The Effects of San Joaquin River Flows and Delta Export Rates During October on the Number of Adult San Joaquin Chinook Salmon that Stray

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Abstract

This report describes a two-part investigation of the effects of fall make-up pumping on straying of adult San Joaquin chinook salmon. The first part is a reevaluation of 1964 to 1967 data collected by Hallock and others (1970) on the migratory behavior of tagged and untagged adult San Joaquin salmon in the Delta. The second part is an evaluation of the recovery of adult salmon that were released in the San Joaquin basin as coded-wire tagged juveniles reared at the Merced River Fish Facility.

There are three important results from Hallock and others (1970) regarding their migration analysis. First, adult salmon are migrating through the San Joaquin Delta near Prisoners Point primarily during October, the period when they are probably most susceptible to low flows and high exports. Second, the fish migrate slowly and do not arrive in the San Joaquin tributaries until about four weeks after they pass Prisoners Point, even when flows, exports, and dissolved oxygen concentrations near Stockton are suitable for migration. And third, migration rates of adult salmon are substantially higher when Vernalis flows exceed about 3,000 cfs and total exports are less than 100% of Vernalis flows. Although most of the tagged fish migrated into the Sacramento and Mokelumne basins when Vernalis flows were less than about 2,000 cfs and total exports exceeded 150% of Vernalis flows, there is uncertainty as to whether these were San Joaquin fish that strayed or Sacramento River fish that were captured in the San Joaquin on their way to the Sacramento River.

The coded-wire-tag (CWT) recovery data may not have been appropriate for a straying analysis because there are no clear records of the number of fish examined for tags during the carcass surveys. Not all fish counted for the carcass survey were examined for tags. These recovery data are necessary to accurately compute the total number of adult salmon with tags in each river. A casual inspection of the CWT recovery data suggests that: (1) straying rates increased as the percentage of San Joaquin flow exported by the CVP and SWP pump-

ing facilities increased and (2) the critical period is between 1 and 21 October. Furthermore, pulse flows from the San Joaquin tributaries, or a reduction of Delta exports that result in no more than a 300% export rate of San Joaquin flows at Vernalis for eight to twelve days in mid-October, are sufficient to keep straying rates below 3%.

The results of these correlation analyses suggest that when more than 300% of Vernalis flow is exported over a ten-day period in mid-October adult San Joaquin chinook salmon stray to the Sacramento and eastside basins. However, further tests are needed due to the limitations of the existing data.

Introduction

To increase production of fall-run chinook salmon (*Oncorhynchus tshawytscha*) in the San Joaquin tributaries, exports at the State Water Project (SWP) and the Central Valley Project (CVP) and San Joaquin River flows were managed to provide a 1:4 ratio of exports to flow at Vernalis during spring 1996 when the salmon smolts were migrating through the Delta. The State Water Resources Control Board Order 96–6 permitted the SWP and the CVP to "make-up" the reduced volume of springtime exports by pumping at near maximum rates during fall, primarily October and November. Sustained high export rates during October and November were cause for concern, since this is the period when adult San Joaquin chinook salmon migrate upstream through the Delta to their spawning grounds. To do this, the salmon require the scent of San Joaquin River flow to return to their natal river. In October 1996, the combined SWP and CVP exports averaged about 9,600 cfs, whereas San Joaquin River flows at Vernalis averaged 2,650 cfs. Fall make-up pumping occurred again in fall 1997, and the combined SWP and CVP exports averaged about 9,700 cfs, while San Joaquin River flows at Vernalis averaged about 1,950 cfs. It is likely that when exports are relatively high compared to Vernalis flows, little if any San Joaquin River water reaches the San Francisco Bay where it is needed to help guide the salmon (see the literature review that follows). If true, a substantial portion of the adult salmon population of the San Joaquin tributaries could stray into the Sacramento and Mokelumne rivers, which provide a majority of the flow through the Central Delta during the fall, particularly when the ratio of exports to San Joaquin River flow is high.

This report describes a two-part evaluation of the possible effects of fall make-up pumping on the straying of adult San Joaquin chinook salmon. The first part is a reevaluation of the data collected by Hallock and others (1970) from 1964 to 1967 on the migratory behavior of tagged and untagged adult San Joaquin salmon in the Delta. The second part is an evaluation of the recovery of adult salmon that were released in the San Joaquin basin as coded-wire tagged juveniles reared at the Merced River Fish Facility. The recovery data are from Department of Fish and Game surveys made between 1983 and 1996.

A Literature Review of Homing Behavior of Adult Pacific Salmon

Adult Pacific salmon rely on olfactory cues to guide their upriver migration to their natal stream, although other factors may be involved (Quinn 1990). It is generally believed that juveniles rearing and migrating downriver acquire a series of olfactory waypoints at every major confluence and retrace the sequence as adults when they return to spawn (Harden Jones 1968; Quinn and others 1989; Quinn 1990). Few adult coho (Wisby and Hasler 1954) and chinook salmon (Groves and others 1968) that had their olfactory pits plugged (to prevent them from sensing waterborne odors) were able to home to their natal stream. Most (67% and 89%) of the control fish in those studies were able to home to their natal stream. During both of these studies, blinded fish were able to home more successfully than were fish with occluded olfactory pits. Normal homing rates for chinook salmon probably range between 84% for 17,671 recovered fish that were reared at a New Zealand hatchery (Unwin and Quinn 1993) and 98.6% for 41,085 recovered fish that were reared at the Cowlitz River Hatchery, Washington (Quinn and Fresh 1984). Experiments have also shown that juvenile coho salmon exposed to artificial waterborne odors while they were reared in hatcheries, homed to waters that contained those artificial odors (Cooper and others 1976; Johnsen and Hasler 1980; Brannon and Quinn 1990; Dittman and others 1994; Dittman and others 1996).

Besides olfactory cues, there is evidence that compass orientation helps adult salmon to home to their natal stream. Adult Pacific salmon, particularly those that migrate long distances in the ocean to feed (stream-type populations), use compass orientation in ocean and coastal waters to locate the mouth of their natal stream, where they switch to olfactory clues (Quinn 1990). However, the mechanism of compass orientation and the transition from compass orientation in coastal waters and estuaries to olfactory-based upriver homing appear to be very complicated and not well understood (Quinn 1990). Furthermore, ocean-type populations of Pacific salmon, such as the fall-run chinook populations in the San Joaquin tributaries, may not have a well-developed means of navigation by compass orientation since they do not migrate far from the coast to feed. This would explain why most sockeye salmon, a stream-type population, that had their olfactory nerves severed in an experiment could still migrate in a homeward direction (Craigie 1926), whereas chinook salmon with plugged olfactory pits could not migrate homeward (Groves and others 1968).

There is contradictory evidence that hereditary factors also influence homing behavior. Bams (1976) and McIsaac and Quinn (1988) provided proof that a high proportion of displaced chinook salmon offspring homed to their ancestral spawning area even though the juvenile fish were never exposed to their ancestral waters. However, Donaldson and Allen (1957) provided evidence that coho juveniles relocated to two different locations prior to smolting would home to their release sites and not to their original hatchery site. The scent from siblings (population-specific odors) did not affect adult coho salmon homing behavior in Lake Washington (Brannon and Quinn 1990), and no other mechanism to account for a hereditary factor has been discovered.

When adult Pacific salmon do not return to their natal stream, they appear to select a new river for spawning based on the magnitude of streamflow. Two field studies conducted by Quinn and Fresh (1984) in Washington and Unwin and Quinn (1993) in New Zealand determined that adult chinook salmon strays selected rivers with the highest streamflow. An experimental study conducted by Wisby and Hasler (1954) also showed that when the scent of the fishes' natal river was not present, coho salmon moved into the arm of a Y-maze with the greatest flow. If true, then adult San Joaquin salmon that cannot use olfaction due to an absence of scent from their natal river would probably return to the Sacramento River, where flows are substantially greater.

A Review of Hallock's Study

The migration of adult fall-run chinook salmon in the Delta and lower San Joaquin River was studied by the Department of Fish and Game between 1964 and 1967. Adult salmon were captured with a trammel net (floating gill net, 23 feet deep and 1,378 to 1,804 feet long) at Prisoners Point in the San Joaquin River, which is about 2.5 miles upstream of the confluence with the Mokelumne River. The daily catch rate was recorded during each year except 1965. Sonic tags were attached to the dorsal surface of the fish just anterior to the dorsal fin with straps and pins. Stationary monitors that recorded the presence of the tags were used in the Sacramento River, Mokelumne River, San Joaquin River, and throughout the Delta to help determine the destination and migration rate of the tagged fish. The authors also presented the number of salmon captured at a trap operated in the Stanislaus River for hatchery stock from 1965 to 1967.

Results

For 1966 and 1967, when catch rates were estimated at both Prisoners Point and the Stanislaus trap, most fish arrived at Prisoners Point between 1 October and 20 October (some were caught through 21 November), whereas most fish were not caught at the Stanislaus River trap until after 5 November (Figures 1 and 2). Hallock reported that few of the tagged fish migrated past Stockton when dissolved oxygen (DO) levels were less than about 5 ppm (4.5 in 1967 and 5.5 in 1965). Furthermore, the catch at the Stanislaus trap tended to increase about one week after DO levels at Stockton stabilized at or above the critical level. The fish usually remained in the Delta for at least three weeks prior to entering the Stanislaus and Hallock reported that some remained in the Delta for up to two months. Therefore, an evaluation of fall make-up pumping on straying of adult fish must be conducted by monitoring fish in the Delta, not the San Joaquin tributaries.

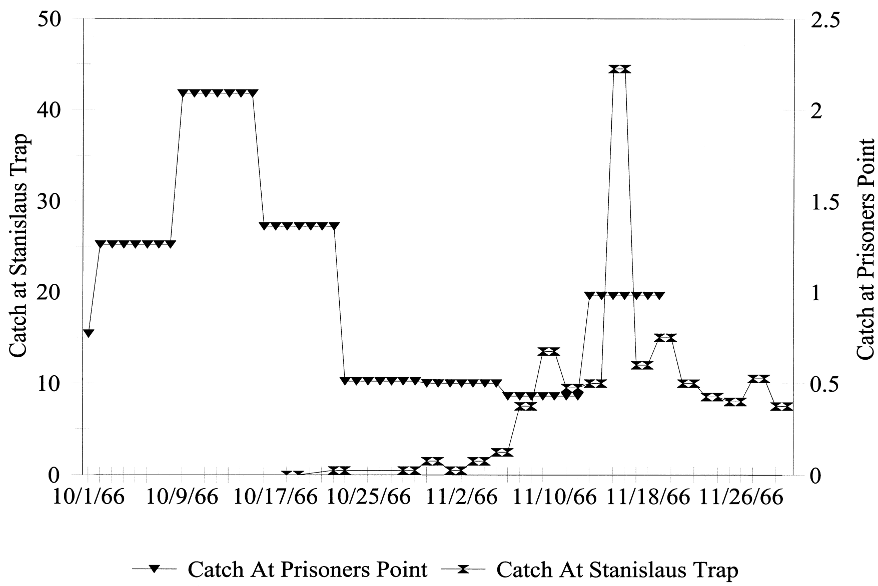

Figure 1 Catch rates of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River (about 2.5 miles upstream of the confluence with the Mokelumne River) and at the Orange Blossom trap in the Stanislaus River in October and November 1966

I evaluated the effects of exports and San Joaquin flow on the number of strays using two sets of data collected by Hallock and others (1970). The first data set evaluated were straying rates for 35 to 77 adult salmon tagged at Prisoners Point each year and the second data set evaluated were catch rates of adult salmon at Prisoners Point relative to flows and exports.

During the first three weeks of October in 1965 and 1967, only 15% of the tagged fish migrated into the Sacramento and Mokelumne rivers when Vernalis flows ranged between 2,000 and 4,000 cfs and the proportion of Vernalis flows exported at Tracy ranged between 45% and 120%. In contrast, during the first three weeks of October, 54% of the tagged fish (35) strayed into the Sacramento and Mokelumne rivers in 1964 and 71% of the tagged fish (52) strayed in 1966 when Vernalis flow ranged between 700 and 1,500 cfs and the proportion of Vernalis flows exported at Tracy ranged between 150% and 250%. A solid rock barrier was installed at the head of Old River in 1964, but not during the other study years, and it is likely that the barrier increased the amount of San Joaquin flow that remained in the San Joaquin River.

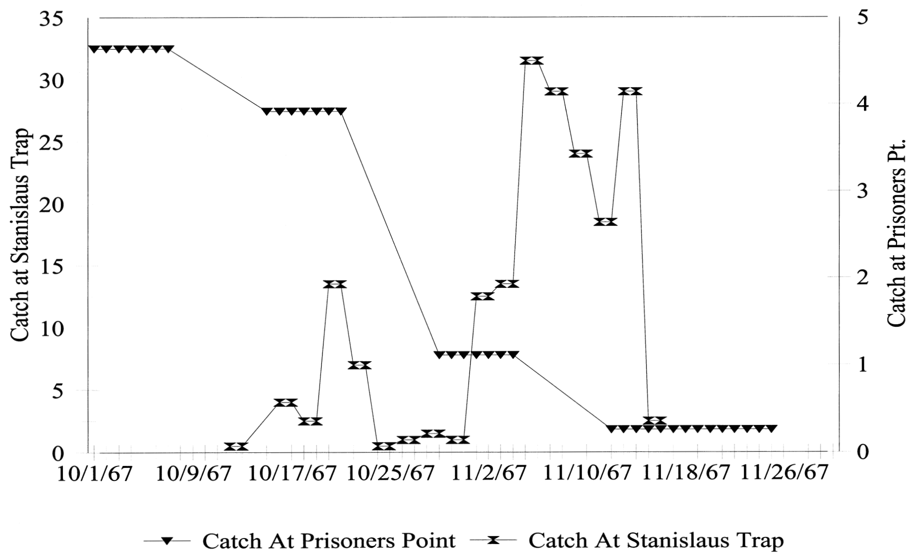

Figure 2 Catch rates of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River, which is about 2.5 miles upstream of the confluence with the Mokelumne River and at the Orange Blossom trap in the Stanislaus River in October and November 1967

Hallock and others (1970) could not verify whether the adult salmon caught at Prisoners Point were actually of San Joaquin origin. They speculated the tagged fish that migrated into the Sacramento and Mokelumne rivers were not San Joaquin basin strays but were Sacramento basin fish guided 2.5 miles upstream of the mouth of the Mokelumne in the Delta (to Prisoners Point) by strong tidal flows. However, they could not reasonably explain why a high number of tagged fish migrated into the Sacramento and Mokelumne rivers in 1964 and 1966 when there was a high proportion of exported San Joaquin flow, but a low number of tagged fish migrated into the same rivers in 1965 and 1967 when there was a low proportion of exported San Joaquin flow.

The effects of Vernalis flows and exports on straying were also evaluated using the catch rate at Prisoners Point determined by Hallock and others (1970). In 1964, catch rates ranged between 0.63 and 1.25 fish/hour between 5 and 25 October, when Vernalis flow ranged between 1,100 and 1,500 cfs (Figure 3) and exports ranged between 130 and 225% of Vernalis flows (Figure 4). After Vernalis flows rapidly increased to about 2,000 cfs and exports began to decline to less than 100% of Vernalis flows on 29 October, catch rates at Prisoners Point increased to 5.36 fish/hour on 4 and 5 November.

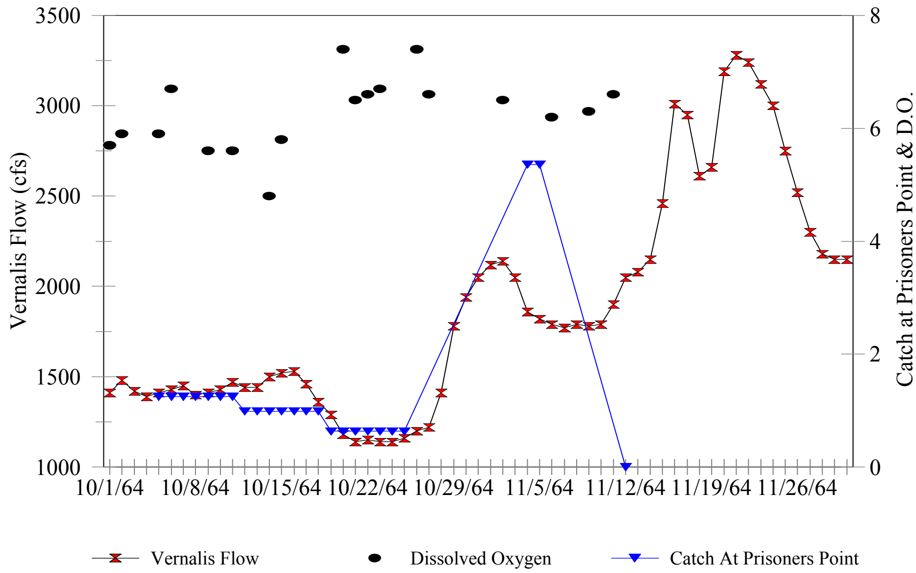

Figure 3 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to the flow in the San Joaquin River at Vernalis and DO levels (ppm) near Stockton in October and November 1964

In 1966, catch rates at Prisoners Point remained low throughout October and November when the straying rates of tagged fish were high (71%). A gradual increase in Vernalis flow from 700 cfs from 1 October to 1,350 cfs on 24 October had no obvious effect on catch rates (Figure 5). Likewise, declining export rates from 250% on 1 October to 100% of Vernalis flows on 24 October also had no effect on catch rates (Figure 6). When Vernalis flows increased to about 1,500 cfs on 8 November and exports decreased to 60% between 8 and 19 November, catch rates increased from a steady 0.5 fish/hour to 0.96 fish/hour on 14 November. This small increase in catch rates suggests most of the adults had already migrated into the Delta, and flow releases and/or export reductions after 8 November were already too late to substantially affect straying rates.

In 1967, catch rates at Prisoners Point remained high between 1 and 17 October when straying rates of tagged fish were low (15%). During high catch rates in early October, Vernalis flows ranged between 2,250 and 2,750 cfs (Figure 7), and exports ranged between 80% and 120% of Vernalis flows (Figure 8). When Vernalis flows increased to about 3,500 cfs and exports declined to 25% of Vernalis flows after 27 October, catch rates remained low suggesting most fish had completed their migration through the Delta.

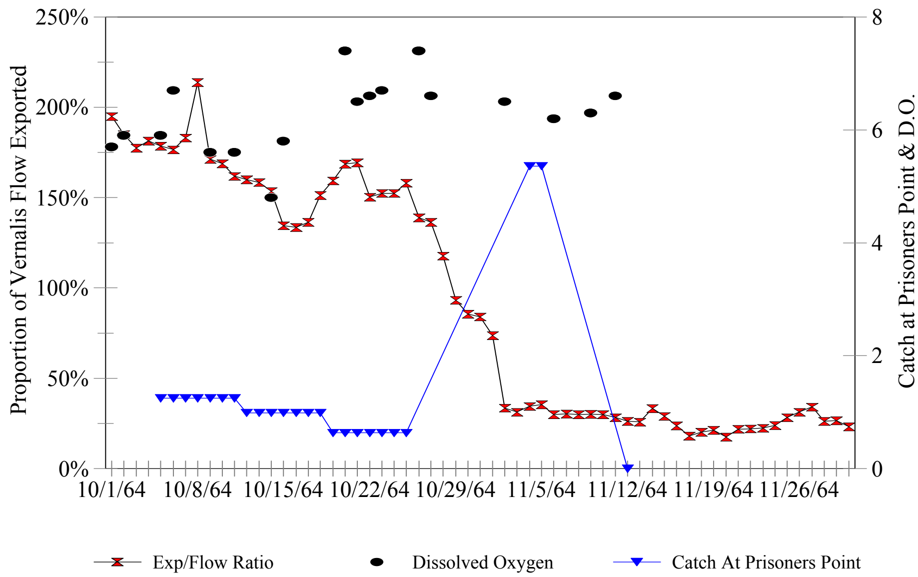

Figure 4 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to the proportion of the flow in the San Joaquin River at Vernalis that was exported at the SWP and CVP Delta pumping facilities and DO levels (ppm) near Stockton in October and November 1964

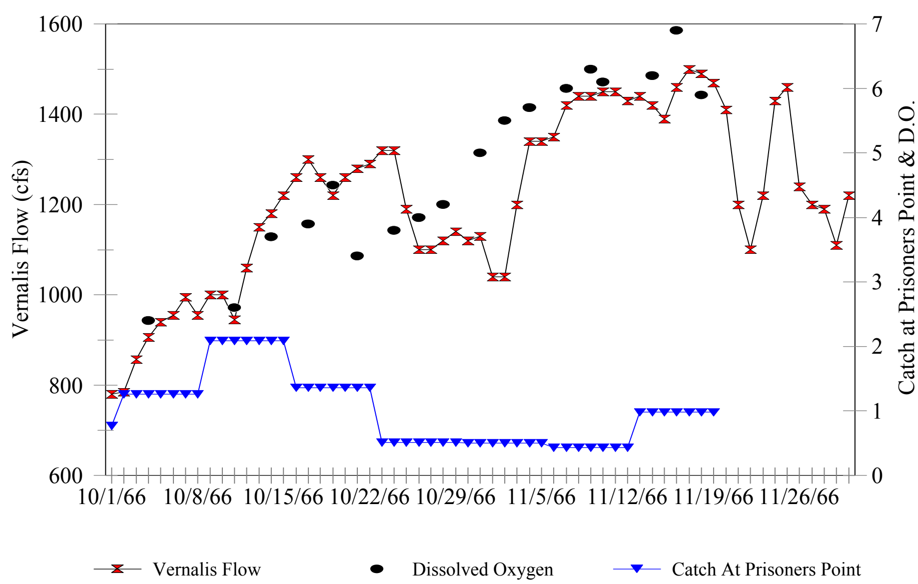

Figure 5 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to flow in the San Joaquin River at Vernalis and DO levels (ppm) near Stockton in October and November 1966

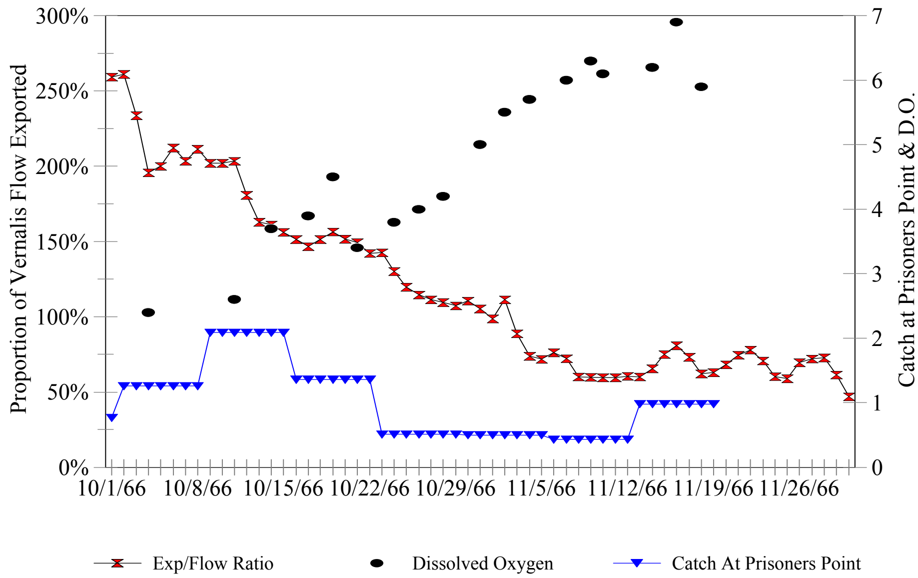

Figure 6 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to proportion of the flow in the San Joaquin River at Vernalis that was exported at the SWP and CVP Delta pumping facilities and DO levels (ppm) near Stockton in October and November 1966

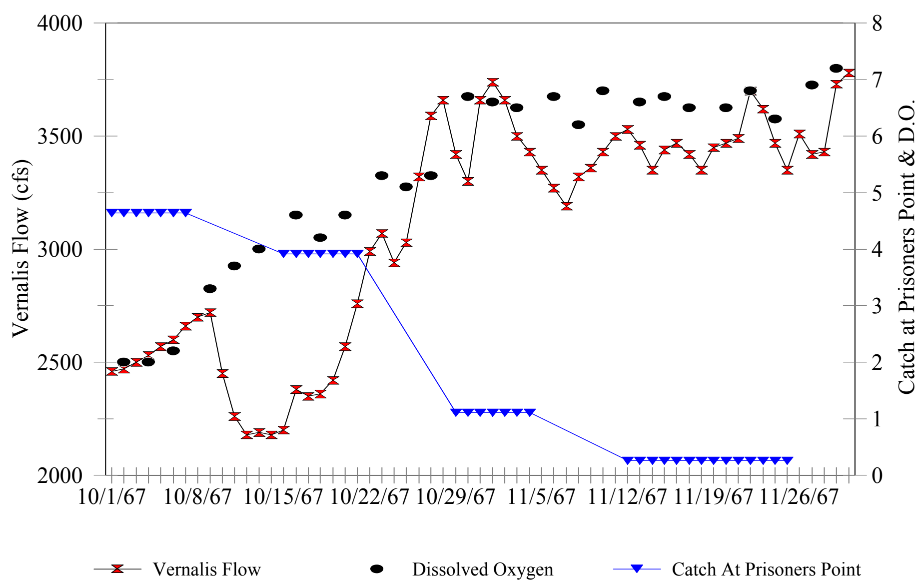

Figure 7 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to flow in the San Joaquin River at Vernalis and DO levels (ppm) near Stockton in October and November 1967

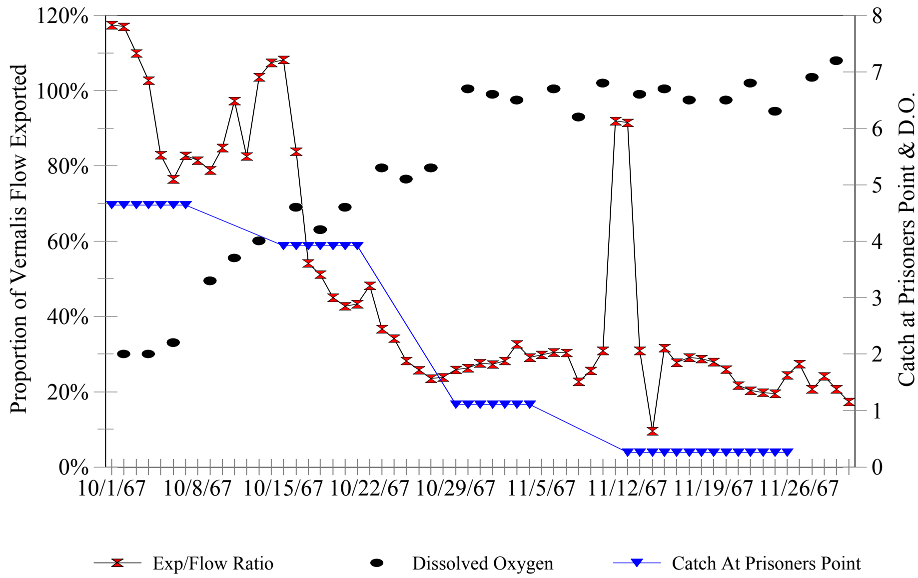

Figure 8 The catch rate of adult chinook salmon with a trammel net at Prisoners Point in the San Joaquin River relative to proportion of the flow in the San Joaquin River at Vernalis that was exported at the SWP and CVP Delta pumping facilities and DO levels (ppm) near Stockton in October and November 1967

There are three important results from Hallock and others (1970) regarding a straying analysis. First, adult salmon were migrating through the San Joaquin Delta near Prisoners Point primarily during October, the period when they are probably most susceptible to low flows and high exports. Second, the fish migrate slowly and do not arrive in the San Joaquin tributaries until about four weeks after they pass Prisoners Point, even when flows, exports, and dissolved oxygen concentrations near Stockton are suitable for migration. And third, migration rates of adult salmon are substantially higher when Vernalis flows exceed about 3,000 cfs and total exports are less than 100% of Vernalis flows. Although most of the tagged fish migrated into the Sacramento and Mokelumne rivers when Vernalis flows were less than about 2,000 cfs and total exports exceeded 150% of Vernalis flows, there is uncertainty as to whether these were San Joaquin fish that strayed or Sacramento River fish that were captured in the San Joaquin on their way to the Sacramento River. The US Fish and Wildlife Service reported that approximately 20% of the Sacramento River fall-run salmon returned to their natal streams by migrating through the lower San Joaquin, into the lower Mokelumne, and then through Threemile or Georgiana sloughs (Erkkila and others 1950). Evidence for this was based on the recapture of 44 adult salmon previously marked at the Coleman National Fish Hatchery as juveniles by the Paladini Fish Company in Pittsburg; nine of the recaptured fish were caught in gill nets drifted in the San Joaquin River below the mouth of the Mokelumne.

Recoveries of Coded-wire Tagged San Joaquin Chinook Salmon

This analysis is based on the number of recoveries of coded-wire tagged (CWT) juvenile chinook salmon in Central Valley streams that were originally reared at the Merced River Fish Facility and the Tuolumne Rearing Facility and released in the San Joaquin basin at Dos Reis Road and all upstream sites. The fish were recovered one to three years after their release when they returned to spawn. If these fish returned to one of the San Joaquin tributaries, they were judged to have successfully "homed." However, if they returned to the Sacramento River basin or one of the eastside streams, which include the Cosumnes, Mokelumne, and Calaveras rivers, they were judged to have strayed. The CWT recovery data were provided by Ralph Carpenter and Robert Kano, Inland Fisheries Division, California Department of Fish and Game (DFG), Sacramento (summarized in Table 1). Updated escapement estimates and the number of fish measured and sexed were obtained from the DFG's annual reports on chinook salmon spawner stocks in California's Central Valley from 1983 through 1989 (Reavis 1986; Kano and Reavis 1996, 1997, 1998; Kano and others 1996). The DFG identifies the 1995 and 1996 CWT recovery data and the escapement estimates from 1990 to 1996 as preliminary (Robert Kano, personal communication, see "Notes").

The accuracy of this analysis is limited because looking for a San Joaquin stray is like looking for a needle in a haystack. The number of spawners in the San Joaquin basin ranges between one and 10% of the numbers in the Sacramento and eastside basins. This means that even if half of the San Joaquin fish stray, the strays would constitute less than 5% of the populations in the Sacramento and eastside basins. Finding the strays is made more difficult because none of the fall-run fish spawning in the mainstem Sacramento River were examined for CWTs through fall 1995. Furthermore, surveys for tagged adults were not conducted every year in the Stanislaus and Merced rivers in the San Joaquin basin, or in the Yuba, American, or Mokelumne rivers in the Sacramento River basin. Overall, the percent of total spawners that was evaluated for tags ranged between 9% and 33% in the San Joaquin tributaries and between 6% and 22% in the Sacramento River basin and eastside rivers.

To compute the total number of salmon with CWTs in each river by survey year, the number of CWT recoveries was divided by the number of fish examined for tags and then multiplied by the escapement estimate. A comparison of the recovery data between the river surveys in the American, Feather, and Merced rivers and the recovery data at the hatcheries in those rivers suggests there are no accurate data to determine the number of fish examined during the escapement surveys. The hatchery data are assumed to be the most accurate, since all fish collected at the hatcheries were fresh and extensively handled, implying that there was a thorough inspection for adipose clips. When the percentage of fish handled during the river escapement surveys was calculated with the assumption that all fish in the carcass counts, those marked and chopped, were examined for adipose clips (and therefore CWTs), the percentage of fish with tags was much lower for the river surveys than those handled at the hatcheries (Table 2).

Table 1 The total number of coded-wire-tags (CWT) recovered by the Department of Fish and Game from adult San Joaquin hatchery reared fish during carcass surveys and at hatcheries in the Sacramento River basin, Eastside tributaries, and the San Joaquin tributaries, and the estimated number of strays and returns and the percent that strayed from 1979 to 1996 [a]

Year	*Total Recoveries*	*Estimated Number of Strays*	*Estimated Number of Returns*	*Percent Strays*
1979	10	7	85	7.6%
1980	26	8	106	7.4%
1981	32	0	361	0.0%
1982	14	4	153	2.2%
1983	300	0	3,129	0.0%
1984	180	32	2,419	1.3%
1985	138	101	1,570	6.1%
1986	149	27	1,519	1.7%
1987	245	680	3,298	17.1%
1988	232	239	1,951	10.9%
1989	120	58	432	11.8%
1990	62	2	137	1.7%
1991	16	6	66	7.9%
1992	74	2	269	0.6%
1993	157	5	269	1.9%
1994	135	10	495	1.9%
1995	237	0	–	0.0%
1996	784	114	2,657	4.1%

[a] Rivers and hatcheries surveyed for CWTs in the Sacramento Basin include Clear Creek, Coleman National Fish Hatchery, Battle Creek, Mill Creek, Red Bluff Diversion Dam, Tehama-Colusa Fish Facility, Feather River Fish Hatchery, Feather River, Yuba River, Nimbus Fish Hatchery, and American River. The Mokelumne River and the Mokelumne River Fish Installation were surveyed in the Eastside tributaries. The Tuolumne River, Stanislaus River, Merced River, Merced River Fish Facility, Los Banos Wildlife Area were surveyed in the San Joaquin basin.

Table 2 A comparison of the percentage of San Joaquin basin adult chinook salmon recovered with coded-wire-tags to the percentages observed at the hatcheries in the Merced, American, and Feather rivers[a]

Merced River								
River Escapement Survey Years	1983	1984	1985	1986	1987	1993	1994	1996
Number of Tags Recovered	5	49	14	13	0	22	38	263
Total Carcass Count	1634	2200	2200	781	426	532	1019	1220
Number Measured & Sexed	1124	448	535	291	138			
Number of Fresh Fish						294	324	147
Number of Fresh Fish & Decayed Adults						517	888	826
Number of Fresh, Decayed Adults & 50% of Decayed Grilse						525	954	1023
Escapement	16453	27640	14841	6789	3168	1995	4635	4599
Merced River Fish Facility								
Number of Tags Recovered	291	146	103	120	26	37	74	291
Number Examined	1795	2109	1211	650	958	409	943	1141
Percentage of Fish Recovered with Tags								
Based on the Hatchery	16.21%	6.92%	8.51%	18.46%	2.71%	9.05%	7.85%	25.50%
Based on Total Carcass Counts	0.31%	2.23%	0.64%	1.66%	0.00%	4.14%	3.73%	21.56%
Based on Number Measured & Sexed	0.44%	10.94%	2.62%	4.47%	0.00%			
Based on Fresh Fish Counts						7.48%	11.73%	178.91%
Based on Fresh & Decayed Adult Counts						4.26%	4.28%	31.84%
Based on Fresh, all Decayed Adults, & 50% of Decayed Grilse						4.19%	3.99%	25.71%

[a] Recovery data for escapement surveys are not presented when no tags were recovered.

Table 2 A comparison of the percentage of San Joaquin basin adult chinook salmon recovered with coded-wire-tags to the percentages observed at the hatcheries in the Merced, American, and Feather rivers[a] (Continued)

American River					
River Escapement Survey Years	1984	1985	1987	1988	1989
Number of Tags Recovered	1	1	3	0	0
Total Carcass Count	10027	4875	9451	3944	5550
Number Measured & Sexed	4875	857	649	908	1070
Escapement	27447	56120	39885	24889	19183
Nimbus Fish Hatchery					
Number of Tags Recovered	3	14	13	6	2
Number Examined	12249	9093	6258	8625	9741
Percentage of Fish Recovered with Tags					
Based on the Hatchery	0.02%	0.15%	0.21%	0.07%	0.02%
Based on Total Carcass Counts	0.01%	0.02%	0.03%	0.00%	0.00%
Based on Number Measured & Sexed	0.02%	0.12%	0.46%	0.00%	0.00%

Feather River				
River Escapement Survey Years	1984	1987	1988	1989
Number of Tags Recovered	4	5	13	4
Total Carcass Count	14603	21714	24099	9677
Number Measured & Sexed	3268	3566	4066	3719
Escapement	41769	67738	42556	40541
Feather River Hatchery				
Number of Tags Recovered	4	75	23	0
Number Examined	9288	10108	6480	7578
Percentage of Fish Recovered with Tags				
Based on the Hatchery	0.04%	0.74%	0.35%	0.00%
Based on Total Carcass Counts	0.03%	0.02%	0.05%	0.04%
Based on Number Measured & Sexed	0.12%	0.14%	0.32%	0.11%

[a] Recovery data for escapement surveys are not presented when no tags were recovered.

Therefore, it is highly unlikely that all of the fish in the carcass counts were closely examined for adipose clips. This is partly true for the San Joaquin tributaries as some of the chopped fish, particularly the grilse, have been too decayed to detect an adipose fin clip and few if any of their heads were taken for CWT evaluation (Jennifer Bull and George Neillands, personal communication, see "Notes"). The problem also appears to have occurred during the escapement surveys in the American and Feather rivers. Even though only fresh fish (clear eyed) were usually marked or chopped in these rivers according to DFG annual reports 1983 through 1989, the percentage of fish with CWTs was also usually much higher at the hatchery than for the river based on the total carcass count (Table 2). On the other hand, when the number of fish measured and sexed during the escapement surveys (DFG 1988–1997) were used to compute the percentage of fish with tags, there was better agreement between the hatchery estimates and the river estimates (Table 2). Therefore, the hatchery data were used to compute the expansion factor for both the hatchery and the corresponding river in most cases. However, in 1989 no CWT recoveries were made at the Feather River Hatchery, whereas four tags were recovered during the Feather River escapement surveys (Table 2). This was very unusual in that usually many more CWT fish were recovered at the hatchery than during the escapement surveys. It was assumed that the Feather River hatchery data were incorrect and the expansion factors for both the river and hatchery were based on the escapement survey for 1989. Whenever total CWT recoveries were estimated for the Feather River in 1989 and for the rivers without a hatchery (primarily the Stanislaus, Tuolumne, and Yuba rivers), the expansion factors was computed using the number of fish measured and sexed, which was available for the 1983 to 1989 surveys. For the 1990 to 1996 surveys, the expansion factor for the Stanislaus and Tuolumne rivers was computed as the number of fresh fish and decayed adults in the carcass counts; decayed grilse were usually not examined for CWTs (George Neillands, personal communication, see "Notes"). The number of fresh fish and decayed adults counted during the escapement surveys in the Merced River provided estimates of "Percentage of Fish Recovered with Tags" that were slightly more similar to the hatchery estimates than estimates computed with the total carcass counts (Table 2).

Since 1984, the DFG has used a trap at Los Banos to collect fish that try to enter the westside agricultural drainage system. DFG Region 4 assumes that approximately half the fish that enter the westside drainage system are recovered at the Los Banos trap (DFG 1988–1997). Therefore, the recoveries for the Los Banos trap were doubled in number to compute the total number of salmon with CWTs entering the westside system.

The total number of CWT strays was computed by summing the estimated total number of salmon with CWTs for each of the Sacramento and eastside rivers and hatcheries surveyed. Rivers and hatcheries surveyed in the Sacramento and eastside basin include Clear Creek, Battle Creek, Mill Creek, Feather River, Yuba River, American River, Mokelumne River, Coleman National Fish Hatchery, Tehama-Colusa Fish Facility, Feather River Hatchery, Nimbus Fish Hatchery, and the Mokelumne River Fish Installation.

The total number of CWT returns was computed by summing the estimated total number of salmon with CWTs for each the San Joaquin tributaries, the Merced River Fish Facility, and the Los Banos trap. No data on CWT recoveries are available for the Stanislaus River for the 1982, 1983, and 1986 surveys. Only the estimates for 1983 were used in the analysis of straying rates, because no strays were recovered in the Sacramento or eastside basins.

The percentage of CWT Merced hatchery fish that strayed was computed using the following equation:

Percent Strays = (Total CWT Strays)/ (Total CWT Returns + Total CWT Strays)

The effects of Vernalis flow and total Delta exports on the estimated Percent Strays was evaluated for four periods. The period from 15 September to 28 October was tested to evaluate whether flow and export conditions affected the homing ability of adult salmon in Suisun Bay that would be present in September and those at Prisoners Point that would be present in October. The period from 1 to 20 October was tested based on the assumption that Hallock's catch data reflected the time when most adult San Joaquin salmon migrated through the Delta. The period from 15 to 21 October was tested to evaluate the ability of short-term pulse flows in mid-October to affect homing behavior. The period from 9 to 15 October was tested to evaluate the peak time of migration based on Hallock's catch data.

The relationship between the estimate of Percent Strays and the ratio of Vernalis flow to total Delta exports for the four periods described above was evaluated for outliers. The estimate for the 1980 survey was relatively high and the estimate for 1981 was relatively low compared to the relationship of the other surveys to flows and exports. Since the number of tags recovered for the 1980 and 1981 surveys was 26 and 32 tags respectively (Table 1), no estimate with less than 33 recoveries was used in the analysis. This eliminated the surveys from 1979 to 1982 and 1991.

Results

The relationship between the estimated Percent Strays and the average ratio of SWP and CVP Export rates to Vernalis flows are shown for various periods in Figures 9 through 12. There are too few data to determine whether the relationship between the estimated Percent Strays and the export to flow ratios was linear, so regression analyses were not conducted. For example, if the

1989 estimate is assumed to be inaccurate, then the Percent Strays estimate appears to increase exponentially relative to the minimum export to flow ratio for both the 1 to 20 October period (Figure 9) and the 15 to 21 October period (Figure 10). However, if the 1987 estimate is assumed to be inaccurate, then Percent Strays appears to have a linear relationship with the minimum export to flow ratios for both periods. Rather than trying to determine the exact nature of the relationship based on the existing data, the uncertainty regarding the true number of fish examined for tags should be resolved first.

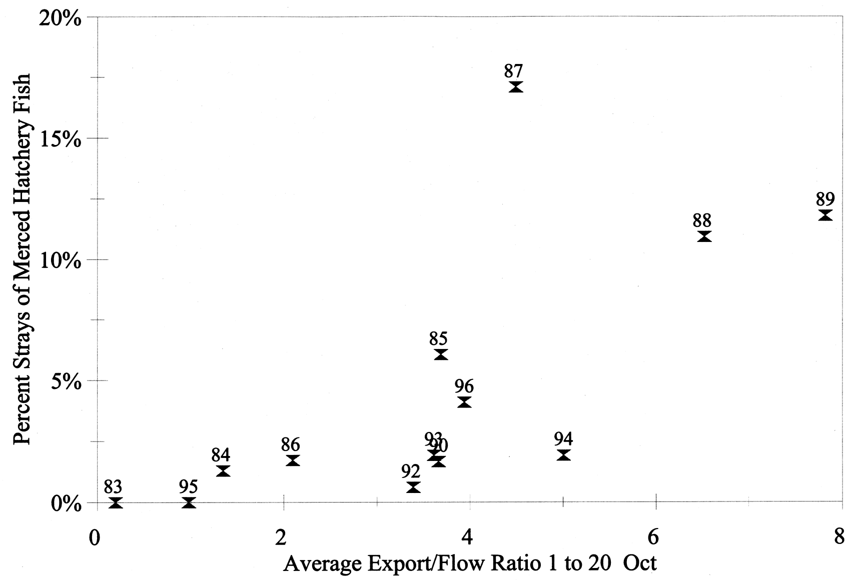

Figure 9 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta to the flow rate in the San Joaquin River at Vernalis during 1 to 20 October from 1983 through 1996

A casual inspection of Figures 9 through 14 suggests the estimates of Percent Strays are accurate enough to reach several conclusions in spite of the above uncertainties. First, this analysis indicates that straying rates increase as the percentage of San Joaquin flow exported by the CVP and SWP pumping facilities increases, and the critical period is between 1 and 21 October. Furthermore, pulse flows from the San Joaquin tributaries or a reduction of Delta exports resulting in no more than a 300% export rate of San Joaquin flows at Vernalis for 8 to 12 days in mid-October is sufficient to keep straying rates below 3%. In October 1990, there were eight days when the export rate was less than 300% of Vernalis flows and the estimated straying rate was about 2%. Since 1991, a 300% export rate or lower occurred for at least 10 days in mid October. During most years evaluated when straying rates were less than 3%, San Joaquin River flows at Vernalis were at least 4,000 cfs. However in 1992, straying rates were estimated to be less than 1% when Vernalis flows averaged less than 700 cfs between 1 and 20 October, but Delta exports declined to less than 50% of Vernalis flows for four days and less than 100% of Vernalis flows for eight days. Conversely, straying rates were high, ranging between 11% and 17%, from 1987 to 1989 when between 400% and 700% of San Joaquin flows were exported and Vernalis flows ranged between 1,000 and 2,000 cfs.

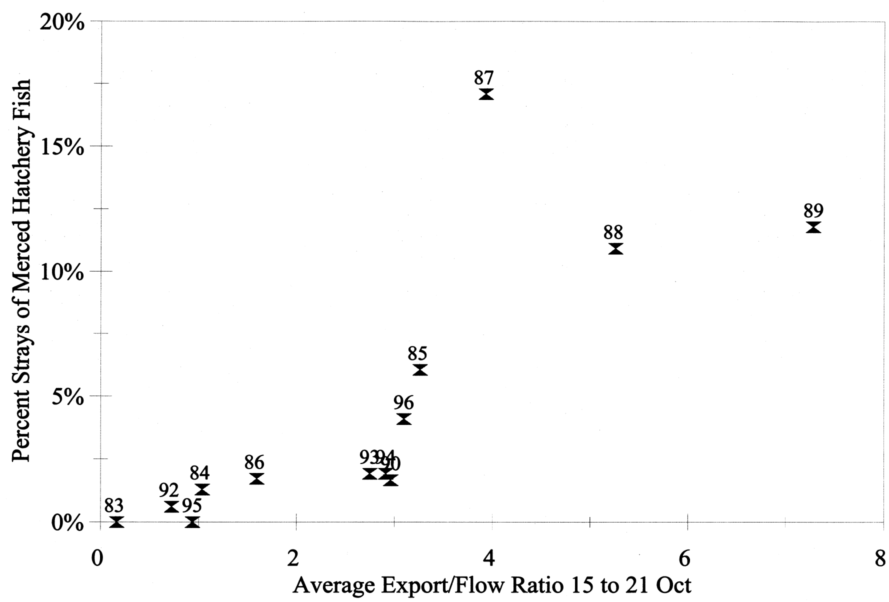

Figure 10 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta to the flow rate in the San Joaquin River at Vernalis during 15 to 21 October from 1983 through 1996

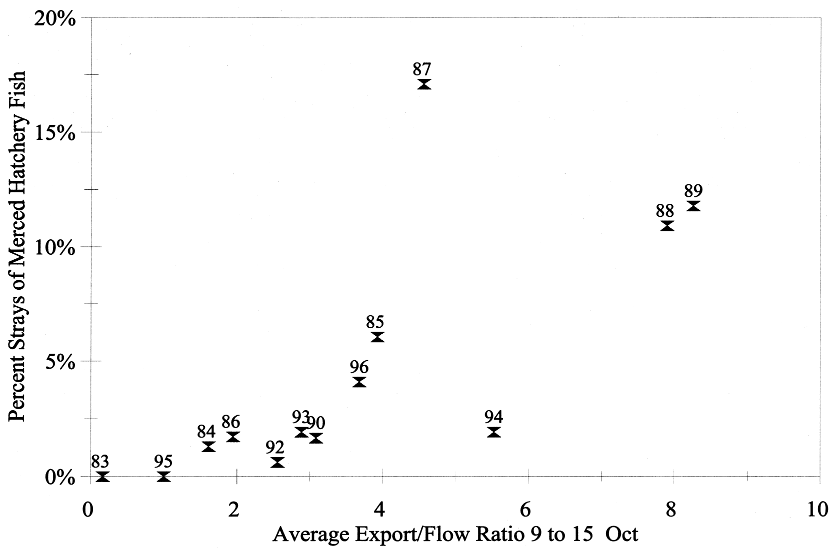

Figure 11 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta to the flow rate in the San Joaquin River at Vernalis during 9 to 15 October from 1983 through 1996

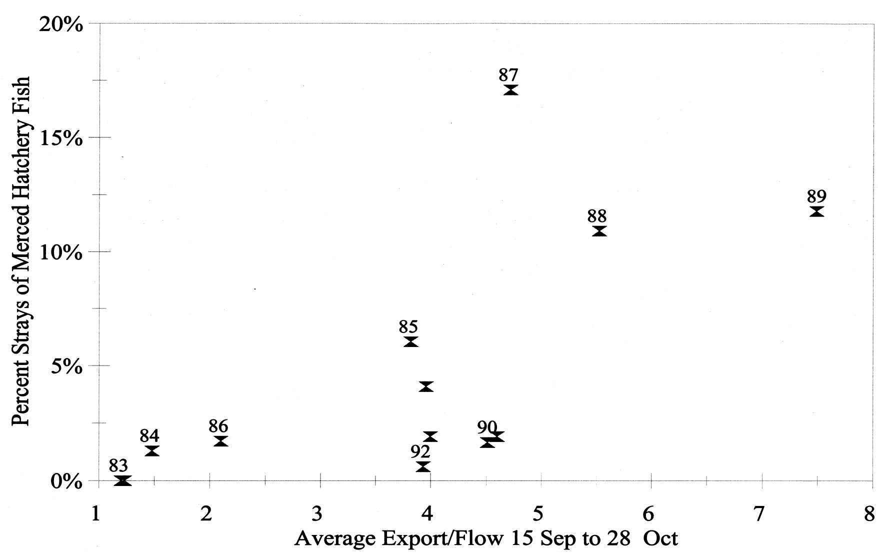

Figure 12 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta to the flow rate in the San Joaquin River at Vernalis during 15 September to 28 October from 1983 through 1996

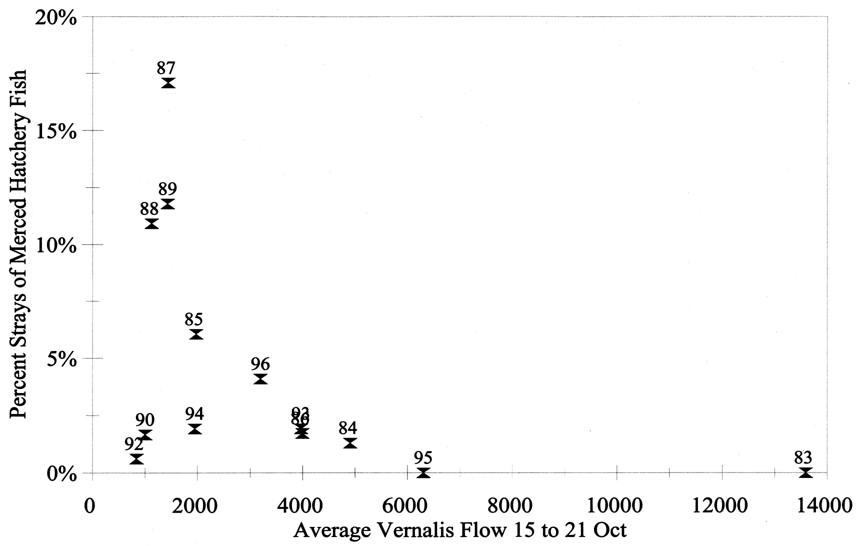

Figure 13 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average flow rate in the San Joaquin River at Vernalis during 15 to 21 October from 1983 through 1996

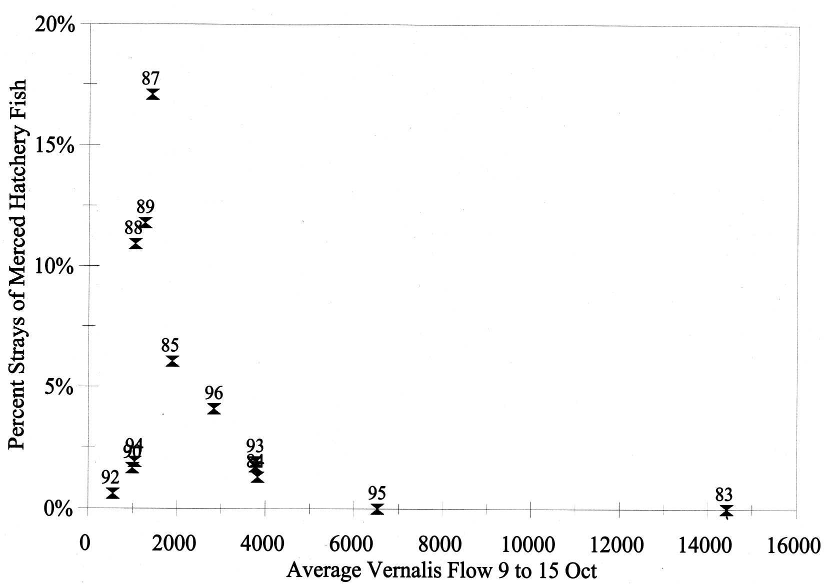

Figure 14 Estimated percent of adult CWT chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile fish, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average flow rate in the San Joaquin River at Vernalis during 9 to 15 October from 1983 through 1996

Conclusions

The two-part investigation provided conflicting results. Reevaluation of the data collected by Hallock and others (1970) suggested that adult salmon that reared in the San Joaquin tributaries strayed when exports at the CVP and SWP pumping facilities exceeded about 100% of flow in the San Joaquin River at Vernalis and Vernalis flows were less than 2,000 cfs during the first three weeks of October. However, there is uncertainty about the origin of their study fish and data were collected in only four years.

The evaluation of the recovery of coded-wire-tagged fish suggests a maximum of about 20% of adult San Joaquin salmon strayed when Delta exports exceeded about 300% of Vernalis flows for a ten-day period in mid-October. Although the accuracy of the estimated number of strays is questionable, the estimates correlate strongly with the ratio of Delta exports to flows at Vernalis and with Vernalis flows.

Considering the results of these investigations, it is reasonable to assume that when more than 300% of Vernalis flow is exported over a ten-day period in mid-October that adult San Joaquin chinook salmon stray to the Sacramento and eastside basins. However due to the limitations of these analyses, further tests should be made by collecting the data needed to accurately evaluate the recoveries of coded-wire-tagged adults during future carcass surveys. These new data should include the results of annual surveys for adults with coded-wire tags in all major tributaries and the number of fish examined for the tags accurately recorded for each river surveyed. These data, along with accurate escapement estimates, records on the releases of tagged juvenile fish, and records on recovered adult fish with tags, will provide the information needed to accurately estimate the percentage of fish that stray.

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Notes

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Robert Kano. California Department of Fish and Game fishery biologist, Sacramento, California. Personal communication with the author on 15 September 1997.

George Neillands. California Department of Fish and Game fishery biologist, Fresno, California. Personal communication with the author on 16 July 1998.