to flow and/or temperature in the river during the time the fish were emigrating, we examined tag retrieval rates from fish that had returned to spawn. We used tag return data supplied CF&G's Anadromous Fisheries Branch in Rancho Cordova, to estimate the tag retrieval rate from spawners and to develop escapement indices just as Stevens, Kjelson, and Brandes did with tags returned from the ocean (Table II-1). Figure II-3 is a comparison between our escapement indices and the ocean indices calculated by Stevens, Kjelson, and Brandes. These indices were correlated. High ocean indices lead to high spawning escapement back into the Sacramento River Basin.

The Effect of Streamflows on the Spawning Escapement of Marked Fish

Because the ocean indices calculated by Stevens, Kjelson, and Brandes are correlated to our escapement indices, it is not surprising to learn that there is a correlation between Sacramento River streamflow and our spawning escapement indices. They are significantly correlated with streamflows in the Sacramento River during June and Delta outflows during the months of June and July (Table II-2). These flows account for approximately 80 percent of the variation in the escapement indices. This is additional evidence that higher flows in the Sacramento River increase survival rates of juvenile chinook planted at or near Sacramento.

INTERPRETATION OF THE RESULTS

In our opinion, the study has provided evidence that fish reared in hatcheries and stocked at or above Sacramento in late May or June survive the journey down the Sacramento much better when flows are high. The question remains, however, as to whether the results can be applied to naturally produced or so-called "wild fish". Of particular concern are differences in migration timing between wild and experimental groups. Differences in temperature tolerance and feeding behavior may be important. Marking large numbers of wild fish would seem a high priority.

PROBABLE CAUSES

An inverse relationship between water temperature and streamflow in the Sacramento River (Figure II-4) leads us to suspect that high water temperature is a major cause of low survival in low flow years (Figure II-5). Chinook salmon smolts can withstand temperatures up to 75^{o} F so long as they have plenty of food, but as water temperatures rise above the low 50s, greater amounts of food are required to maintain even basic metabolic processes and growth. We suspect the abundance of zooplankton near Port Chicago may be the principal cause of the higher survival rates of fish planted there during years of high water temperatures and reduced Sacramento River flows.

Table II-1. Retrieval rates and survival indexes of ocean caught and spawning escapement portions of chinook salmon released at Discovery Park and Port Chicago for 1977 to 1980 brood years. Ocean tag retrieval rates and ocean survival indexes from Stevens et al. (1984). Escapement retrieval rates and survival indexes calculated from data supplied by CF&G Anadromous Fisheries Branch, Region II, 1984.

Brood Year	Release Date	Location	Ocean Tag Retrieval Rate	Ocean Survival Index	Spawning Escapement Tag Re-trieval Rate	Spawning Escapement Survival Index
1977	5 June 1978	Discovery Park	0.00033	0.012	0.0007	0.008
	6 June 1978	Port Chicago	0.02718		0.0869	
1978	4 June 1979	Discovery Park	0.00038	0.063	0.003	0.091
	6 June 1979	Port Chicago	0.006		0.033	
1979	4 June 1980	Discovery Park	0.0071	0.458	0.158	0.752
	5 June 1980	Discovery Park	0.0071	0.458	0.09	0.428
	10&13 June 1980	Port Chicago	0.0155		0.2101	
1980	2-5 June 1981	Discovery Park	0.0003	0.016	0.005	0.021
	2-5 June 1981	Discovery Park	0.0003	0.016	0.0087	0.035
	8 June 1981	Port Chicago	0.01913		0.2364	
	5 May 1981	Knights Landing	0.0027	0.24	0.0359	0.152

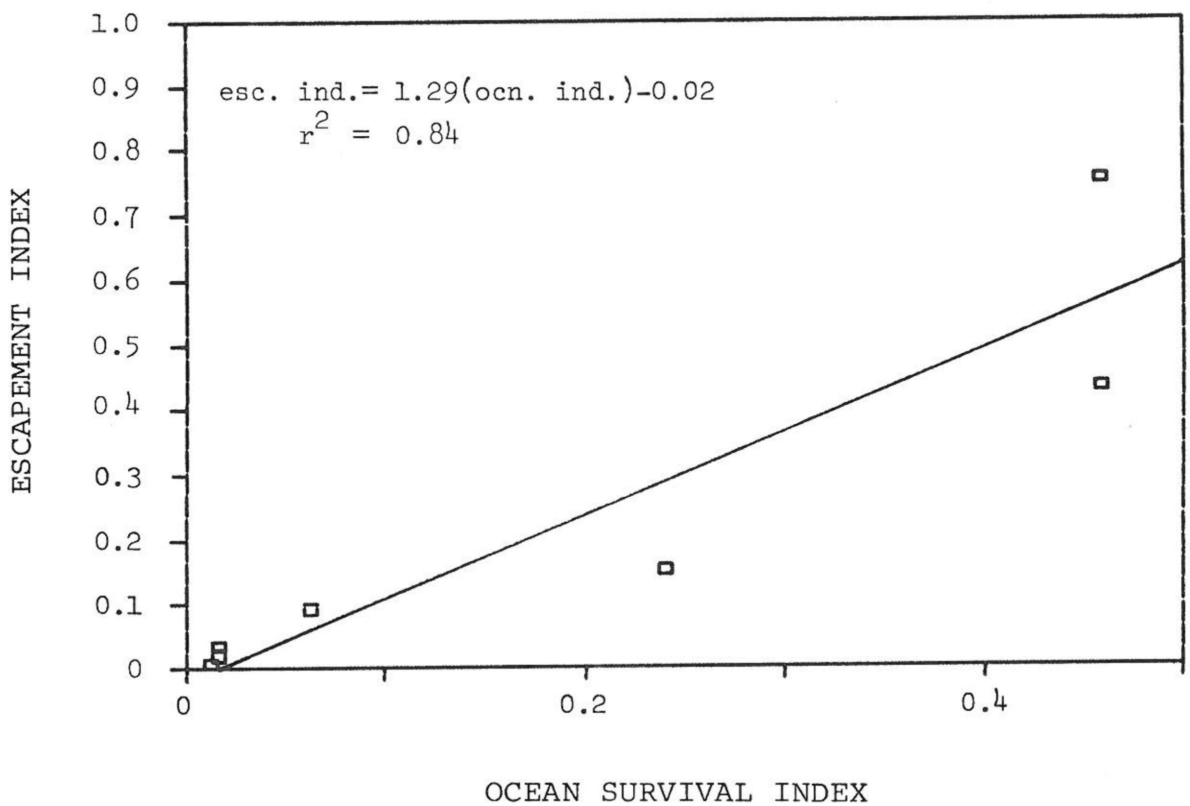

Figure II-3. Relationship between escapement index and ocean survival index. Indexes based on tag return data from ocean caught and spawning escapement portions of chinook salmon released into the Sacramento River at Discovery Park and Port Chicago. High survival rates to the ocean populations are reflected in high survival rates to the spawning populations.

Table II-2. Regression results describing relationship between spawning escapement survival index and selected mean monthly flows in the Sacramento Basin. Indexes based on retrieval rates of coded wire tagged fish in spawning escapement groups between 1978 and 1981.

x Variable	y Variable	n	r^2	y intercept	regression coefficient
Sacramento River Flow	Escapement 1/ Index				
April		6	0.01^{ns}		
May		6	0.05^{ns}		
June		6	0.84**	-956.8	.08173
Delta Outflow	Escapement 1/ Index				
June		6	0.76*	-265.3	55.78
July		6	0.88**	-414.5	91.37

* Significant at α = .05
** Significant at α = .01
ns = not significant
1/ Escapement index multiplied by 1×10^7 prior to analysis.

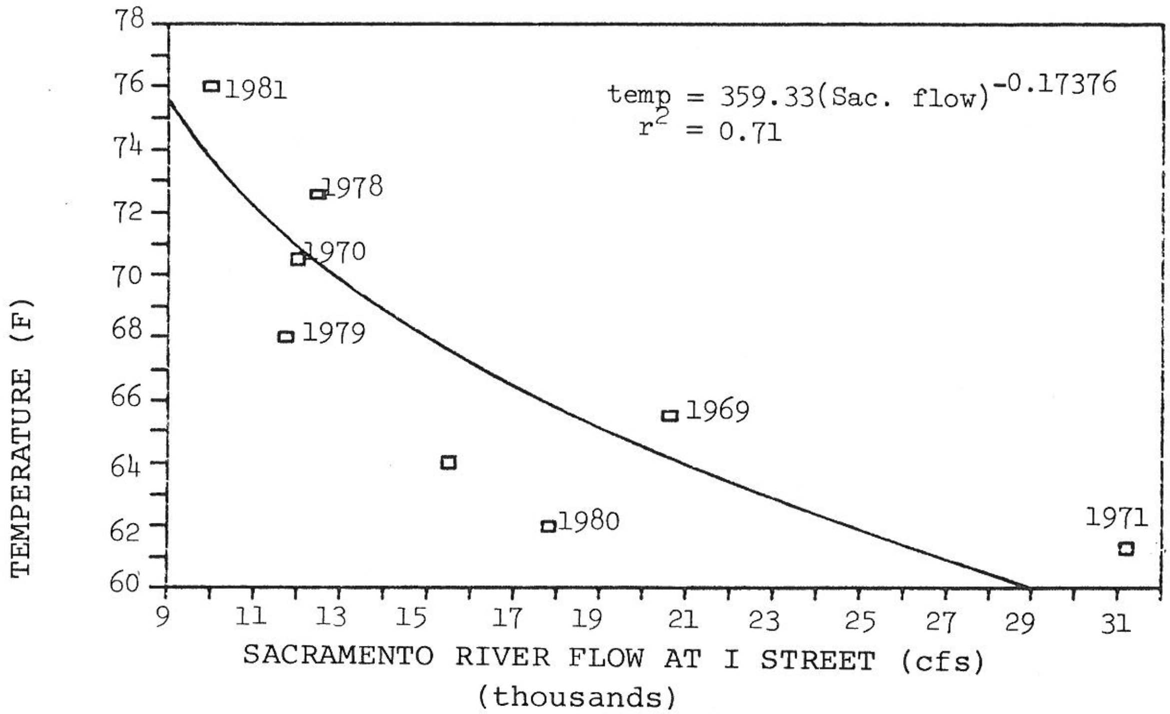

Figure II-4. Relationship between Sacramento River water temperature at fish planting site and streamflow at I Street.

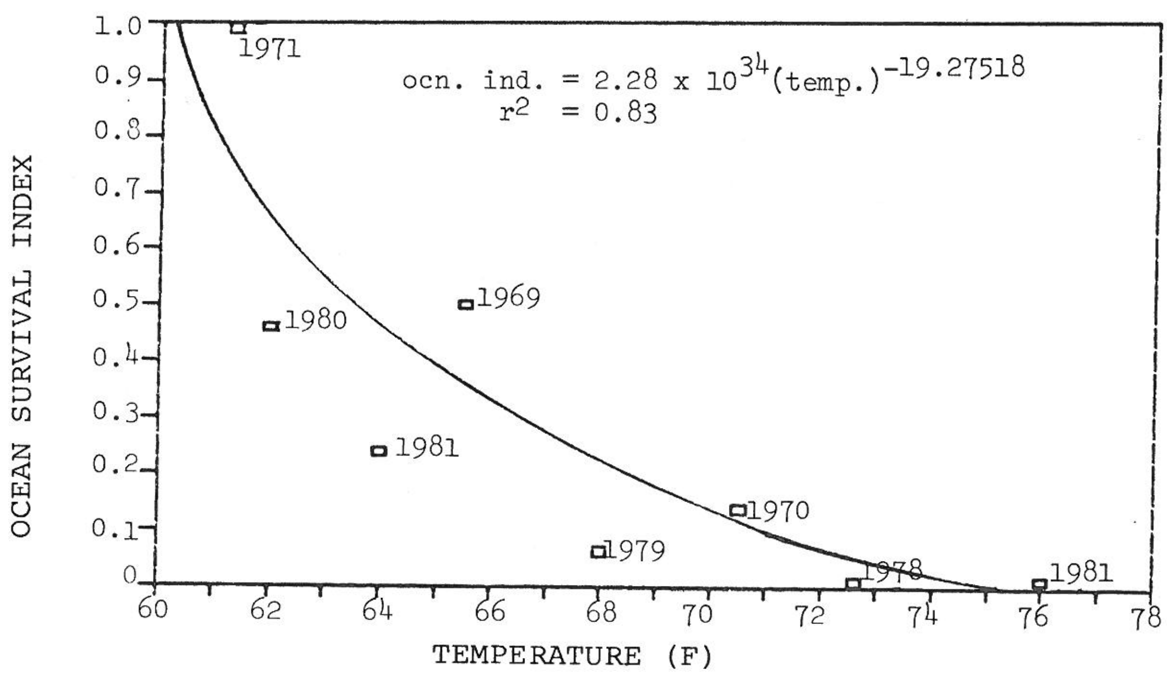

Figure II-5. Relationship between survival index of late May and June plants of chinook salmon from Sacramento to Chipps Island and water temperatures at fish planting site. Survival rate estimates based on ocean tag recoveries (Stevens et al. 1985).

The marked groups of fish released at Sacramento appear to be taking a week or more to reach Chipps Island, and, although we have not had time to investigate it, it seems to us that the relative scarcity of food in the Sacramento River could cause serious problems when water temperatures are above the mid-60s as they are in dry years. Fish migrating downstream before late May or in years when water temperatures were lower would not be subjected to the same kind of problems.

CHAPTER III. HISTORICAL FLUCTUATIONS IN CENTRAL VALLEY ADULT CHINOOK SALMON POPULATIONS.

Is the relationship between salmon smolt survival and flow reflected in adult salmon populations? We began to examine this question by collecting the available salmon population information.

HISTORICAL REVIEW UP TO 1957

In conjunction with planning for the State Water Project, Skinner (1962) reviewed catch records of the Sacramento-San Joaquin gill net fishery that existed from 1864 to 1958. He noted that salmon runs in the Sacramento-San Joaquin system fluctuated widely since records were first kept. The peak catches occurred at intervals of 8 to 30 years, and were followed by poor catches midway between the peaks (Figure III-1). Skinner divided the historical catch record into two periods--from 1870 to 1915, and from 1915 to 1957. Peak catches occurred in 1880-83, 1907-10, 1918, and 1945-46. The mean annual catch for the earlier period was about 6 million pounds, and for the latter period 2 million pounds. Skinner attributed much of this difference to the large increase in the ocean troll fleet which reduced the number of fish available to the gill net fishery. He also considered the influence of the Central Valley Project and other water projects which have reduced or eliminated flows below dams, blocked spawning areas, diverted water into irrigation canals, and changed the general flow regime of streams.

RECENT REVIEW UP TO 1978

In a more recent review, Cannon (1980) discussed the status of the Sacramento-San Joaquin chinook salmon population and factors related to its decline. He used spawning escapement data from the upper Sacramento system to document a decline from 1953 through 1980. In the Sacramento River, he attributed the decline to poor flow during the spawning and incubation period, overfishing, dams and diversions, loss of spawning habitat, and floods. He noted the number of fall run adult salmon counted in the mainstem of the Sacramento River had declined from about 400,000 spawners in 1951 to about 50,000 spawners in 1978. He defined a relationship between the number of spawners and the subsequent number of recruits to the spawning population and showed that the number of recruits per spawner gradually declined in a somewhat consistent way between 1953 and 1974. He divided the historical returns from 1953 through 1974 into three data sets, and constructed three curves describing shifts in the relationship between spawners and subsequent returns. He suggested that there may have been several mechanisms responsible for the shift: increased ocean harvest, increase in the number of years with low spring outflows in the period between 1967 and 1974, the initial operation of the Red Bluff Diversion Dam and Oroville Dam, and the initiation of the State Delta pumping plant. He also suggested that the commercial fishery may have overfished the wild portion of the population that utilizes the river above Red Bluff.

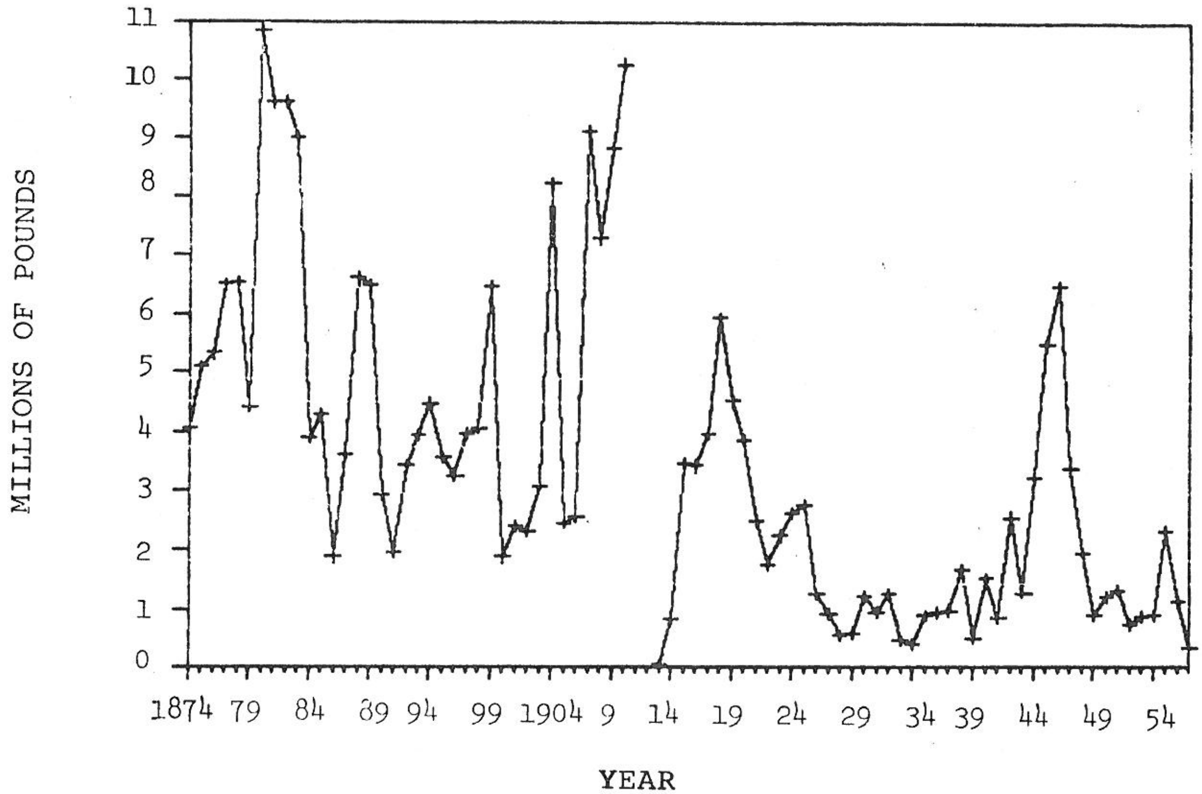

Figure III-1. Annual landings of the Sacramento-San Joaquin gill net fishery between 1874 and 1957. Mean annual catch during the late 1800s and early 1900s was 6 million pounds. A major decline in catch to extremely low levels in the 1920s and 1930s contributed to a reduction in mean annual catch to 2 million pounds for the period 1915 to 1957. No data for years 1911 and 1912 (from Skinner 1962). Data in Appendix A-1.

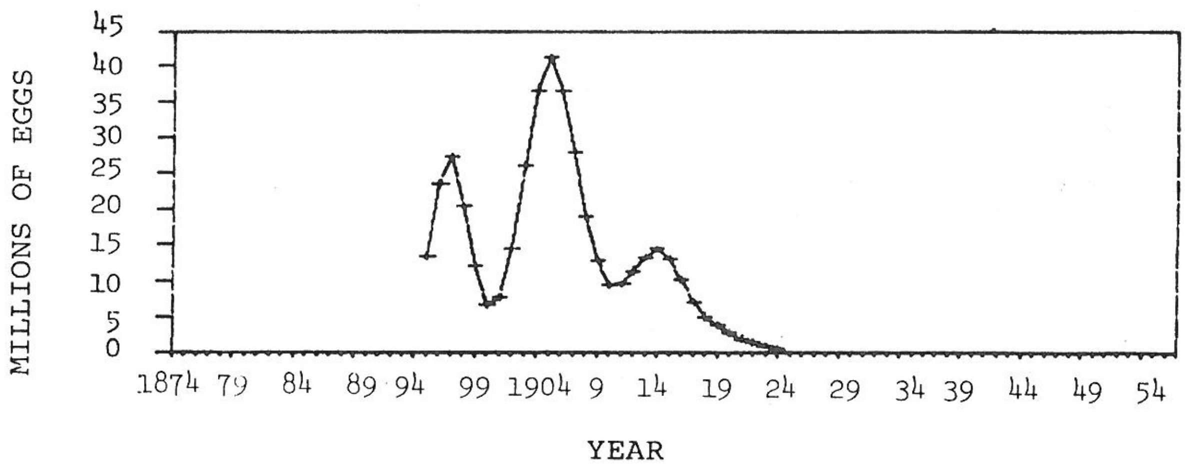

Figure III-2. Record of egg take from adult female chinook salmon at Battle Creek, 1895-1924 (from Clark 1929). Comparison of annual egg take, as an index of escapement, with gill net landings (Figure III-1) reveals that changes in escapement are generally paralleled by changes in catch in subsequent years.

CURRENT STATUS OF THE CHINOOK SALMON POPULATION IN THE CENTRAL VALLEY AND HISTORICAL REVIEW OF CATCH AND ESCAPEMENT DATA

To update previous reviews of the salmon population, assess the size of the population returning to the Central Valley, and develop an index we could compare to historical streamflow, we compiled estimates of the gill net fishery, the ocean commercial fishery, the sport catch, and spawning escapements. In the following four sections, we describe the data that is available for each of these groups, and discuss any trends during the period of record.

Gill Net Fishery

The Sacramento-San Joaquin gill net fishery in the Sacramento River began about 1864, and historical estimates of the weight of canned salmon produced by that fishery are available back that far. However, accurate estimates of the catch were not made until 1916, when the California Department of Fish and Game required that the total catch be weighed. The number of pounds of salmon caught in the gill net fishery between 1916 and 1957, when gill netting was outlawed, is listed in Appendix A-1. We have converted these data into estimates of the number of fish by dividing the total pounds of salmon landed by the mean weight of adult salmon gill netted in the years 1952 to 1957 (18.23 lbs.) (Jensen and Swartzell 1967). No other weight data is available.

The gill net fishery produced peak catches of between 300,000 and 350,000 fish in 3 years--1918, 1945, and 1946. Catches after 1918 declined sharply to a low of about 25,000 fish in 1933 and 1934. The catch in the gill net fishery was substantially larger before 1915, reaching levels between 1870 and 1910 of approximately double those of the later periods (Figure III-1).

Clark (1929) noted that this decline in the gill net catch was related to low spawning escapements in the Sacramento system. Figure III-2 is a graphical record of the number of eggs taken from adult female chinook salmon at Battle Creek in the years 1895 to 1924. By comparing this record as the only early years index of escapement with commercial landings presented in Figure III-1, we concluded that years of high escapement were probably followed by years of excellent catch or increasing catch. For example, the highest escapement in Battle Creek in 1905 was followed by very high catches 2 to 5 years later. In addition, a significant decline in catch between 1918 and 1922 followed a period of decreasing escapement 4 years previous to the beginning of the decline of catch. There are also years of high catch, for example 1907-1910, that are followed by periods of declining escapement. These comparisons indicate that during the early years of the salmon fishery there was a relationship between escapement and the gill net catch. In general, high escapement led to subsequent years of excellent catches, but high catch years generally led to a subsequent decline in escapement. The outcome of this interaction between catch and escapement appears to have been a reduction of both to critical levels following the peak catch in 1918. Clark (1929) noted that in addition to fishing, environmental changes including the destruction of spawning grounds by dams, the loss of salmon in overflow basins in the Sacramento Valley, and the loss of fish by pollution and predatory fishes, probably influenced the reduction to critical levels before 1929.

The gill net fishery recovered spectacularly but briefly in the late 1940s, then collapsed and was finally outlawed in 1957.

Ocean Troll Fishery

CF&G began tallying total weight of salmon landings from commercial ocean trollers in 1916. Until 1952 these were reported only as total pounds of salmon landed (Appendix A-2). We converted estimates of the total pounds of salmon landed at major port areas into numbers of chinook salmon landed at those ports by: multiplying the total weight landed times the fraction, 0.9 (CF&G 1954), that was estimated to be chinook salmon and dividing the result by the mean weight of adults landed in these areas between 1952 and 1965 (calculated from data in Jensen and Swartzell 1967). After 1952, the total catch was apportioned into weight and estimated numbers by species (coho and chinook salmon), and landings were reported from several zones along the coast (Appendix A-3).

Only a portion of these salmon originated in Central Valley rivers. Using CF&G landing records we estimated the catch of king salmon originating from the Central Valley rivers between the years 1916 and 1977 in the following manner. By using coded wire tag returns from 1977-1986, fishery biologist Mike Maahs, of the Pacific Coast Federation of Fishermen's Associations, developed a method for estimating what fraction of these landings at each port were salmon from the Central Valley rivers. He assumed:

1. That 95 percent of the salmon landed in Monterey were from Central Valley rivers--a reasonable assumption since it is the southernmost port and there are no chinook spawning runs south of the Central Valley.

2. The ratio of tagged salmon from the Central Valley to untagged salmon from the Central Valley would be the same at all ports--a reasonable assumption since tagged fish appear to be well mixed throughout the population.

For each year, Maahs calculated the fraction of the Monterey landings of Central Valley (CV) fish that were tagged by:

$$\frac{\text{Total Central Valley tagged fish landed at Monterey}}{\text{Total landings at Monterey} \times 0.95} = \text{fraction of CV landings tagged}$$

He then applied that fraction to the total landings of salmon from each port that year. For example, if the total CV tagged salmon landed in Monterey in 1979 was 1.98 percent of the CV salmon landed in Monterey, then the total CV tagged salmon landed in each port represented 1.98 percent of the total CV salmon landed there. This approach has been reviewed by L. B. Boydstun of the CF&G Ocean Salmon Management Program and Steven P. Cramer of the Oregon Department of Fish & Wildlife Research and Development Section. They, and we, believe it to be a better approach to estimating the contribution of Central Valley salmon to total chinook landings than the one we used in 1986. The data and annual calculations are in Appendix A-6.

The data to make such calculations is only available for the years 1977-1986. We estimated landings of Central Valley chinook in California waters each year between 1916 and 1977 by multiplying total number of chinook landed at each port (from Tables A-2 and A-3) times the overall fraction of salmon that were CV fish from 1977-1986. Oregon landings of CV fish were estimated by multiplying the ratio of Oregon to California landings from 1977-1986 times the California landings for the earlier years.

The pattern in Figure III-3 illustrates three distinct periods. In the first period between 1916 and 1941, the ocean troll catch declined as did the estuarine gill net catch. It reached low levels of less than 100,000 fish in 1932 and remained low for more than 10 years. The years 1942 to 1945 marked a rapid recovery period followed by a second major increase after the gill net fishery collapsed in the early 1950s.

The commercial salmon catch of Central Valley chinook has shown no declining trend since the serious one that affected both the ocean and estuarine fisheries in the 1920s and 1930s. It now averages about 365,000 fish, with 331,000 fish caught in California and 34,000 caught in Oregon. An unknown but probably small number are caught off Washington and British Columbia. The size of the fish has declined some as fishing pressure has increased and the catch is now shared by many more fishermen.

Ocean Sport Catch

The record of chinook salmon ocean sport catch began in 1947 when party boat operators voluntarily reported their daily catch. Intensive sampling of sport landings, both party boat and skiff fisheries, began in 1960. Beginning in 1962, sampling was reported by area.

The ocean sport catch of salmon originating from the Central Valley system from 1947 to 1976 was estimated by calculating the fraction of CV fish caught at each port or in California, and multiplying the fraction times the estimate of chinook landed at each port or in California. The method of Maahs, previously described for the ocean troll fishery, was used to calculate the fraction of CV fish in the sport catch. The estimates of CV sport catch are summarized in Appendix A-4 and A-7, and illustrated in Figure III-3.

In the last 25 years, the ocean sport catch of chinook salmon from the Central Valley system has ranged from 41,000 to 137,000 fish. The sport catch represents about 16 percent of the overall ocean catch of chinook salmon that originate from the Central Valley rivers. Like the commercial catch, the sport catch has fluctuated dramatically but there has been no upward or downward trend.

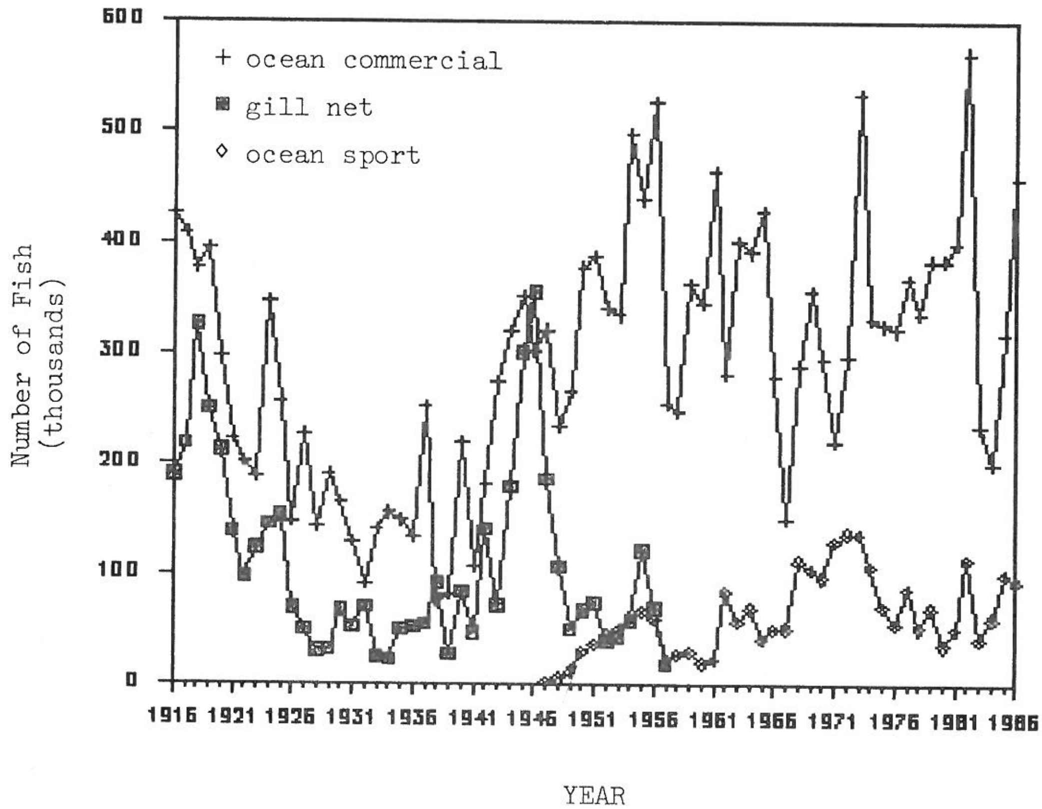

Figure III-3. Estimates of annual California ocean commercial and sport catch of chinook salmon originating from the Central Valley from 1916 to 1984. Estimates based on CF&G catch records. See text for procedure used in estimating Sacramento-San Joaquin contribution. Relatively small catches between 1916 and 1941 coincided with a major decline in Sacramento-San Joaquin gill net catches. After a marked increase between 1942 and 1945, total ocean catch, while fluctuating widely, has remained at a relatively high level. Catches reflect changes in stock size and a general increase in fishing effort over the years (Skinner 1962).

CENTRAL VALLEY SPAWNING ESCAPEMENT

CF&G has estimated the Central Valley spawning escapement of king salmon each year since 1953. Beginning in 1967, these estimates were supplemented with counts by the USF&WS at Red Bluff Diversion Dam on the upper Sacramento River. We used reports by Taylor (1973), Reavis (1983), and the Pacific Fisheries Management Council (1984; 1985; 1986; 1987) to compile annual escapement estimates for the rivers on which estimates are regularly made (Appendix A-5, Figures III-4, III-5, and III-6).

The fall run in the mainstem Sacramento has decreased persistently since what we believe to be a peak run of the early 1950s, to stabilize between 50,000 and 100,000 fish since 1970 (Figure III-4). The last few years suggest an encouraging increase. The late fall and winter runs have experienced persistent declines to dangerously low levels since counting of them began after the erection of the Red Bluff Diversion Dam.

Average escapement during the 30-year period has increased in the Feather River by about 11,000 fish and in the American River by about 15,000 (Figure III-5). Runs in the Yuba River are being sustained. Those in Battle Creek have increased in recent years.

Figure III-6 illustrates the remarkable fluctuations of spawning escapement into the San Joaquin River Basin. We understand that biologist William Laudermilk, of the CF&G Region IV staff, is preparing analyses of these runs. The major and regular fluctuation in these runs suggests to us that the San Joaquin River still has a major potential to produce salmon.

To help clarify when the reduction in escapement to the mainstem Sacramento River occurred we constructed Figure III-7, a comparison of the 2-year moving average escapements in the mainstem Sacramento and Feather rivers. We used a 2-year-average because the available data for an age-class distribution of returning adults suggests that most spawn as 3- and 4-year olds. Therefore, to compare the escapement between two rivers it is necessary to include returns from adjacent years because it is unknown whether or not in any given year the same proportion of 3- and 4-year-olds return to both rivers. Examination of Figure III-7 reveals that, up until 1970, the 2-year moving averages in the mainstem Sacramento and Feather rivers were, with the exception of 1954, strongly correlated. Figure III-8 shows the correlation between average escapement in the Sacramento and Feather rivers between 1955 and 1969 and also the lack of correlation in the years following. Based upon this analysis, we believe that populations in the Sacramento and Feather rivers were responding to similar environmental factors and reacting in similar ways to those factors between 1955 and 1969. Populations in these rivers began to respond independently or were affected by other changes after 1969. The three most obvious changes were the construction of the Oroville Dam and Feather River Hatchery in 1967 on the Feather, and the Red Bluff Diversion Dam on the Sacramento in the mid-1960s.

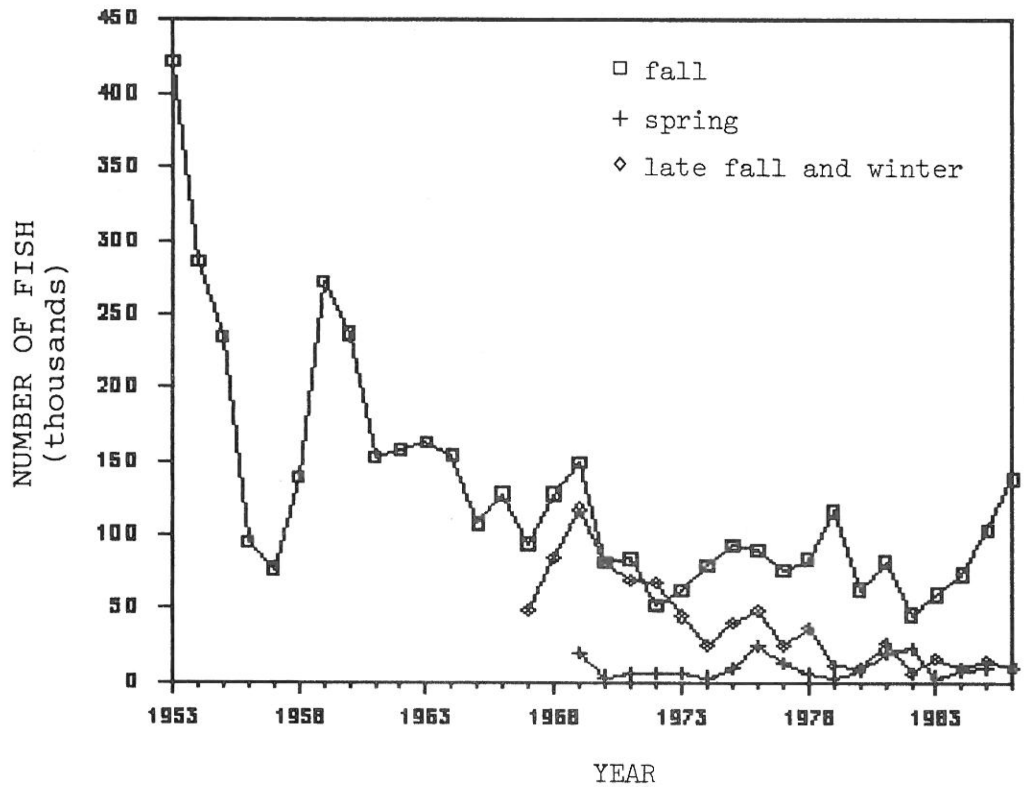

Figure III-4. Annual estimates of fall run, spring run, and late fall and winter run of chinook salmon in the main Sacramento river (Taylor 1972; Pacific Fisheries Management Council 1987; Reavis 1983. Data in Appendix A-5).

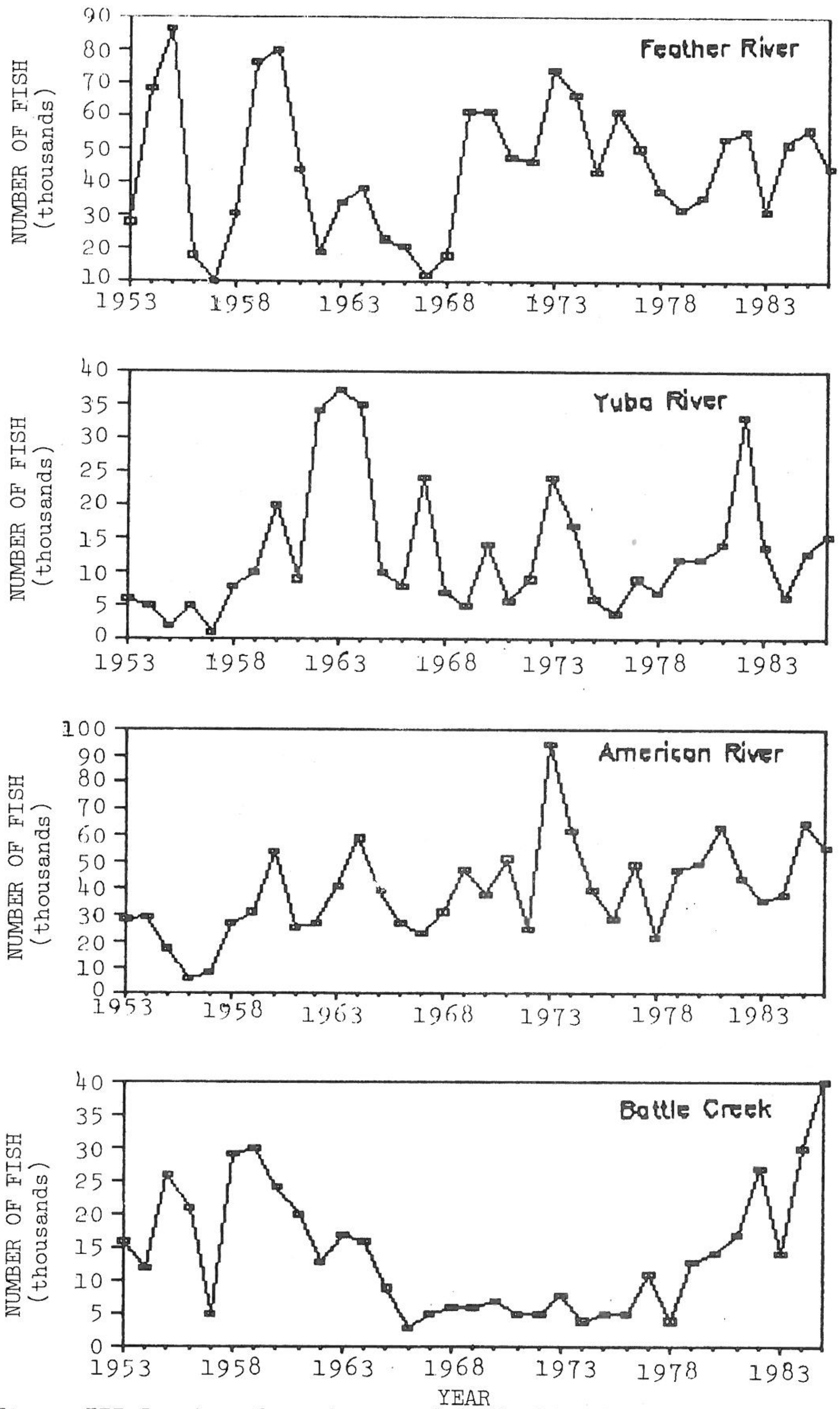

Figure III-5. Annual estimates of fall chinook spawning in the principal tributaries of the Sacramento River. All are partially supported by hatcheries (Taylor 1972; Pacific Fisheries Management Council 1987; Reavis 1983. Data in Appendix A-5).

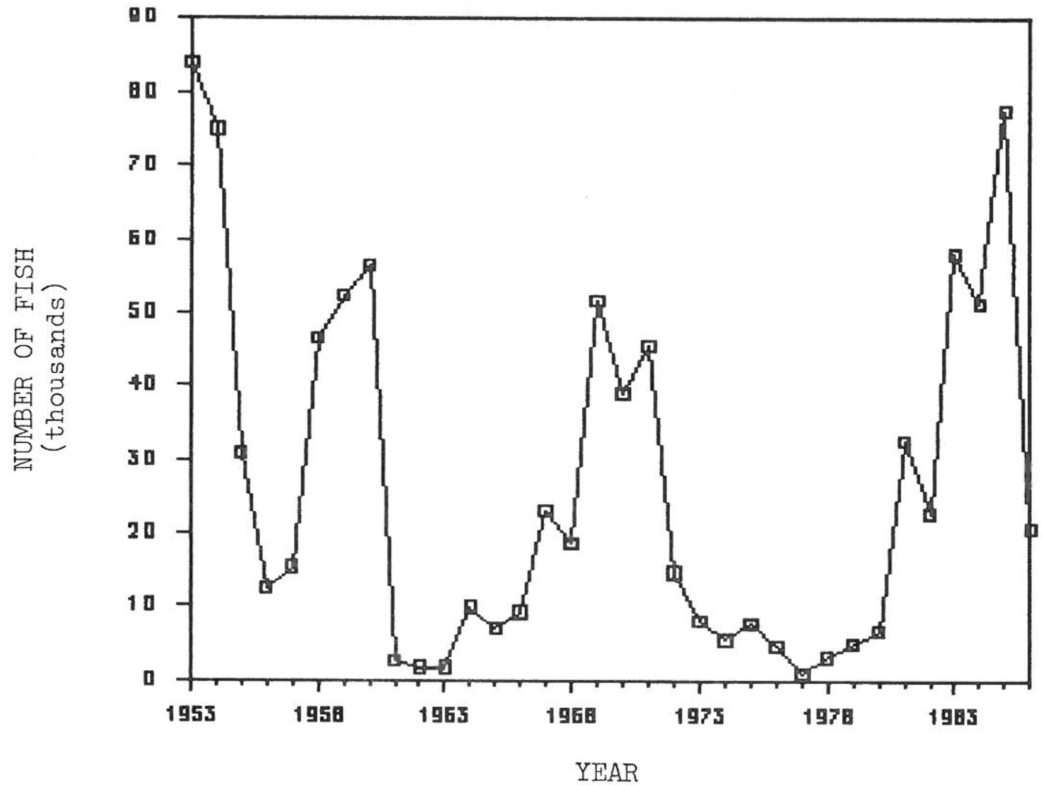

Figure III-6. Annual estimates of fall run chinook spawning in the San Joaquin River Basin (Taylor 1972; Pacific Fisheries Management Council 1987; Reavis 1983. Data is in Appendix A-5).

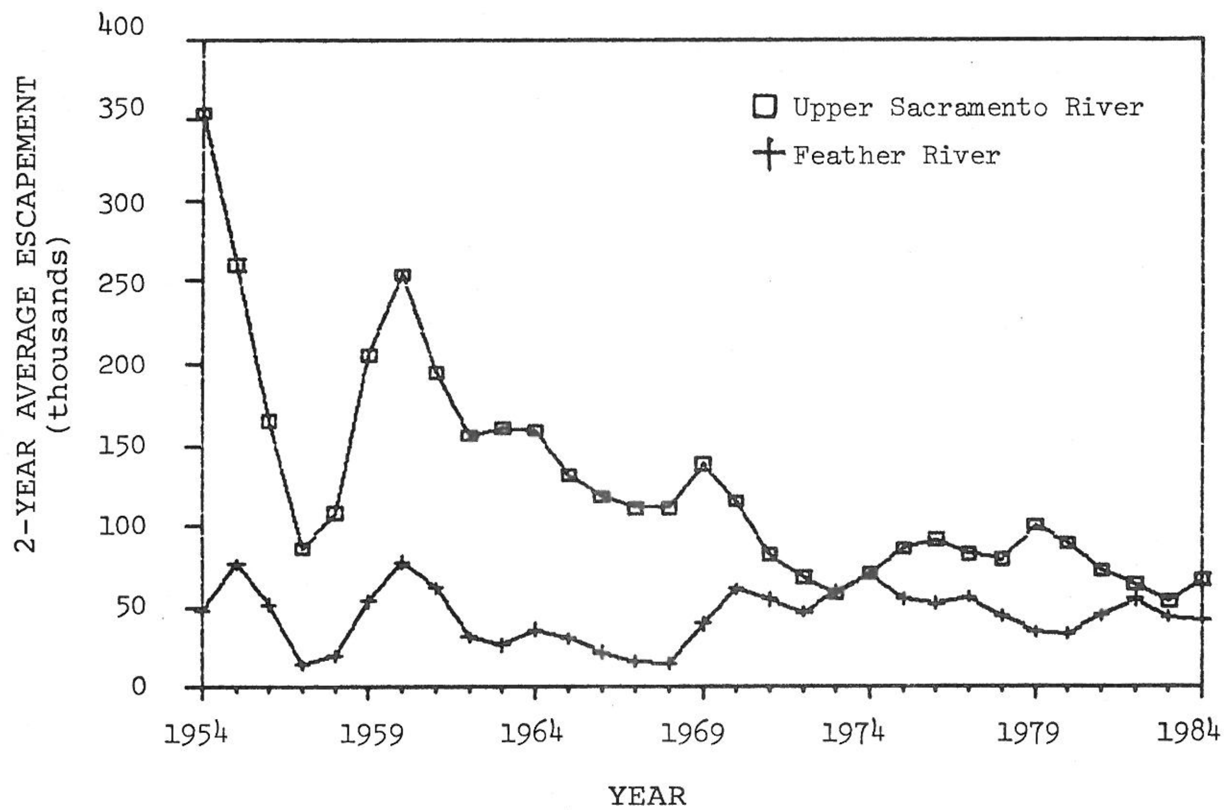

Figure III-7. Comparison of 2-year moving averages of spawning escapement in the mainstem Sacramento and Feather rivers for the period 1954 to 1984. A strong correlation between Sacramento River and Feather River escapement existed between 1955 and 1969. After 1969, the correlation broke down as Sacramento River escapement began a steady decline and Feather River escapement increased and stabilized (see Figure III-8).

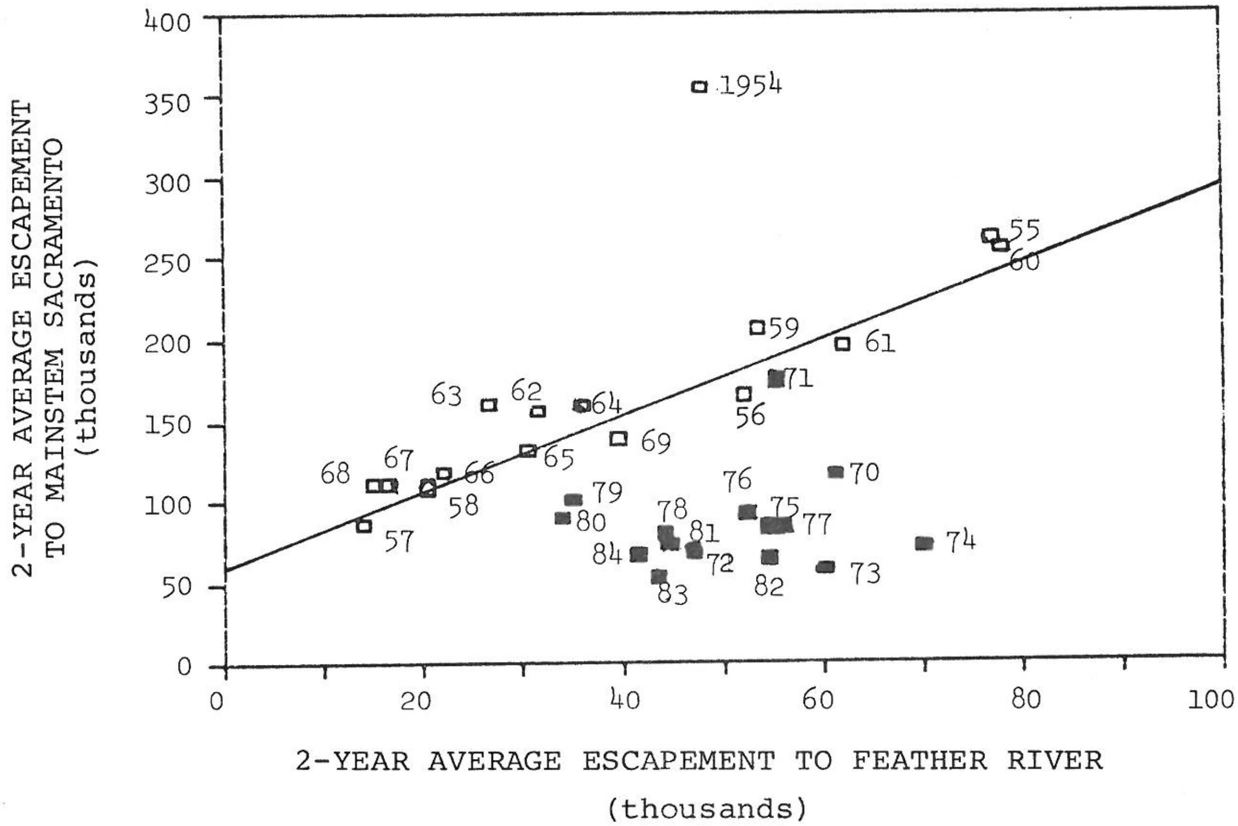

Figure III-8. Correlation between 2-year average escapement in the Sacramento and Feather rivers between 1955 and 1969 (open squares), and lack of correlation in subsequent years (closed squares). Data for 1954 excluded from analysis (see Figure III-7).

CHANGES IN OVERALL STOCK SIZE

To assess the historical changes in the total chinook salmon population originating in the Sacramento-San Joaquin basins we constructed Figure III-9, which presents a record of total adult populations from 1916 to 1983 based on estimates of commercial and sport catches in the ocean, catches in the gill net fishery from 1915 to 1957, and a basin-wide escapement since 1953.

In the last 30 years, the overall spawning escapement has declined in that the occasional very large runs of the 1950s and 1960s have not reappeared. The total run has fluctuated less and settled between 200,000 and 300,000 fish. The ocean catch including commercial and sport caught fish has averaged about 435,000 fish and has no increasing or decreasing trend. We believe that hatchery reared juveniles contribute to a substantial part of the ocean catch, and are responsible for preventing a decline in the ocean fishery and for stabilizing the spawning escapement as well. The effect of this on "natural" production must be addressed.

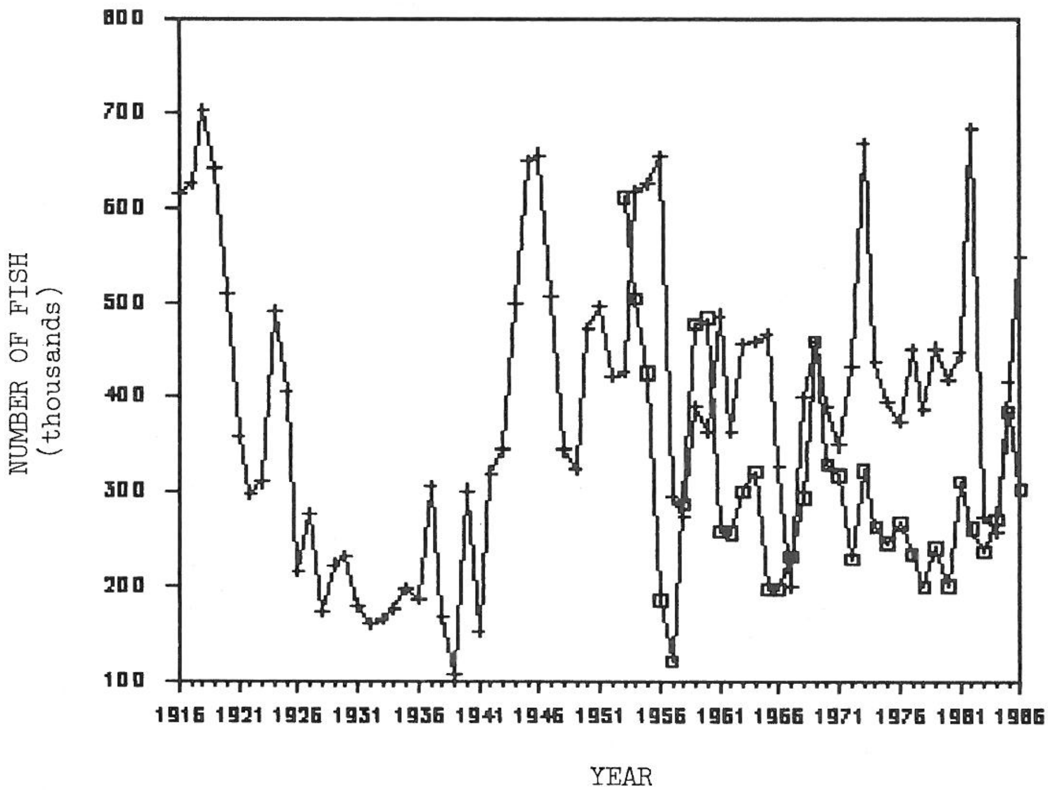

Figure III-9. Annual estimates of total catch and spawning escapement of Sacramento-San Joaquin chinook from 1916 through 1986 and total annual spawning escapement since 1953 (Taylor 1973; Pacific Fisheries Management Council 1987; Reavis 1983).

CHAPTER IV. IS THERE A RELATIONSHIP BETWEEN SACRAMENTO RIVER FLOW OR DELTA OUTFLOW AND THE SIZE OF THE ADULT CHINOOK SALMON POPULATION?

While the California Department of Fish and Game and the US Fish & Wildlife Service are presently studying the effects of flow reduction on the survival of specific juvenile salmon planted in the Sacramento River, they have not attempted to correlate streamflow changes with adult populations. This chapter is our attempt to do that.

EFFECTS OF VARIABLE AGE AT SPAWNING ON THE ASSESSMENT OF HOW FLOW AFFECTS ADULT SALMON RETURNS

Chinook salmon have historically returned to the Sacramento Basin at ages ranging from 2 to 5 years. Consequently, as many as four year classes may contribute to the adult spawning escapement in any one year. This life history characteristic causes difficulty when attempting to relate catch or spawning escapement to flows of previous years that would have affected juveniles.

To determine if an assumption of constant age-class distribution was valid for chinook salmon in the Sacramento system, we assembled and examined the available age-class data (Table IV-1). Between 1919 and 1983, there has been a dramatic shift in the age composition of ocean-caught fish and fish returning to the Sacramento River. Earlier in this century, 4- and 5-year-olds were common in the ocean fishery and the spawning runs into the Sacramento River. Two- and six-year-olds made up a small portion of the catch and escapement, usually averaging less than 10 percent.

In the last 10 years, very few 5- and 6-year-olds have been noted in the returning groups to Nimbus and Feather River Hatcheries. Usually the run is mostly 3-year-olds. In 1981, 75 percent of the run as indexed by tag returns were 2-year-old fish (Table IV-1).

While there appears to have been a shift in the age composition of the return groups, the available data should be treated with caution. Data on age composition in recent years are based on returns from hatchery releases which have varied from one year to the next with respect to number, size of fish, and site of release. These differences influence the relative contribution of release groups to each year's returns and could introduce substantial biases into the age composition estimates in recent years. In view of these limitations, we chose to use estimates of age composition based on tag recovery data for the American and Feather rivers (Table IV-2), and restrict our analysis of the relationship between streamflow and escapement to the period between 1969 and the present during which the age composition of returning adults appears to have been relatively stable.

Table IV-1. Historical estimates of age class composition of Sacramento-San Joaquin chinook salmon.

Return Year	Sample Location	Percent Age Composition in Sample 2	3	4	5	6	Reference
1919	Sacramento River 1/	0.2	21.7	49.6	24.6	3.9	Clark, 1929
1919	Monterey Bay 2/	7.0	33.0	43.0	16.0	1.0	Synder, 1931
1920	Sacramento River 1/	2.2	11.5	44.3	41.4	0.7	Clark, 1929
1920	Monterey Bay 2/	7.3	29.2	37.3	24.2	1.7	Synder, 1931
1921	Monterey Bay 2/	0.6	30.0	43.0	24.0	2.0	do.
1928	Monterey Bay 3/	56.9	31.4	10.9	0.8	-	do.
1929	Monterey Bay 2/	17.5	62.3	17.2	2.9	0.1	do.
1952	Pacific Troll Fishery 4/	0.1	60.0	36.8	3.1	-	Kutkuhn, 1963
1952	Sacramento River 1/	1.2	53.6	42.5	2.7	-	do.
1955	Pacific Troll Fishery 5/	0.1	52.7	43.5	3.1	-	do.
1969	Pacific Troll Fishery 6/	16.3	56.9	26.3	0.4	-	Boydstun, 1972
1975	Merced, Tuolumne & Stanislaus rivers 7/	13.3	64.3	21.5	1.0	-	AFB Files, Taylor, 1984
1976	Escapement to Nimbus & Feather R. Hatcheries 8/	35.4	25.9	38.6	-	-	CF&G AFB Files March 21, 1984
1977	Escapement to Nimbus & Feather R. Hatcheries 8/	26.4	68.9	4.7	-	-	do.
1978	Escapement to Nimbus & Feather R. Hatcheries 8/	25.5	48.5	12.8	-	-	do.
1979	Escapement to Nimbus & Feather R. Hatcheries 8/	21.3	66.5	12.2	-	-	do.
1980	Escapement to Nimbus & Feather R. Hatcheries 8/	3.5	84.1	12.4	-	-	do.
1981	Escapement to Nimbus & Feather R. Hatcheries 8/	74.7	16.4	8.0	0.9	-	do.
1981	Pacific Troll Fishery 9/	4.7	85.7	9.6	-	-	PFMC Report Table III-5 1984
1982	Escapement to Nimbus & Feather R. Hatcheries 8/	19.0	79.0	1.9	-	0.1	CF&G AFB Files March 21, 1984
1983	Escapement to Nimbus & Feather R. Hatcheries 8/	22.9	64.4	12.7	-	-	do.

1/Scales from gill net fishery.
2/Scales from undisturbed boat loads.
3/Scales analysis selected catches.
4/Scales from commercial salmon catch, sport, partial months.
5/Scales from commercial salmon catch.
6/Scales from April/May commercial troll sample Fort Bragg to Eureka.
7/Scales from salmon carcasses.
8/Coded wire tag returns at hatcheries.
9/Coded wire tag returns from commercial salmon landings.

Table IV-2. Age composition of coded wire tagged chinook salmon returning to the American and Feather rivers by brood year. Preliminary estimates based on CWT recovery data. Not corrected for differences in sampling effort or efficiency between years. Source: CF&G Memorandum, dated March 22, 1984, Anadromous Fish Branch, Coded Wire Tag Recovery Data for King Salmon of Central Valley Streams, 1975 through 1983.

Brood Year		Number and percent returning by age				
		Age 2	Age 3	Age 4	Age 5	Total
1975	number	18	217	204	1	440
	percent	4.1	49.3	46.4	0.2	
1976		98	341	71	3	513
		19.1	66.5	13.8	0.6	
1977		104	558	125	0	787
		13.2	70.9	15.9	0	
1978		21	158	80	0	259
		8.1	61	30.9	0	
1979		232	797	97	0	1126
		20.6	70.8	8.6	0	
Totals		473	2071	577	4	3125
Percent		15.1	66.3	18.5	0.1	

ANALYSIS OF THE RELATIONSHIP BETWEEN THE RETURN INDEX AND FLOW

In Tables IV-3, IV-4, IV-5, and IV-6, we present estimates of the number of fish returning to spawn in the American, Feather, and mainstem Sacramento rivers and the total Sacramento Basin by return year and age class for the period 1971 to 1984. These estimates were obtained by applying the average age composition presented in Table IV-2 to the spawning escapement estimates for each stream or system. We calculated a "return index" for each brood year by summing the number of 2, 3, 4, and 5-year-old returns from each brood over a period of 4 years (Table IV-7). We then used these indices as the variable to correlate with streamflow in the Sacramento River during April, May, and June, and historic Delta outflow during June and July.

Comparison of these "return indexes" for the American and mainstem Sacramento rivers failed to show significant correlations with either Sacramento River streamflow or Delta outflow. In the Feather River, the return from individual broods exhibited a significant positive correlation with mean monthly streamflow in the Sacramento River in June and Delta outflow in July (Figures IV-1, IV-2). Evaluated independently, June streamflow and July Delta outflow explained 57 and 55 percent, respectively, of the variation in the return index. Correlations between total returns to the Sacramento system and Sacramento flow and Delta outflow were not significant.

ALTERNATIVE ANALYSIS OF THE EFFECT OF FLOW ON ESCAPEMENT IN THE SACRAMENTO RIVER

The preceding correlation analysis included only 12 of the 30 years of escapement estimates in the Sacramento River Basin, and was based upon the assumption that the age composition of tagged adults recovered in the American and Feather rivers is representative of the entire Sacramento Basin salmon run. Because of these limitations we conducted another analysis using an escapement index that could be applied over the entire historical record and did not require estimation of age class composition. In this analysis, we calculated a 2-year moving average of escapement for the years 1953 through 1983 and then examined the relationship between this index and the 2-year moving averages of monthly Sacramento flow and Delta outflow. For example, the 2-year average escapement in 1970 (1970 and 1969 runs) would include returns from the 1967 brood (2- and 3-year-olds), and the 1966 brood (3- and 4-year-olds). Flows that coincided with the downstream movement of young from these two brood years occurred in the spring and early summer of 1967 and 1968. Therefore, there is a 2-year lag between the moving averages of escapement and flows. This escapement index is slightly biased because it includes one group of 4-year-olds (1965 brood in example) and one group of 2-year-olds (1968 brood in example). We believe that this bias does not significantly offset low returns resulting from poor conditions or large returns resulting from favorable conditions during downstream migration.

We calculated 2-year moving averages of mean monthly Sacramento streamflow at I Street for April, May, and June, and 2-year moving averages of the historic Delta outflow for April, May, June, and July in years 1951 through 1981 (Table IV-8). These tables also include the historic 2-year

Table IV-3. Estimated number of fall run chinook salmon by age class returning to the mainstem Sacramento River for return years 1971 to 1984. The return index is calculated by summing the number of 2-, 3-, 4-, and 5-year-old returns from a given brood over a period of 4 years as shown for brood year 1969.

Return Year	Total Escapement Sac. R. Mainstem (x1000)	Estimated Age Composition (Number of Fish x1000) Age 2	Age 3	Age 4	Age 5	Brood Year	Return Index
1971	84	12.7	55.7	15.5	0.1	1969	59.6
1972	53	8.0	35.1	9.8	0.1	1970	64.7
1973	63	9.5	41.8	11.7	0.1	1971	79.8
1974	80	12.1	53.0	14.8	0.1	1972	90.5
1975	93	14.0	61.7	17.2	0.1	1973	87.9
1976	90	13.6	59.7	16.7	0.1	1974	79.6
1977	76	11.5	50.4	14.1	0.1	1975	88.9
1978	84	12.7	55.7	15.5	0.1	1976	102.2
1979	117	17.7	77.6	21.6	0.1	1977	75.3
1980	64	9.7	42.4	11.8	0.1	1978	72.6
1981	82	12.4	54.4	15.2	0.1	1979	54.1
1982	46	6.9	30.5	8.5	0.0	1980	60.4
1983	60	9.1	39.8	11.1	0.1	1981	
1984	74	11.2	49.1	13.7	0.1	1982	

Table IV-4. Estimated number of fall run chinook salmon by age class returning to the Feather River for return years 1971 to 1984. See Table IV-3 for derivation of return index.

Return Year	Total Escapement Feather River (x1000)	Estimated Age Composition (Number of Fish x1000) Age 2	Age 3	Age 4	Age 5	Brood Year	Return Index
1971	48	7.2	31.8	8.9	0.0	1969	52.2
1972	47	7.1	31.2	8.7	0.0	1970	68.4
1973	74	11.2	49.1	13.7	0.1	1971	62.9
1974	66	10.0	43.8	12.2	0.1	1972	49.8
1975	43	6.5	28.5	8.0	0.0	1973	56.2
1976	61	9.2	40.4	11.3	0.1	1974	49.4
1977	50	7.6	33.2	9.3	0.1	1975	38.7
1978	38	5.7	25.2	7.0	0.0	1976	33.7
1979	32	4.8	21.2	5.9	0.0	1977	38.6
1980	36	5.4	23.9	6.7	0.0	1978	51.0
1981	53	8.0	35.1	9.8	0.1	1979	50.9
1982	56	8.5	37.1	10.4	0.1	1980	38.6
1983	31	4.7	20.6	5.7	0.0	1981	
1984	52	7.9	34.5	9.6	0.1	1982	

Table IV-5. Estimated number of fall run chinook salmon by age class returning to the American River for return years 1971 to 1984. See Table IV-3 for derivation of return index.

Return Year	Total Escapement American River (x1000)	Estimated Age Composition (Number of Fish x1000) Age 2	Age 3	Age 4	Age 5	Brood Year	Return Index
1971	51	7.7	33.8	9.4	0.1	1969	41.1
1972	24	3.6	15.9	4.4	0.0	1970	77.5
1973	94	14.2	62.3	17.4	0.1	1971	62.5
1974	62	9.4	41.1	11.5	0.1	1972	40.4
1975	39	5.9	25.9	7.2	0.0	1973	33.5
1976	28	4.2	18.6	5.2	0.0	1974	40.6
1977	49	7.4	32.5	9.1	0.0	1975	30.1
1978	21	3.2	13.9	3.9	0.0	1976	43.6
1979	47	7.1	31.2	8.7	0.0	1977	52.1
1980	50	7.6	33.2	9.3	0.1	1978	58.2
1981	64	9.7	42.4	11.8	0.1	1979	45.3
1982	44	6.6	29.2	8.1	0.0	1980	36.9
1983	35	5.3	23.2	6.5	0.0	1981	
1984	38	5.7	25.2	7.0	0.0	1982	

Table IV-6. Estimated number of fall run chinook salmon by age class returning to the Sacramento River Basin for return years 1971 to 1984. See Table IV-3 for derivation of return index.

Return Year	Total Escapement Sac. R. Basin (x1000)	Estimated Age Composition (Number of Fish x1000) Age 2	Age 3	Age 4	Age 5	Brood Year	Return Index
1971	193	29.1	128.0	35.7	0.2	1969	169.5
1972	138	20.8	91.5	25.5	0.1	1970	237.8
1973	263	39.7	174.4	48.7	0.3	1971	226.3
1974	229	34.6	151.8	42.4	0.2	1972	193.5
1975	187	28.2	124.0	34.6	0.2	1973	189.3
1976	188	28.4	124.6	34.8	0.2	1974	187.0
1977	196	29.6	129.9	36.3	0.2	1975	172.8
1978	154	23.3	102.1	28.5	0.2	1976	202.4
1979	221	33.4	146.5	40.9	0.2	1977	192.2
1980	175	26.4	116.0	32.4	0.2	1978	217.2
1981	230	34.7	152.5	42.6	0.2	1979	200.0
1982	206	31.1	136.6	38.1	0.2	1980	170.2
1983	154	23.3	102.1	28.5	0.2	1981	
1984	200	30.2	132.6	37.0	0.2	1982	

Table IV-7. Chinook salmon return index by brood year (1969-1980) for the Feather, American, and mainstem Sacramento rivers, and total Sacramento Basin; and average monthly Sacramento flows and Delta outflows during the period of smolt outmigration. See Table IV-3 for derivation of return index.

	Return Index					Average Monthly Sacramento River Flow at I Street (cfs)			Average Monthly Delta Outflow (cfs)	
Brood Year	Feather River	American River	Sac. R. Mainstem	Total Sac. R. Basin	Flow Year	April	May	June	June	July
1969	52.2	41.1	59.6	169.5	1970	14529	14646	11707	6212	5311
1970	68.4	77.5	64.7	237.8	1971	38026	29977	27371	21242	11824
1971	62.9	62.5	79.8	226.3	1972	13043	13193	13744	3106	6412
1972	49.8	40.4	90.5	193.5	1973	20541	16850	14846	7315	4810
1973	56.2	33.5	87.9	189.3	1974	66115	29960	24265	17134	9519
1974	49.4	40.6	79.6	187.0	1975	32966	31079	23564	21677	10287
1975	38.7	30.1	88.9	172.8	1976	12642	11206	10872	4208	4409
1976	33.7	43.6	102.2	202.4	1977	5929	7799	6764	2500	3200
1977	38.6	52.1	75.3	192.2	1978	38643	25868	12575	9100	4000
1978	51.0	58.2	72.6	217.2	1979	16550	17980	12210	5300	5400
1979	50.9	45.3	54.1	200.0	1980	22590	15890	17810	14900	11200
1980	38.6	36.9	60.4	170.2	1981	17220	13780	10730	4600	5300

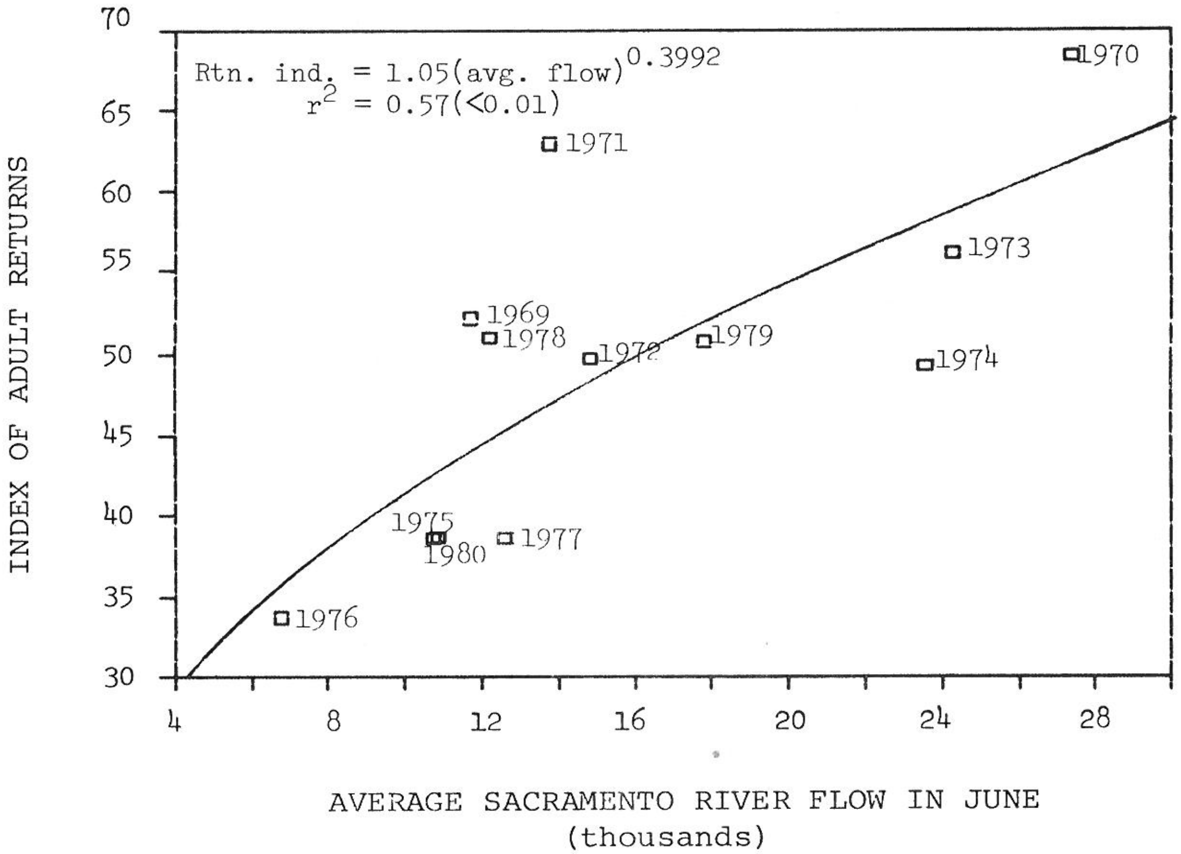

Figure IV-1. Relationship between Feather River return index and Sacramento River flow in June for brood years 1969 to 1980.

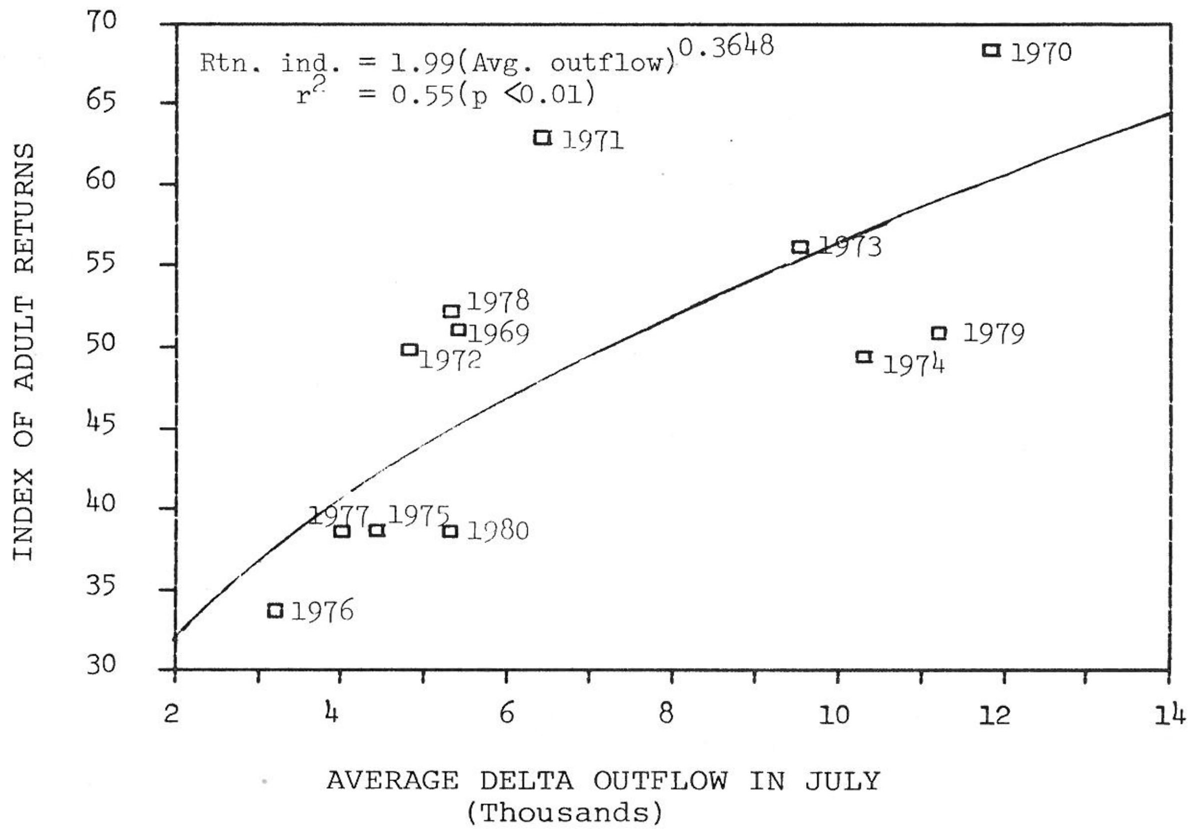

Figure IV-2. Relationship between Feather River return index and Delta outflow in July for brood years 1969 to 1980.

Table IV-8. Historic 2-year moving averages of mean monthly Sacramento River flow at I Street, and mean monthly Delta outflow during the period of smolt outmigration; and 2-year moving averages of spawning escapement to the Feather, American, and mainstem Sacramento rivers for flow years 1952 to 1981.

Year	Historic 2-year Moving Average of Mean Monthly Sacramento River Flow at I Street (cfs)			Historic 2-year Moving Average of Delta Outflow (cfs)				Historic 2-year Moving Average of Spawning Escapement (x1000) in Sacramento Basin (for year+2)		
	April	May	June	April	May	June	July	Feather River	American River	Sac. R. Mainstem
1952	47144	50184	26244	66842	75528	38502	11306	48	29	354
1953	48522	54392	36548	67143	73480	49441	11891	77	23	260
1954	39663	31296	21142	44355	34235	19673	3365	52	12	164
1955	31722	23840	11532	35396	25142	6789	1403	14	7	86
1956	22804	32891	18721	26612	40623	21510	5361	21	18	108
1957	25894	37709	21009	29760	47787	25743	5628	54	29	206
1958	45758	43437	25768	86740	57724	33208	7290	78	43	254
1959	42744	33392	21410	82465	44406	26177	7356	62	40	195
1960	16483	14120	9386	13636	10121	2956	2346	32	26	156
1961	17970	14988	10839	14805	10805	4033	1904	27	34	160
1962	22437	16867	11899	20141	13703	7265	2188	36	50	159
1963	44648	32106	15206	64604	36465	15013	4250	31	49	132
1964	36841	29125	9262	55453	32156	12417	4417	22	33	118
1965	27171	22612	13477	32950	21693	11006	4447	17	25	111
1966	31738	22746	12717	37926	21819	9686	4568	15	27	111
1967	35805	33951	26136	47086	42068	32081	13653	40	39	138
1968	32189	33500	27021	42535	40381	32465	13861	62	42	115
1969	29709	27689	17134	39512	35588	25017	8400	55	45	166
1970	29801	28173	17345	40164	37642	26319	9219	47	39	68
1971	26278	22312	19539	23948	18738	13727	8568	61	60	58
1972	25535	21585	20558	22245	16032	12174	9119	70	79	71
1973	16792	15022	14295	14679	8668	5211	5612	55	51	86
1974	43328	23405	19556	64729	18788	12225	7165	53	34	92
1975	49541	30520	23915	68554	26278	19406	9903	54	38	83
1976	22804	21143	17215	18504	15556	12943	7348	42	35	80
1977	9268	9503	8818	5358	4104	3354	3805	36	35	100
1978	22286	16834	9670	32200	22450	5800	3600	34	49	90
1979	27597	21924	12393	37900	27150	7200	4700	44	57	73
1980	19570	16935	15010	21600	17150	10100	8300	55	54	64
1981	19905	14835	14270	20200	15000	9750	8250	46	40	53

moving averages of spawning escapement of fall run chinook to the Feather, American, and mainstem Sacramento rivers for the years 1953 through 1983. All averages are referenced to flow year so that in 1952, for example, the corresponding flow values are the averages for 1951 and 1952, and the escapement values are the averages for 1953 and 1954.

Figures IV-3 and IV-4 present a comparison of escapement indices in the Feather, American, and Sacramento rivers with the 2-year average June streamflow in the Sacramento River. In general, high flow in June corresponds with high escapement indices. This is most notable for 1953, 1958, 1967 and 1968. After 1967, the Sacramento River run continued to decline and no longer responded to the changes in streamflow. In the Feather and American rivers, the spawning escapements continued to respond to high flows although, after 1970, the relationship between the escapement index and June flow appears to have weakened.

To increase our understanding of how the historic streamflows were related to historic runs in the Sacramento, Feather, and American rivers, we conducted a correlation analysis of the moving averages of flow and escapement presented in Table IV-8. We do not believe it is appropriate to analyze overall escapement into the Sacramento Basin in relation to flow because juveniles from some tributaries may be affected differently by streamflow, Delta outflow, temperature, and food.

CORRELATIONS FOR THE SACRAMENTO RIVER MAINSTEM RUN

We divided the record of escapement indices for the Sacramento mainstem run into two discrete periods, from 1954 to 1969 (1952-67 flow years), and from 1970 to 1983 (1968-81 flow years). The break between periods corresponds to the first year when effects of the Red Bluff Diversion Dam would have been noted in the escapement index.

Between 1952 and 1967 we found significant positive correlations between average escapement and streamflow in the Sacramento River during April, May, and June (Table IV-9 and Figure IV-5). Delta outflow exhibited the same degree of correlation with escapement for these months, as well as a positive correlation for July (Table IV-10, Figure IV-6).

For the period 1968 to 1981, we found no significant correlation between escapement and streamflow or Delta outflow (Tables IV-9, Table IV-10, and Figure IV-5, Figure IV-6).

During the period 1953-1969 an average of 192,000 adults escaped annually into the upper Sacramento River (including Battle Creek). During the period following completion of Red Bluff Diversion Dam (1970-1983), escapement to the upper Sacramento River averaged 84,000 adults, a decline from the earlier period that was commensurate with reduction in survival measured by Hallock (1981), for juveniles released upstream of Red Bluff Diversion Dam. These results confirm our observation that the runs into the upper Sacramento no longer respond to flow as they once did.

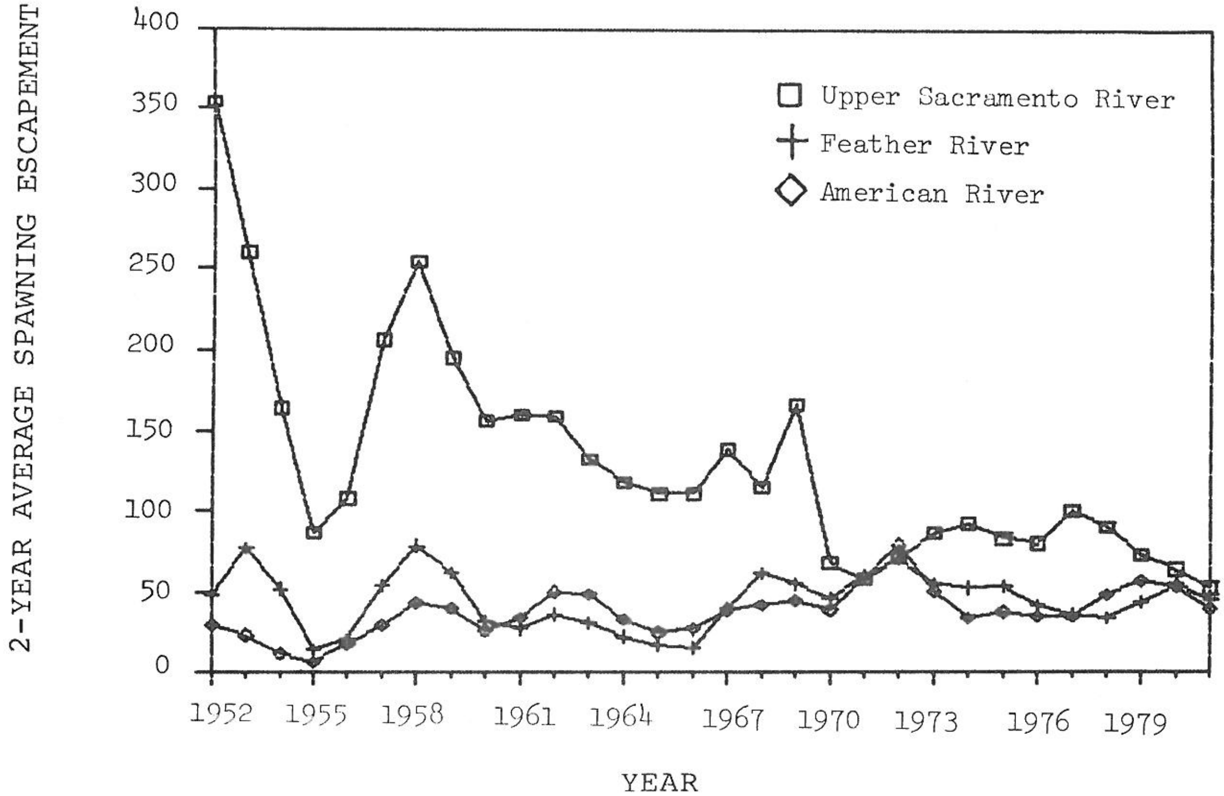

Figure IV-3. Two-year moving averages of escapement in the Feather, American, and mainstem Sacramento rivers for flow years 1952 to 1981. Escapement for a given flow year represents the average return in the next 2 years.

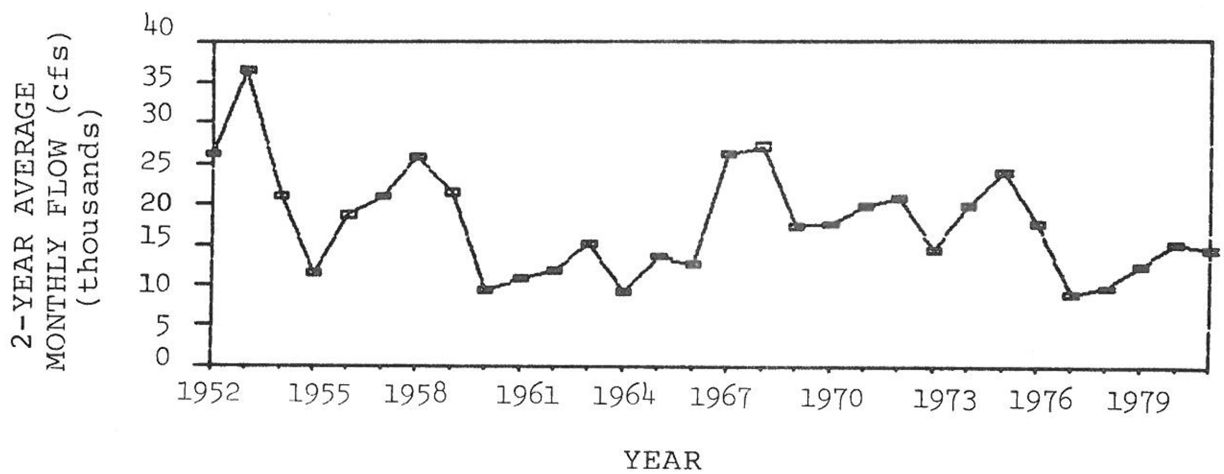

Figure IV-4. Two-year moving averages of Sacramento River flow at I Street during June for flow years 1952-1981. By comparing this figure with Figure IV-3 it appears that, in general, high flow during the smolt outmigration period corresponds with peaks in adult returns. After 1967, however, the Sacramento River run continued to decline and no longer responded to changes in streamflow (see Figures IV-5 and IV-6).

Table IV-9. Regression results describing relationship between 2-year moving average escapement of fall run chinook salmon in Sacramento Basin streams and 2-year moving average of mean monthly streamflow in the Sacramento River at I Street. Average of historic escapement based on CF&G spawning stock estimates. Averages of streamflow based on USGS measurements.

Return Stream	Month	Period	n	r^2	Y Intercept	Regression Coefficient
SACRAMENTO RIVER[1] mainstem	April	1952-81	30	0.25**	35.00	3.14
		1952-67	16	0.28**	51.87	3.50
		1968-81	14	0.02(ns)		
	May	1952-81	30	0.53**	4.76	4.73
		1952-67	16	0.52**	35.88	4.33
		1968-81	14	0.12(ns)		
	June	1952-81	30	0.26**	36.59	5.33
		1952-67	16	0.47**	55.93	6.24
		1968-81	14	0.01(ns)		
FEATHER RIVER[2]	April	1952-81	30	0.11(ns)		
		1952-68	17	0.31*	2.36	1.14
		1969-81	13	0.10(ns)		
	May	1952-81	30	0.17*	26.72	0.68
		1952-68	17	0.49**	0.57	1.29
		1969-81	13	0.15(ns)		
	June	1952-81	30	0.49**	11.65	1.88
		1952-68	17	0.67**	-0.73	2.20
		1969-81	13	0.54**	22.77	1.70
AMERICAN RIVER	April	1952-81	30	0.04(ns)		
	May	1952-81	30	0.08(ns)		
	June	1952-81	30	<0.01(ns)		

* Significant at α = .05
** Significant at α = .01
ns Not significant

1 Separate analyses performed for periods before and after effects of Red Bluff Diversion Dam would have been noted in escapement index.

2 Separate analyses performed for periods before and after effects of Feather River Hatchery would have been noted in escapement index.

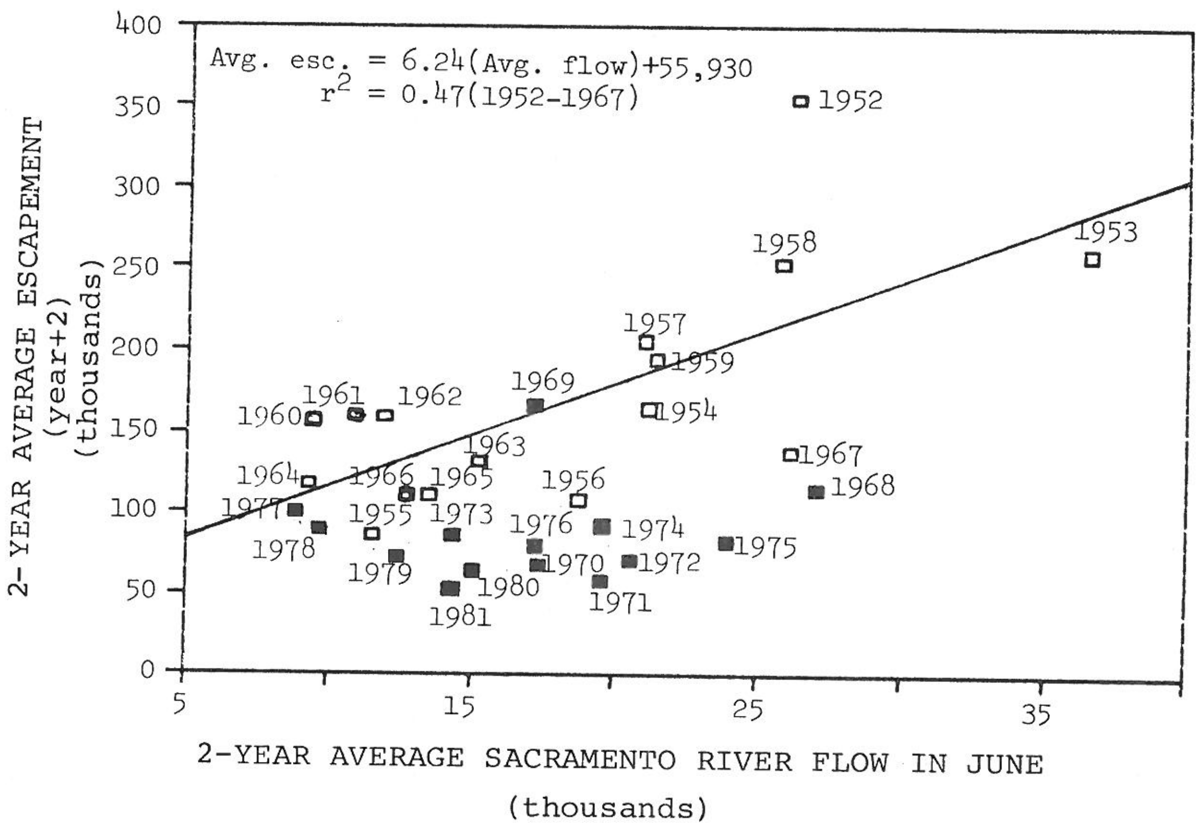

Figure IV-5. Correlation between 2-year moving average of escapement to the mainstem Sacramento River and 2-year moving average of Sacramento River flow at I Street during June for flow years 1952 to 1967, (open squares), and lack of correlation in subsequent years, (closed squares). Break between periods corresponds to the first year when effects of Red Bluff Diversion Dam would have been noted in the escapement.

Table IV-10. Regression results describing relationship between 2-year moving average escapement of fall run chinook salmon in Sacramento Basin streams and 2-year moving average of mean monthly Delta outflow. Averages of historic escapement based on CF&G spawning stock estimates. Averages of Delta outflow based on DWR computations (DAYFLOW program).

Return Stream	Month	Period	n	r^2	Y Intercept	Regression Coefficient
SACRAMENTO RIVER[1] mainstem	April	1952-81	30	0.27**	65.64	1.65
		1952-67	16	0.27*	97.60	1.58
		1968-81	14	0.05(ns)		
	May	1952-81	30	0.59**	42.50	2.96
		1952-67	16	0.59**	70.54	2.69
		1968-81	14	0.15(ns)		
	June	1952-81	30	0.43**	64.77	3.85
		1952-67	16	0.53**	94.91	3.78
		1968-81	14	0.17(ns)		
	July	1952-81	30	0.03(ns)		
		1952-67	16	0.34*	106.33	11.06
		1968-81	14	<0.01(ns)		
FEATHER RIVER[2]	April	1952-81	30	0.13(ns)		
		1952-68	17	0.37**	14.67	0.57
		1969-81	13	0.02(ns)		
	May	1952-81	30	0.14*	33.71	0.37
		1952-68	17	0.48**	12.93	0.75
		1969-81	13	<0.01(ns)		
	June	1952-81	30	0.31**	30.59	0.83
		1952-68	17	0.63**	15.27	1.23
		1969-81	13	0.11(ns)		
	July	1952-81	30	0.39**	23.23	3.23
		1952-68	17	0.35*	21.65	3.04
		1969-81	13	0.48**	26.53	3.27
AMERICAN RIVER	April	1952-81	30	0.02(ns)		
	May	1952-81	30	0.07(ns)		
	June	1952-81	30	0.03(ns)		
	July	1952-81	30	0.06(ns)		

* Significant at α = .05
** Significant at α = .01
ns Not significant

1 Separate analyses performed for periods before and after the first effects of the Red Bluff Diversion Dam would have been noted in escapement index.

2 Separate analyses performed for periods before and after the first effects of the Feather River Hatchery would have been noted in escapement index.

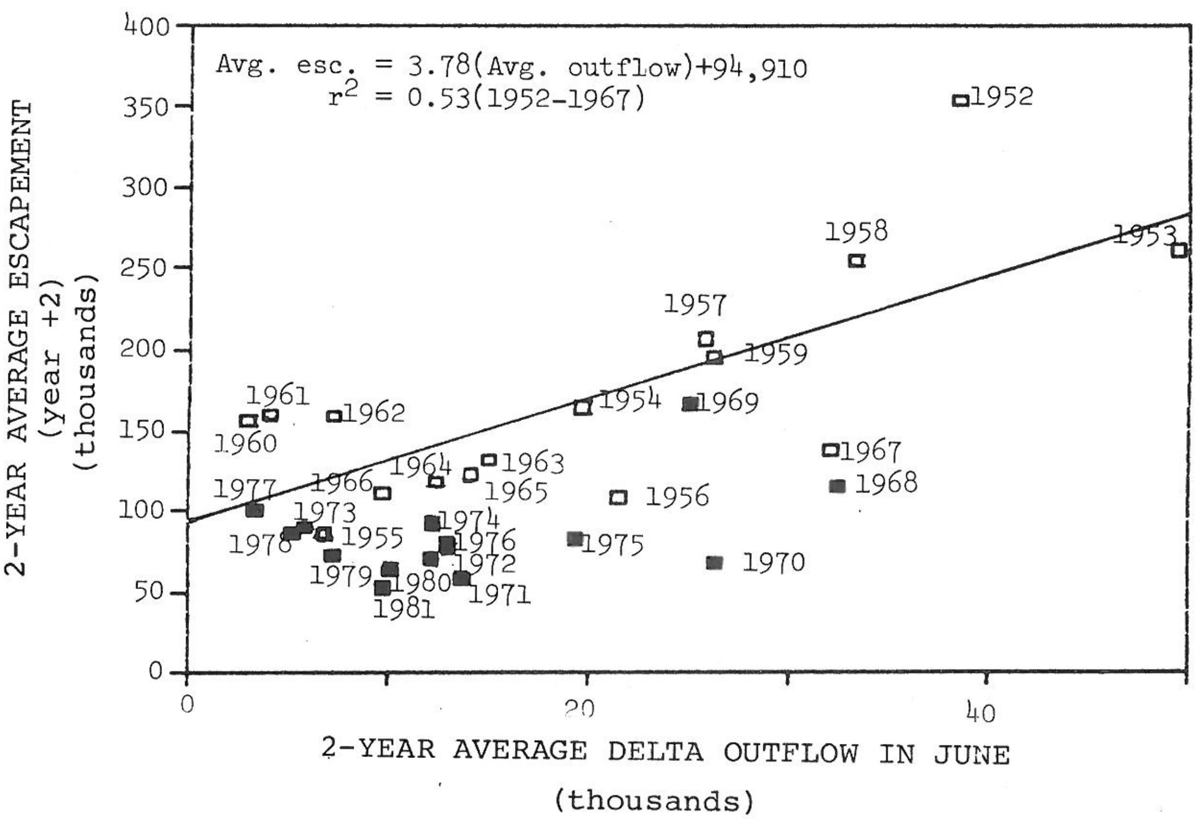

Figure IV-6. Correlation between 2-year moving average of escapement to the mainstem Sacramento River and 2-year moving average of Delta outflow during June for flow years 1952 to 1967 (open squares), and lack of correlation in subsequent years (closed squares). Break between periods corresponds to the first year when effects of Red Bluff Diversion Dam would have been noted in the escapement.

FEATHER RIVER

We divided the record of escapement indices for the Feather River run into two periods from 1954 through 1970, and 1971 through 1983. The returns for 1971 were the first that were affected by releases of fish from the Feather River Hatchery. For the years 1952 to 1968, the escapement index for the Feather River is correlated significantly with Sacramento River streamflows and Delta outflows in all months examined (Tables IV-9 and Table IV-10). For the latter historical period, 1969 through 1981, significant correlations were found between the index and streamflow in June and Delta outflow in July. This finding is in agreement with the results of our first correlation analysis which encompassed roughly the same period.

In a previous section we noted that the Feather River now supports more fish than it did prior to installation and operation of the Feather River Hatchery and Oroville Dam. This trend is depicted in Figure IV-7 which shows the relationships between the escapement index and Sacramento River flow at I Street for the two historic periods. Based upon these relationships, it appears that the Feather River now produces more fish at lower flows than it did under historical conditions. We suspect that this is a direct result of hatchery production. The relationships between escapement and streamflow for both of our correlation analyses summarized in Figures IV-1 and IV-7, indicate that the average escapement of 50,000 fish into the Feather River is associated with streamflows in the Sacramento River of about 16,000 cfs in June. Relationships between escapement and July outflow (Figure IV-2) indicate the average escapement is associated with July outflows equal to 7000 cfs.

AMERICAN RIVER

The relationship between escapement to the American River and streamflow and Delta outflow was not significant for the period 1952-1981 (Tables IV-9 and IV-10). We conducted a separate analysis of the relationship between 2-year average escapement to the American River and 2-year average Sacramento River flow and Delta outflow for the same set of years examined in the first analysis. In like manner, all correlations were insignificant. At first the lack of correlation surprised us but recently we have found that the salmon run in the lower American River is largely supported by Nimbus Hatchery reared smolts planted in the estuary. Lower American River flows have no major influence on them.

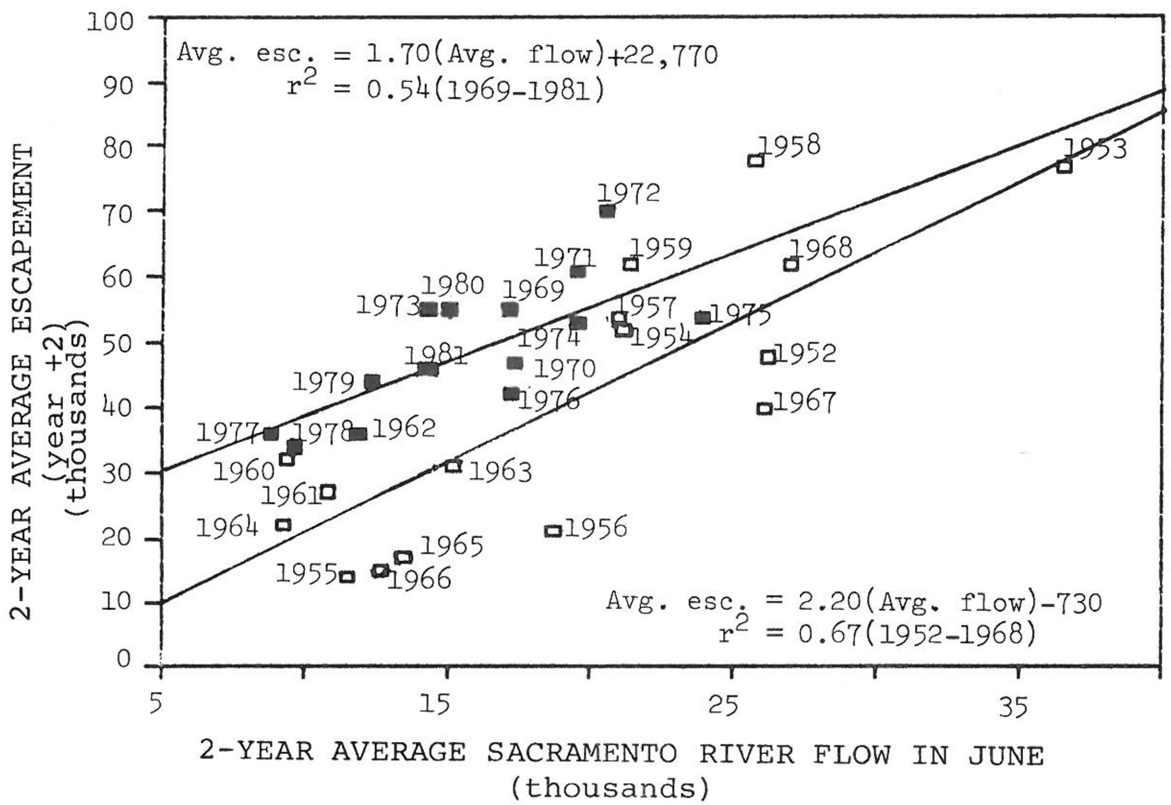

Figure IV-7. Correlation between 2-year moving average of escapement to the Feather River and 2-year moving average of Sacramento River flow at I Street during June for flow years 1952 to 1968, (open squares), and 1969 to 1981, (closed squares). Since the construction and initial operation of Feather River Hatchery and Oroville Dam in the late 1960s, the Feather River has produced more fish at lower flows than it did under historical conditions.

CITATIONS

Boydstun, L. B. 1972. The ages and lengths of king salmon (O. tshawytscha) and silver salmon (O. kisutch) in a troll catch made off northern California during 1969. Anadromous Fisheries Branch, Administrative Report No. 72-13. California Department of Fish and Game. 14 pp.

California Department of Fish and Game. 1949. The commercial fish catch of California for the year 1947 - with an historical review, 1916-1947. Bureau of Marine Fisheries, Bulletin 74. 267 pp.

California Department of Fish and Game. 1954. The commerical fish catch of California for the year 1952 with proportion of king and silver salmon in California's 1952 landings. Marine Fisheries Branch, Bulletin 95. 64 pp.

California Department of Fish and Game. 1981. The J. E. Skinner Delta Fish Protective Facility: A Summary of the First 13 Years of Operation. Anadromous Fisheries Branch Administrative Report 81-6. 22 pp. + Appen.

Cannon, T. C. 1980. Status of the Sacramento-San Joaquin chinook salmon and factors related to their decline. Report prepared for National Marine Fisheries Service, South West Region, by Envirosphere Co., Newport Beach, CA. 11 pp and figures.

Clark, G. H. 1929. Sacramento River Salmon Fishery. California Fish and Game. Vol. 15(1):1-10.

Gangmark, H. A. and R. D. Broad. 1956. Further observations on stream survival of king salmon spawn. California Fish and Game. Vol. 42:37-49.

Godin, J. J. 1982. Migration of salmonid fishes during early life history phases: daily and annual timing. Pp. 22-50. In Brannon, E. L. and E. O. Salo (eds.) Proceedings of Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle, WA. 309 pp.

Hallock, R. J. 1981. Effect of Red Bluff Diversion Dam on chinook salmon (O. tshawytscha) and fingerlings. California Department of Fish and Game, Anadromous Fisheries Branch Office Report. 9 pp.

Hallock, R. J. and D. H. Fry, Jr. 1967. Five species of salmon (Oncorhynchus), in the Sacramento River, California. California Fish and Game. Vol. 53(1):5-22.

Heubach, W. 1968. Environmental requirements and the future of king salmon (O. tshawytscha) in the Sacramento-San Joaquin Estuary. In Kelley, et al. 1968. Fish and Wildlife Resources of San Francisco Bay and Delta: Description, Environmental Requirements, Problems, Opportunities, and the Future. California Department of Fish and Game. 338 pp.

Citations (continued)

Jensen, P. T. and P. G. Swartzell. 1967. California salmon landings 1952 through 1965. California Department of Fish and Game, Fish Bulletin 135:43-57.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1982. Life history of fall run juvenile chinook salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin Estuary, California. Pp. 393-411. In Kennedy, V. B. (ed.) Estuarine Comparisons, Academic Press.

Kutkuhn, J. H. 1963. Estimating absolute age composition of California salmon landings. Fish Bulletin No. 120. California Department of Fish and Game. 47 pp.

Messersmith, J. 1966. Fishes collected in Carquinez Strait in 1961-62. In Kelley, D. W., et al. Ecological Studies of the Sacramento-San Joaquin Estuary. California Department of Fish and Game, Fish Bulletin 133. 133 pp.

Pacific Fisheries Management Council. 1984. A review of the 1983 ocean salmon fisheries and status of stocks and management goals for the 1984 salmon season off the coasts of California, Oregon, and Washington.

Pacific Fisheries Management Council. 1985. A review of the 1984 ocean salmon fisheries and status of stocks and management goals for the 1985 salmon season off the coasts of California, Oregon, and Washington.

Pacific Fisheries Management Council. 1986. A review of the 1985 ocean salmon fisheries and status of stocks and management goals for the 1986 salmon season off the coasts of California, Oregon, and Washington.

Pacific Fisheries Management Council. 1987. A review of the 1986 ocean salmon fisheries and status of stocks and management goals for the 1987 salmon season off the coasts of California, Oregon, and Washington.

Reavis, R. 1983. Annual Report. Chinook salmon spawning stocks in California Central Valley, 1981. California Department Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 83-2. 41 pp.

Rutter, C. 1903. Natural history of the quinnat salmon. A report of investigations in the Sacramento River, 1896-1901. US Fish Commission, Bull. 22:65-141.

Sasaki, Shoken. 1966. Distribution and food habits of king salmon (O. tshawytscha) and steelhead trout (S. gairdneri), in the Sacramento-San Joaquin Delta. Pp. 108-114. In Turner, J. L. and D. W. Kelley (eds). Ecological Studies of the Sacramento-San Joaquin Delta, California. California Fish and Game, Fish Bull. 136:1-168.

Skinner, J. E. 1962. A historical review of the fish and wildlife resources of San Francisco Bay area. California Department of Fish and Game, Water Projects Branch Report, No. 1. 225 pp + maps.

Citations (continued)

Snyder, J. O. 1931. Salmon of the Klamath River. California Fish Bulletin, No. 34. Division of Fish and Game of California. 125 pp.

Stevens, D. E., M. A. Kjelson, and P. L. Brandes. 1984. An evaluation of the relationship between survival of chinook salmon smolts and river flow in the Sacramento-San Joaquin Delta. Appendix to Bay-Delta Fishery Project, Annual Progress Report - AWPA 750-29. 39 pp.

Stevens, D. E., M. A. Kjelson, and P. L. Brandes. 1985. Determine survival and productivity of juvenile chinook salmon in the Sacramento-San Joaquin Estuary. Bay-Delta Fishery Project, Annual Progress Report - AWPA 750-29. 49 pp.

Taylor, S. N. 1973. King salmon spawning stocks in California Central Valley, 1971. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 73-2. 36 pp.

Van Hyning, J. M. 1973. Factors affecting the abundance of fall chinook salmon in the Columbia River. Fish Commission of Oregon, Research Report, Vol. 4(1). 87 pp.

Wales, J. H. and M. Coots. 1954. Efficiency of chinook salmon spawning in Fall Creek, California. Trans.Am.Fish.Soc. 84:13-147.

Wickwire, R. H. and D. E. Stevens. 1971. Migration and distribution of young king salmon (O. tshawytscha) in the Sacramento River near Collinsville. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 71-4. 20 pp.

APPENDIX

Appendix A-1. Annual estimates of weight and number of chinook salmon landed in the Sacramento-San Joaquin gill net fishery between 1916 and 1957. Number of salmon estimated by dividing total pounds landed by the mean weight (18.23 pounds) of an adult fish gill netted in the years 1952 to 1957 (Jensen and Swartzel 1967). Catch data from Skinner (1962).

Year	Pounds x 10^6	Numbers	Year	Pounds x 10^6	Numbers
1916	3.451	189269	1937	0.974	53419
1917	3.975	218007	1938	1.668	91481
1918	5.938	325667	1939	0.497	27258
1919	4.529	248391	1940	1.516	83144
1920	3.860	211700	1941	0.845	46344
1921	2.511	137715	1942	2.553	140018
1922	1.765	96801	1943	1.295	71024
1923	2.244	123071	1944	3.265	179068
1924	2.640	144790	1945	5.468	299890
1925	2.779	152413	1946	6.463	354461
1926	1.262	69214	1947	3.380	185375
1927	0.917	50293	1948	1.940	106399
1928	0.553	30329	1949	0.899	49305
1929	0.581	31865	1950	1.211	66417
1930	1.214	66581	1951	1.343	73656
1931	0.942	51664	1952	0.738	37851
1932	1.265	69378	1953	0.870	43291
1933	0.454	24899	1954	0.901	57704
1934	0.397	21773	1955	2.321	120847
1935	0.889	48757	1956	1.140	68390
1936	0.949	52048	1957	0.321	17532

Appendix A-2. Annual estimates of weight of total salmon landings in the California ocean commercial fishery by area, and estimated number of Central Valley (CV) chinook caught in the commercial ocean fishery off California for the period 1916 to 1951. Weights of total landings based on CF&G estimates. Number of Central Valley chinook salmon estimated by applying mean weights from 1952-1965 period and fractions described below and listed in Table A-6.

	California Ocean Troll Catch by Area[1] (pounds)					California Ocean Troll Catch of Central Valley Chinook by Number[2]				
Year	Eureka	San Fran	Monterey	Other	Total	Eureka	SanFran	Monterey	Other	Total
1916	98,353	262,889	5,230,839	135	5,592,216	2,871	16,268	407,073	7	426,218
1917	924,192	1,280,312	3,879,487	2,006	6,085,997	26,974	79,227	301,908	98	408,207
1918	1,110,611	1,928,794	2,892,876	1,065	5,933,346	32,414	119,355	225,129	52	376,950
1919	2,949,642	1,442,708	2,816,022	10	7,208,382	86,089	89,276	219,148	0	394,513
1920	3,115,381	1,459,932	1,490,877	0	6,066,190	90,926	90,342	116,023	0	297,290
1921	2,300,259	938,886	1,243,960	0	4,483,105	67,136	58,099	96,807	0	222,042
1922	2,496,841	961,317	880,129	30	4,338,317	72,873	59,487	68,493	1	200,855
1923	1,693,711	1,314,877	728,336	0	3,736,924	49,433	81,366	56,680	0	187,479
1924	1,880,342	3,617,045	877,186	0	6,374,573	54,880	223,825	68,264	0	346,969
1925	3,111,885	1,270,936	1,098,715	0	5,481,536	90,824	78,646	85,504	0	254,974
1926	2,849,509	962,413	51,755	0	3,863,677	83,166	59,555	4,028	0	146,749
1927	2,715,806	1,488,746	717,027	21	4,921,600	79,264	92,125	55,800	1	227,190
1928	2,293,832	815,815	334,654	5	3,444,306	66,948	50,483	26,043	0	143,475
1929	2,320,846	658,718	1,054,096	0	4,033,660	67,737	40,762	82,032	0	190,530
1930	2,797,993	1,008,242	279,409	6	4,085,650	81,663	62,391	21,744	0	165,798
1931	3,254,846	428,298	91,471	0	3,774,615	94,996	26,503	7,118	0	128,618
1932	2,656,788	124,010	80,884	16	2,861,698	77,541	7,674	6,295	1	91,511
1933	2,943,962	158,806	569,859	48	3,672,675	85,923	9,827	44,347	2	140,100
1934	2,824,743	818,852	286,230	0	3,929,825	82,443	50,671	22,275	0	155,389
1935	3,790,733	337,751	219,700	15	4,348,199	110,637	20,900	17,097	1	148,635
1936	3,655,768	266,440	144,924	1,020	4,068,152	106,698	16,488	11,278	50	134,514
1937	3,895,867	1,108,402	891,083	931	5,896,283	113,705	68,589	69,346	46	251,685
1938	1,868,706	94,975	199,474	183	2,163,338	54,540	5,877	15,523	9	75,950
1939	1,821,931	285,194	125,498	0	2,232,623	53,175	17,648	9,766	0	80,590
1940	3,369,492	1,177,653	613,224	34	5,160,403	98,343	72,874	47,722	2	218,940
1941	2,413,368	375,766	153,662	3,198	2,945,994	70,437	23,253	11,958	157	105,805
1942	2,255,862	1,642,051	164,931	462	4,063,306	65,840	101,611	12,835	23	180,309
1943	2,162,368	2,021,208	1,101,934	17	5,285,527	63,111	125,074	85,754	1	273,940
1944	3,792,103	2,646,714	575,579	7,452	7,021,848	110,677	163,781	44,793	365	319,615
1945	4,627,714	2,431,954	816,303	36,783	7,912,754	135,065	150,491	63,526	1,803	350,885
1946	4,545,299	2,017,703	569,350	2,120	7,134,472	132,660	124,857	44,308	104	301,928
1947	5,868,577	1,485,657	738,469	0	8,092,703	171,281	91,934	57,469	0	320,684
1948	4,033,992	1,544,479	250,906	0	5,829,377	117,737	95,573	19,526	0	232,836
1949	2,601,390	2,455,543	473,741		5,530,674	75,925	151,951	36,867	0	264,743
1950	2,217,558	4,072,973	769,705	4,715	7,064,951	64,722	252,039	59,900	231	376,891
1951	1,895,267	4,508,571	679,128	2,637	7,085,603	55,316	278,994	52,851	129	387,289

1 Sources: Years 1916-1950, Fry and Hughes (1951); 1951, CF&G Fish Bulletin No. 89.

2 Annual contributions of Central Valley chinook estimated by: 1) multiplying the weight of total salmon landings times the fraction of the 1952-1965 landings that were chinook to estimate weight of chinook landings; 2) dividing the weight of chinook landings by the average weight of chinook caught during the 1952-1965 period to estimate number of chinook landed in California; and 3) multiplying the number of fish landed times the overall fraction of fish in the fishery that were estimated to be from the Central Valley during the 1977-1986 period.