

# Survival of Chinook Salmon Smolts in the Sacramento-San Joaquin Delta and Pacific Ocean

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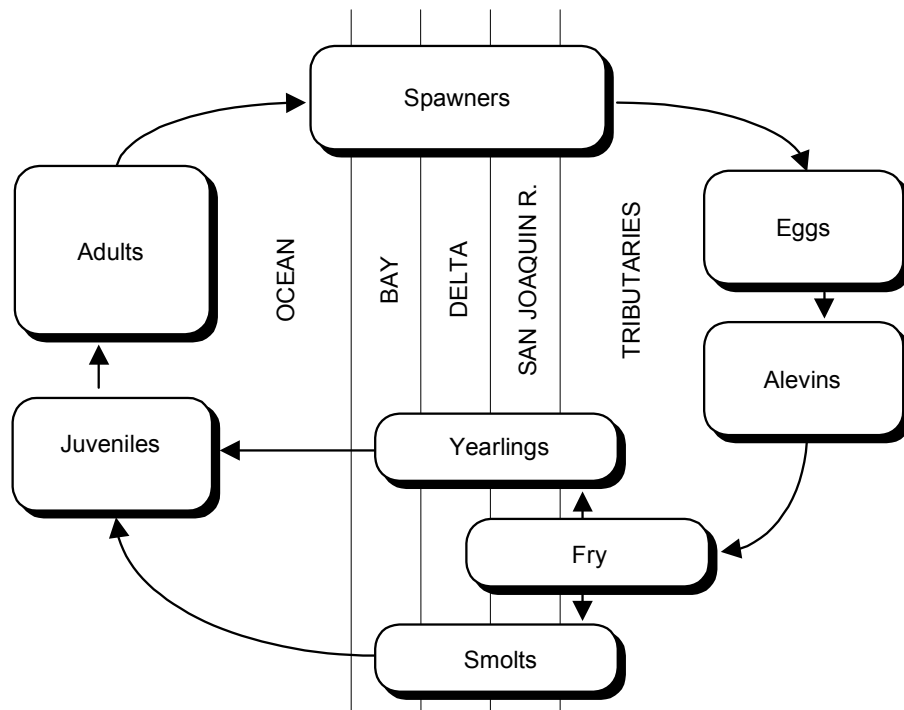
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## Abstract

This paper summarizes current knowledge about the effects of river flow and water export on the survival of San Joaquin River Basin chinook salmon smolts migrating through the Sacramento-San Joaquin Delta. As will become clear, there are serious deficiencies in our understanding of the needs of smolts as they pass through this region, but there is a general agreement that mortality can be high and can probably be reduced by management actions. The potential for success of the various alternatives remains speculative; something needs to be done, but it remains unclear what will work best. For example, smolt survival is usually better at very high (flood) flows than at very low flows, but there is little solid information about the potential for improved survival in the range that might be managed regularly. Researchers have not really begun the search for optimal flows for smolt survival; analyses to date offer, at best, only the qualitative guidance that "higher" flows are "better" for salmon, without any indication of just how much better survival can be or should be. Similarly, although there is reason to believe that strategically placed barriers should improve smolt survival, by keeping smolts well away from the Delta export pumps; however, experiments to date have not been able to demonstrate or refute the effectiveness of such barriers directly.

## San Joaquin Chinook Salmon Life History

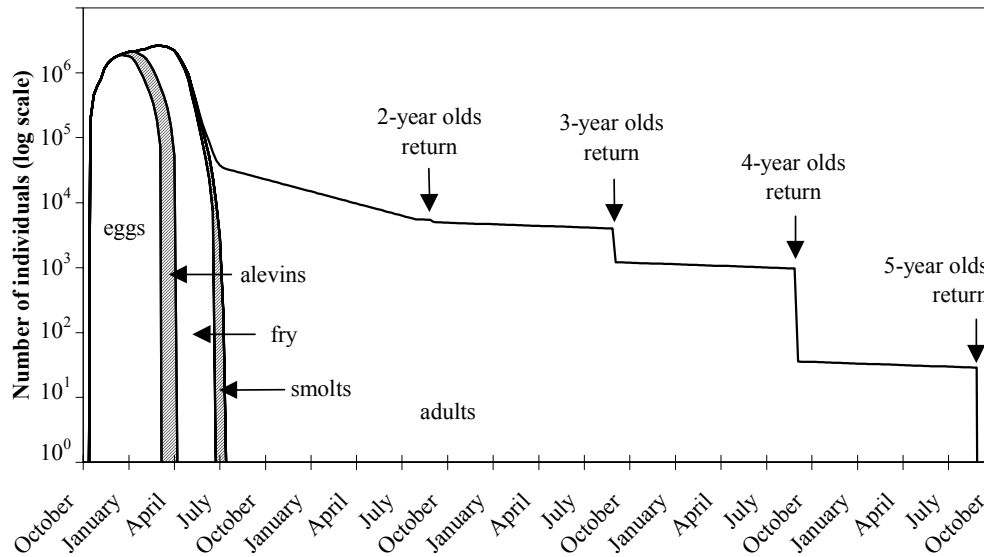
Only one chinook salmon run, the San Joaquin fall run, is generally recognized in the San Joaquin basin. This run forms spawning populations in the Stanislaus, Tuolumne, and Merced rivers (hereafter called simply "the tributaries"). These populations are distinguished from other Sacramento runs not just by geography, but also in many details of life-history. In particular, the timing of the runs to the San Joaquin tributaries is quite distinct from that of the Sacramento system fall runs.



**Figure 1 Schematic life history of San Joaquin fall-run chinook salmon.** Salmon are vulnerable to export effects during upstream passage through the Delta as spawners, during emigration as smolts or yearlings, and as fry rearing in the Delta.

The life-history pattern of San Joaquin River chinook salmon is shown schematically in Figure 1. Adult chinook salmon typically migrate into the Stanislaus, Tuolumne, and Merced rivers as two-, three-, and four-year-olds. The age composition of the run varies considerably from year to year, but overall about half the migrants are three-year-olds, the remainder divided fairly evenly between two- and four-year-olds. Two-year-olds are disproportionately male, and are often reported separately as jacks, although the percentage of two-year-olds which are female is much higher for the San Joaquin runs than for other chinook salmon stocks, and such females contribute significantly to production in some years. The upstream migrants are collectively called the year's escapement.

The spawning run typically extends from October through December, with the bulk of the run appearing in the tributaries in November. Spawners are occasionally seen in September and are frequently reported in small numbers in January. They begin to construct nests, called redds, and spawn as soon as they arrive in the spawning reaches of the tributaries. Females defend their redds for seven to ten days after spawning. All adults die after spawning.



**Figure 2 Representative numbers of individuals occurring in different life stages of a typical San Joaquin Basin cohort of chinook salmon.** Estimates are derived from average numbers estimated by the EACH dynamic simulation population model.

The development of an idealized cohort over its lifetime is shown in Figure 2. The young fish emerge from the redds as fry from late December through April, with most emerging in February. Some fry soon migrate downstream into the San Joaquin River and the Delta, or are involuntarily displaced from the tributaries by high flows; whether such fry survive to contribute significantly to the total production is not known.

Most fry remain in the tributaries until spring, when they undergo smoltification, a set of physiological changes preparing them for ocean life, and begin their seaward migration. The smolt emigration peaks in April and May, but can extend from late February through June. Some fry do not join the spring emigration, but instead remain in the tributaries over the summer, emigrating in October and November as yearlings. Conditions in the tributaries for summer rearing have been highly variable until recently, however, and is not clear how important these fish have been to total San Joaquin Basin production.

Emigrating smolts experience considerable mortality in the lower reaches of the tributaries, the San Joaquin River, the Delta and San Francisco Bay, and during the first year of ocean life. Smolt mortality in the San Joaquin Delta, in particular, is known to be quite high in most years, and has become a principal focus of efforts to enhance San Joaquin salmon populations: this paper deals primarily with this issue.

Figure 2 illustrates the relative numbers of a typical cohort over the course of its life cycle based on average results from the EACH dynamic population simulation model (EA 1991). A few million eggs are produced in an average year. By the time the developing smolts reach the ocean, their number is reduced by two orders of magnitude. Comparatively minor improvements to survival in these early life stages can greatly improve the numbers of returning adults.

## Sources of Information About Smolt Survival

Because of their complex life history, chinook salmon fall under multiple regulatory jurisdictions over their lifetimes. They are studied by many agencies; although there are many exceptions and much interagency coordination, the general tendency is for the California Department of Fish and Game (DFG) to study chinook salmon in the upstream tributaries, the U.S. Fish and Wildlife Service (USFWS) in the Delta, and the National Marine Fisheries Service (NMFS) in the ocean. The DFG's Region 4 annual reports are an important source of information about all stages of San Joaquin Basin salmon from spawning escapement to smolts in the San Joaquin River. The annual reports of the USFWS' Sacramento-San Joaquin Estuary Fishery Resource Office are a principal source of information about smolt survival in the Delta.

Since 1970, research activity by the State and Federal governments into environmental matters in the Delta has been consolidated under the Interagency Ecological Program (IEP). The IEP is a cooperative effort of the DFG, USFWS, NMFS, California Department of Water Resources, State Water Resources Control Board, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Geological Survey, and U.S. Environmental Protection Agency. Activities under the IEP are reported in the quarterly *IEP Newsletter*. Bulk data generated by IEP studies are published electronically and can be accessed at the IEP web site (<http://www.iep.water.ca.gov>).

Although these are the primary "official" sources of data on San Joaquin salmon, many other entities have conducted studies or published analyses relevant to the needs of salmon in the Delta. Most such material has been presented at the Bay-Delta Hearings, and is part of the Administrative Record for the 1995 Water Quality Control Plan (SWRCB 1995a, 1995b). See also Brandes and McLain (this volume) for additional analyses and another view of survival of Central Valley juvenile salmon moving through the Delta.

### Coded-wire-tag Releases Release and Recapture Studies

The principal source of information about smolt survival in the Delta is the recovery of coded-wire-tagged salmon. Coded-wire tags (CWTs) are short

lengths of wire, encoded with a group serial number, which are inserted into the heads of the salmon. These tags are not visible externally, so tagged fish also have their adipose fins clipped for recognition. Normally, fish bearing the same tag number are released at the same time and place, although in the past, tags left over from one experiment were occasionally used in another. Adipose fins do not regenerate, so tagged fish can be identified visually throughout their lives. To read the tag number, however, the fish must be killed.

In principle, all tag recoveries are reported to the Pacific States Marine Fisheries Commission (PSMFC), which maintains the Regional Mark Information System database (RMIS). In practice, the conversion from older, local archives is not complete. Information about all CWT releases, and all information about ocean recoveries, is accessible through RMIS; however, inland recovery data from California are most easily obtained through the DFG or the USFWS, depending on the nature of recovery.

CWT experiments are of two sorts. Most commonly, two or more groups are released at approximately the same time, and treatment effects are estimated by comparing the numbers recovered at downstream locations. It is convenient to refer to these as “paired release” experiments, although more than two groups may be involved. The virtue of this approach is that if the releases are arranged so that both groups reach the recovery locations at approximately the same time, estimates of relative survival between groups can be calculated using only qualitative assumptions about the sampling procedures used. Sometimes it is necessary to estimate absolute, instead of relative, survival, in which case additional information is needed, such as the probability of capture. Such estimates are often referred to as “survival indices” to alert readers to the extra level of uncertainty. The CWT experiments most relevant to San Joaquin salmon issues can be grouped as follows.

**Upstream Survival Experiments.** In a long-standing series of experiments, CWT groups are released in the Merced, Tuolumne, and Stanislaus rivers to investigate in-river migration and survival. These are always arranged as paired releases; one group is released “upstream” (usually near the passage-blocking dam), and another group is released “downstream” (usually near the mouth) in the same river a few days later. These releases are often further coordinated with releases at Mossdale or Dos Reis, to provide paired-release data for survival in the San Joaquin River between the mouths of the tributaries and the Delta.

**Old River-San Joaquin River Survival Experiments.** In another long-standing series of experiments, CWT groups are released in the vicinity of the Old River-San Joaquin River split. These are usually arranged as paired releases, groups being released simultaneously in two of the following three locations: Mossdale on the San Joaquin River (upstream of the split), Dos Reis on the San Joaquin

River (downstream of the split), and Stewart Road on Old River (downstream of the split). These releases are often further coordinated with releases at Jersey Point.

**Lower San Joaquin River Survival Experiments.** In 1991, two sequences of CWT releases were made at locations along the San Joaquin River between the head of Old River and Jersey Point: groups were released at Dos Reis (River Mile 50), Buckley Cove (RM39), Empire Tract (RM29), Lower Mokelumne (RM19), and Jersey Point (RM12) on April 15, 16, 17, 18, and 19, respectively, and again at Buckley Cove, Lower Mokelumne, and Jersey Point on May 6, 9, and 13, respectively.

**Interior South Delta Survival Experiments.** In many years CWT groups are released in Old River at Palm Tract. These are usually coordinated with releases at Stewart Road on Old River or at Mossdale on the San Joaquin River.

## Trawl Surveys

Since 1978, as part of IEP, the USFWS has monitored the relative abundance of chinook salmon smolts emigrating from the Central Valley with mid-water trawl surveys at Chipps Island. The sampling effort varies over course of the season, but during the peak of the emigration season is typically at its maximum level of ten 20-minute trawls per day, seven days per week. Smolts with adipose fin clips are killed and their CWTs are read. The number of smolts captured is expanded to account for the amount of time spent sampling and the ratio of the net width to channel width to form an estimate of absolute abundance. For CWT-bearing smolts, the expanded recovery for each tag group is divided by the number of smolts originally released and reported as a smolt survival index (SSI).

The Chipps Island trawls are of special importance for investigating questions of Delta smolt survival, because this trawl location can be loosely regarded as marking the transition from delta to bay environments, and because data have been gathered quite consistently at this location for two decades. In the spring of 1997, as part of the Vernalis Adaptive Management Plan, a new USFWS trawl survey location was added at Jersey Point on the San Joaquin River, to supplement the Chipps Island data with data more specific to San Joaquin salmon populations.

Since 1989, DFG has conducted similar monitoring in the San Joaquin River near Mossdale Landing County Park, just upstream of the head of Old River. Ten 10-minute trawls are conducted during a five-hour "index" period each day, typically for 5 days each week during the peak of the emigration season. The number of smolts captured is expanded by an efficiency index obtained by experiments in which smolts marked with subcutaneously-injected paint

are released a short distance upstream of the trawl location. Sampling at this location is expected to become more consistent and intensive in future years.

### **Smolts Captured at the Delta Water Export Pumping Stations**

Both the federal government's Central Valley Project (CVP) and California's State Water Project (SWP) export facilities in the South Delta include systems for the salvage of entrained fish: the Tracy Fish Collection Facility at the CVP's Tracy Pumping Plant and the John E. Skinner Fish Protection Facilities at the SWP's Harvey O. Banks Pumping Plant. In both cases, fish entrained at the facility are diverted by screens into a separate system of bypasses and holding tanks, from which they are loaded onto trucks for transport and release at one of two locations at Sherman Island. The salvage facilities are operated by USBR (Tracy) and by DWR and DFG (Skinner).

The salvage release locations are upstream from Chipps Island. Salvaged smolts are therefore vulnerable to recovery in the Chipps Island trawls, creating difficulties in interpreting Chipps Island trawl data: one doesn't know the route of the tagged smolts. Did they arrive through export salvage operations or on their own through Old and Middle rivers?

At both facilities, samples are taken at regular intervals by diverting the entire fish salvage flow into a separate holding tank. All salmonids in each sample are counted and measured, and used to estimate total salvage numbers. Salmon with clipped adipose fin are killed and their tags are read.

In addition to this regular sampling, the entire bypass system is flushed from time to time to remove predators that have taken up residence. A complete census is taken of the fish present, and all tagged smolts are killed and their tags are read.

### **Ocean Recoveries**

Chinook salmon from the San Joaquin Basin are captured as adults in the commercial and sport fisheries. Detailed information about ocean recoveries in general, and CWT recoveries in particular, is collected by state, provincial, and federal agencies of the United States and Canada, and maintained by the PSMFC in the RMIS database.

### **Adult Escapement Estimates**

From the size of the escapement it is possible to draw inferences about the survival of the adult salmon as smolts. In the San Joaquin Basin, all escapement estimates are based on carcass surveys, or returns to the Merced River Fish Facility, except for a few years in the early 1940s when counting weirs were used.

## Management and Smolt Survival

Although it is generally recognized that considerable smolt mortality occurs between the mouths of the San Joaquin tributaries and the Delta, this mortality is not usually addressed directly. It is usually assumed that flow requirements upstream (for the benefit of fry and smolts in the tributaries), and downstream (for the benefit of smolts in the Delta), would equally benefit smolts in the San Joaquin River itself.

Smolt survival in the San Joaquin Delta is known to be poor, and there are many factors that could plausibly be manipulated to the benefit of survival. Foremost among these are the “usual suspects” in inland fisheries problems: flows, diversions, and water quality.

### Flow and Export

As described above, the needs of smolts in the Delta have been studied by releasing large numbers of smolts marked with coded-wire tags upstream of the Delta and recovering them downstream of the Delta (near Chipps Island, in the ocean fisheries, or as returning adults). Researchers relate the observed recoveries to variables like flow and export in an attempt to determine empirical relationships that could be used to guide policy decisions.

This black-box approach, although it ignores the underlying mechanisms causing observed changes in survival, has merit. After all, the ultimate goal is to enhance salmon populations through management. If it could be shown that certain management actions would enhance survival, it would not be necessary to know why they did, or how survival depends on factors outside management control.

Unfortunately, this approach has not been entirely effective in the Sacramento-San Joaquin Delta. Although relationships between Delta smolt survival, flows, and exports have been the subject of investigation for many years, there is surprisingly little agreement on the value of management actions deriving from these relationships.

There are at least three reasons why these experiments have been so unsatisfactory:

- The data sets are small. Only a few points are added by each year's experiments.
- Recapture numbers are generally small, and expansion to survival indices is highly uncertain.



- Many potentially confounding factors cannot be satisfactorily controlled or taken into account.

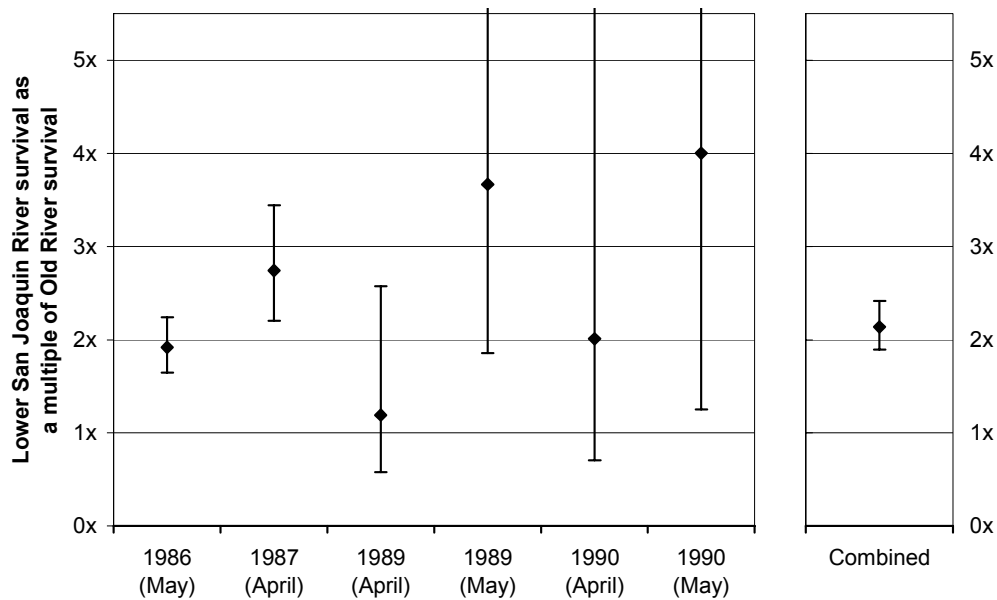
The last reason is probably the most fundamental. The South Delta is a complex environment for smolts from the black-box point of view, some factors are simply distractions which contribute a great deal of noise. Increasingly, researchers have been compelled to study the mechanisms by which flow and export affect smolt survival in an effort to divide the problem into more digestible pieces. Two major steps have been taken in this direction.

The first step has been to separate the dual role of export on smolt survival. Export affects smolts directly, by entraining fish at the facilities, and indirectly, by altering Delta flow patterns. The direct entrainment effects can be studied through mortality experiments, screen efficiency experiments, fish salvage records, and so on. The effects of export on Delta flow patterns are naturally treated in combination with those of inflow, with the help of hydrodynamic modeling.

The second step has been to divide in-Delta flow effects on smolt survival into two parts: first, the effects of these flows on the routes taken by smolts through the Delta, and second, survival along individual routes. This step is motivated by the fact that smolt survival often varies greatly from one part of the Delta to another. The clearest expression of this comes from a series of six experiments conducted by USFWS between 1986 and 1990 (Figure 3). In each of these experiments, two groups of smolts were released on the same date in the Lower San Joaquin River and in Old River. Both release sites are a short distance downstream of the Old River-lower San Joaquin River split, but the two groups would be expected to take different routes through the Delta. The lower San Joaquin River group survived better than the Old River group in all six experiments – a result which is already significant, with no further statistical assumptions, at the 98% confidence level. Overall, smolts released in lower San Joaquin River were more than twice as likely to reach the recovery site at Chippis Island than were smolts released in Old River.

Current efforts to understand the scope for improving smolt survival through flow and export management are thus organized around the following questions:

- How do San Joaquin River flow and CVP-SWP export affect in-Delta flows?
- How do in-Delta flows affect smolt migration patterns?
- How do in-Delta flows affect smolt survival along particular migration routes?



**Figure 3 Survival of smolts released in lower San Joaquin River at Dos Reis, as a multiple of the survival of smolts released in upper Old River at Stewart Road, based on recoveries in trawls at Chipps Island and in the ocean fisheries. A value of 1x represents equal survival for both release. The survival ratio for all experiments combined was 2.14. The confidence intervals (95%) are calculated assuming that capture for each group at each location is a Poisson process and should be regarded as conservative.**

### San Joaquin River Flow, CVP and SWP Exports, and In-Delta Flows

In principle, the relationships between San Joaquin River flow, CVP-SWP export, and in-Delta flows are completely knowable, with the help of hydrodynamic models. There are several of such models in current use and more under development. Although there are important differences between these models, it may be safely said that the hydrodynamics of the Delta are understood far more thoroughly than are the effects of these hydrodynamics on Delta biota.

Two basic facts about Delta hydrodynamics important to emigrating smolts are (1) tidal flows are much larger than the tidally-averaged, or "net" flows, and (2) Old River is a principal channel through the Delta, typically receiving well over half the total flow of the San Joaquin River even in the absence of export.

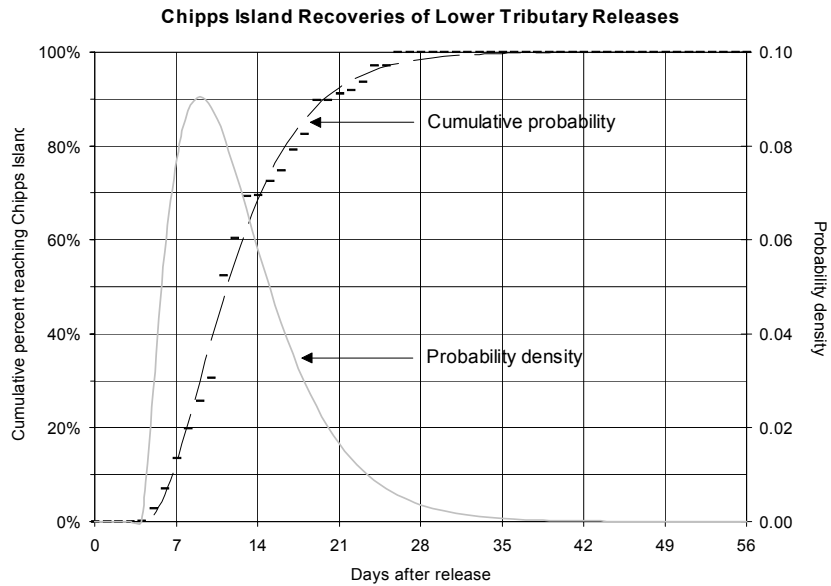
It would be difficult to exaggerate the difference in magnitude between net and tidal flows. From water year (WY) 1940 through WY 1991, the average flow at Vernalis was 4,550 cfs, and the highest annual average flow over this period was 21,281 cfs (WY 1983). In the San Joaquin River near Columbia Cut and the mouth of Middle River, typical summer flows swing from roughly 50,000 cfs westward to 50,000 cfs eastward, and back again, each day (DWR 1993). At the confluence of the San Joaquin and Sacramento rivers, the typical daily excursion in each direction exceeds 300,000 cfs.

### **In-Delta Flows, Smolt Travel Time, and Smolt Migration Patterns**

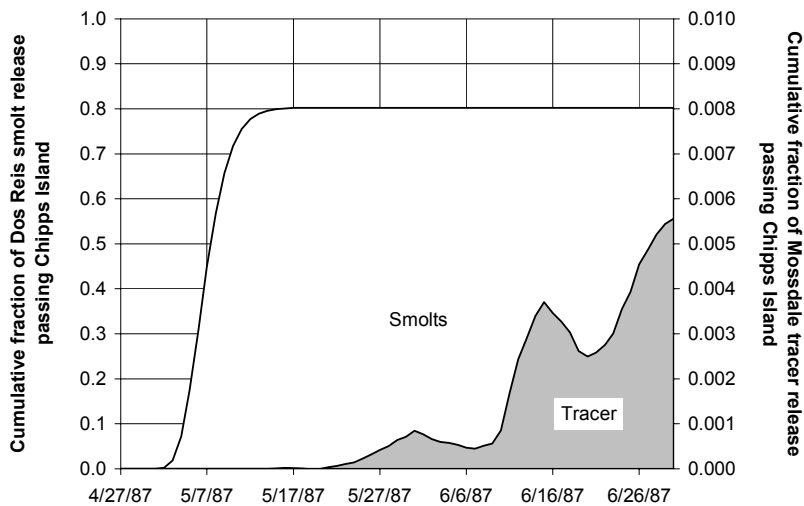
There is little theory available on the mechanisms by which smolts find their way through the estuary, or about how these mechanisms are affected by flow. Much of what is currently known about emigration mechanisms is negative. For example, the most straightforward model, that the movement of smolts mirrors the movement of water, has been shown to be incorrect. Smolts and water travel through the Delta at very different rates, and end up at very different places.

San Joaquin smolts pass through the Delta in a median time of 11 days, some arriving at Chipps Island as early as five days after release at the point where the San Joaquin River joins the Delta, and some taking as long as 26 days (Figure 4). This is considerably shorter than the transit time for neutrally-buoyant tracer particles, at least in hydraulic simulations. Figure 5 shows an example comparing the speed of smolt passage and the speed of tracer particles for a release made on April 4, 1987, in which 80% of the smolts were estimated to have been recovered after two weeks, but only 0.55% of the tracer particles were recovered after two months. (The estimated survival for this smolt group was atypically high, but the transit time was not. Typical survival estimates for smolts are still much larger than 0.55%.)

Not only do the tracer particles which reach Chipps Island take a long time to get there, but most of them go somewhere else. That somewhere else is the CVP and SWP pumps, at least for the hydraulic simulations available to us. Figure 6 shows that for the April 27, 1987 simulation, 77% of the tracer particles ended up at the export pumps, while only 13% of the smolts arrived there.

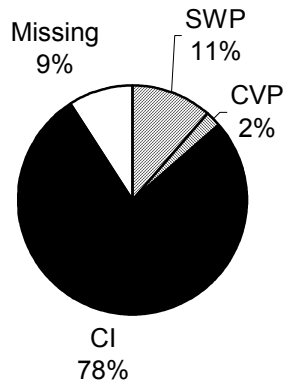


**Figure 4 Empirical pattern of smolt recovery (cumulative) at Chips Island as a function of days after release in Merced (1989), Stanislaus (1986, 1988, 1989), and Tuolumne (1986, 1987, 1990) rivers.** The dashed (---) line indicates smoothed recovery (cumulative); the gray line indicates probability density of reaching Chips Island based on smoothed recoveries. After release, the fastest smolts arrived at Chips Island in five days and the slowest in 26 days. Peak recoveries occurred on the tenth day after release, and half of the fish had arrived within 11 days.

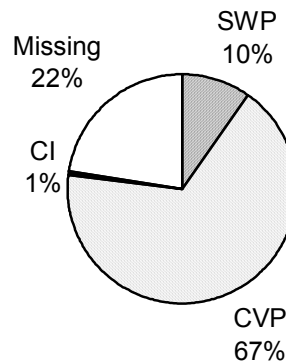


**Figure 5 Comparisons of the movements of salmon smolts and passive particles released near the head of Old River on April 27, 1987.** Cumulative recoveries at Chips Island of smolts released at Dos Reis, and simulated mass flux past Chips Island of tracer material released at Mossdale. The smolt recovery data have been fitted to an inverse gaussian distribution. Hydraulic simulations by Flow Science (1998).

**Smolts released in Lower San Joaquin River at Dos Reis**

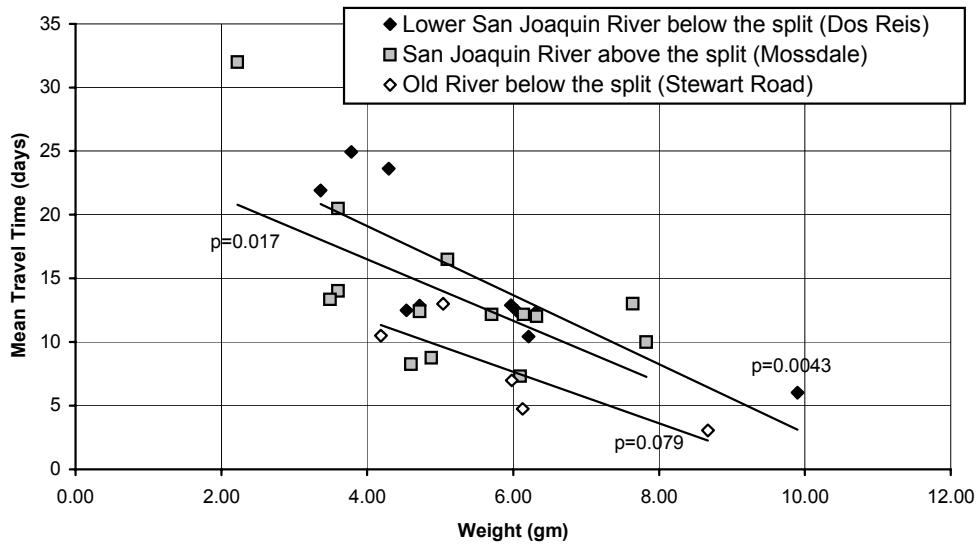
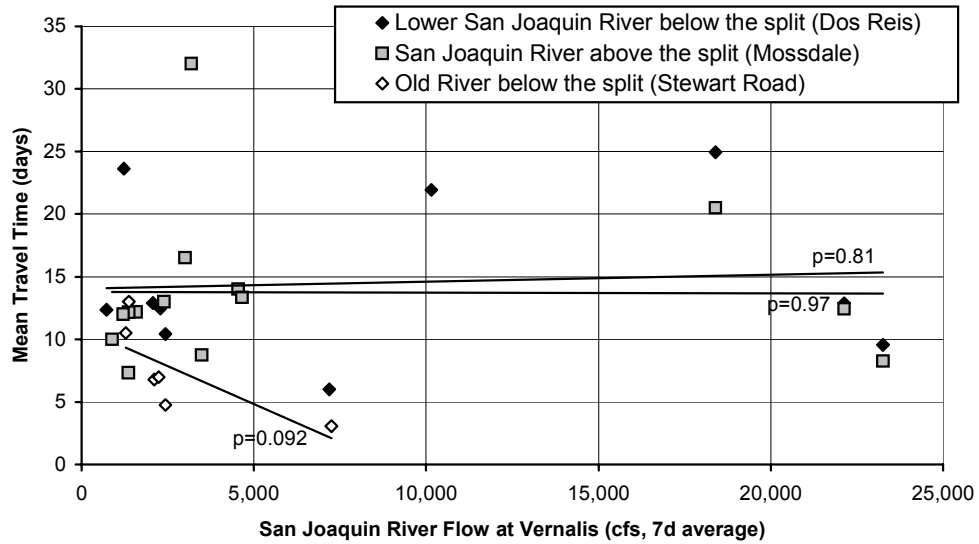


**Tracer released in San Joaquin River at Mossdale**



**Figure 6 Comparisons of the final destinations of salmon smolts and passive particles released near the head of Old River on April 27, 1987.** Estimated final disposition of tagged chinook salmon smolts released at Dos Reis and simulated disposition as of June 30, 1987 of tracer material released at Mossdale. For the smolts, the CVP and SWP values represent total entrainment, including estimates of screen inefficiency and mortality in Clifton Court Forebay, and the Chipps Island value represents successful emigration exclusive of release after salvage. Hydraulic simulations by Flow Science (1998).

Initially it seems intuitively reasonable that increased flows entering the Delta from the San Joaquin River at Vernalis would decrease travel times and speed passage, with concomitant benefits to survival. The data, however, show otherwise. Figure 7 (top) shows that Delta inflow has little if any effect on smolt travel time, probably because the large tidal flows swamp any passive effect of the incoming flows from the San Joaquin River, as suggested by the particle tracking results. On the other hand, Figure 7 (bottom) shows that the larger the smolts at the time of release, the shorter the travel time. This is in accordance with the striking difference between the passage time of smolts and passive particles: smolts actively swim toward the ocean, and the bigger they are the faster they do it.

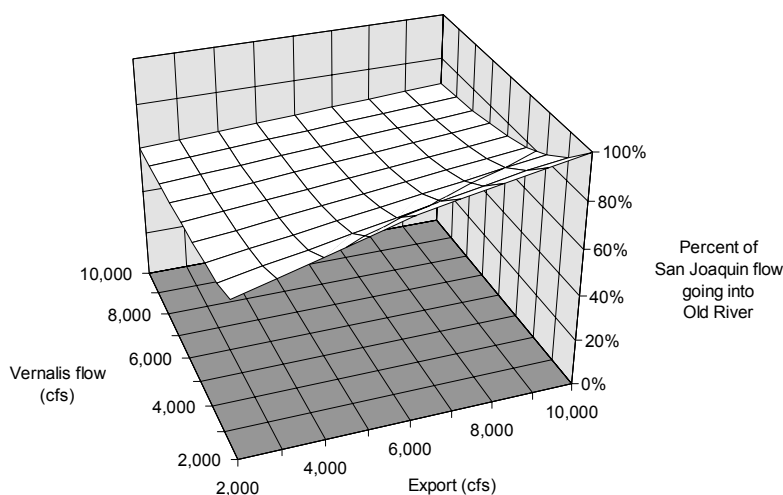


**Figure 7 Mean smolt migration times from three locations near the Old River-San Joaquin River split to Chippis Island.** The vertical ordering of the three trendlines in each plot agrees with the vertical ordering of the corresponding release locations in the legend. Top: Migration time and San Joaquin flow for the seven days following release. The regression for the Old River releases is significant only at the 90% confidence level, the other two are not significant at any acceptable confidence level. Bottom: Migration time and smolt weight at release. The regressions for both the San Joaquin and Lower San Joaquin releases are both highly significant (99% and 98% confidence levels, respectively). The regression for the Old River releases is only significant at the 90% level, but is still better than the corresponding regression with flow.

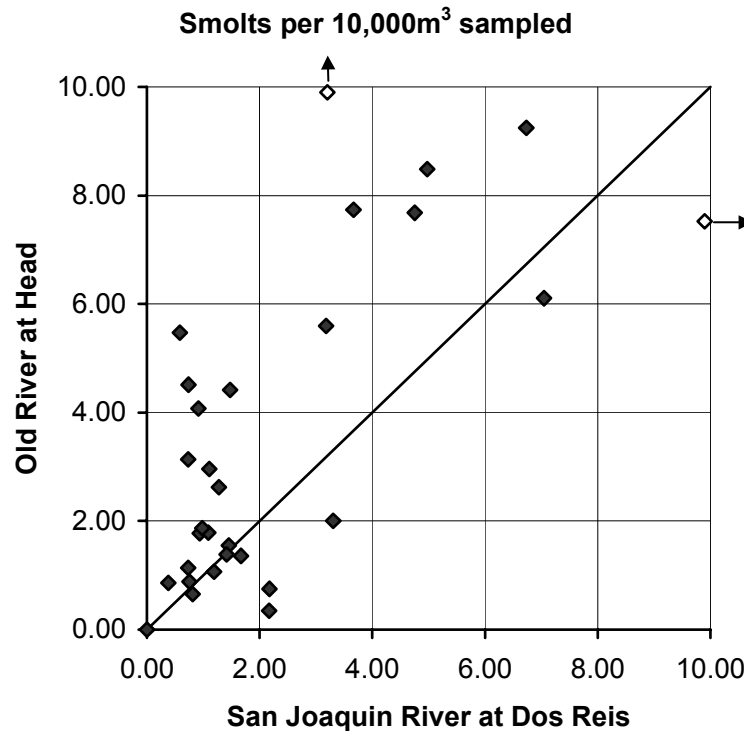
## Choice of Routes Through the Delta

When arriving at the Delta from the San Joaquin River, smolts have a choice of routes, the initial decision of which is whether to remain in the larger channel, Old River, at the point that the San Joaquin River diverges toward the north. This decision is critical to their survival, because the Old River channel soon branches into two meandering through channels (Old and Middle rivers), a number of major canals (Grant Line, Fabian and Bell, Victoria), and various dead-ends (Paradise Cut, Tom Paine Slough). The through channels and canals all deliver smolts to or near the intake structures for the CVP and SWP pumping plants.

Under conditions of no export pumping, about 60% of the water arriving via the San Joaquin River goes down the Old River channel; as pumping increases, that proportion can increase to 100% (Figure 8). If smolts simply traveled at a fixed speed relative to the water they were in, one would expect 60% or more of them to go to the pumps as well. In fact, in the few experiments that have been done, the results show an even higher percentage of the smolts go down Old River than would be expected if they simply went with the flow. Figure 9 shows the results from a series of daily trawls in the San Joaquin River and in Old River below the flow split. The results are expressed as the number of naturally migrating smolts captured per 10,000 m<sup>3</sup> of water sampled. If the smolts were simply following the flow, their concentrations in the two rivers would be identical. In fact, most of the daily data points occur well above the line of equal concentration, showing a higher concentration of smolts in Old River.



**Figure 8 Percentage of net flow (calculated from 1986 DWR net flow equations) in the San Joaquin River at Vernalis flowing into Old River.** At least 59% of the flow goes into Old River at any Vernalis flow, but as much as 100% can flow into Old River if Delta pumping is high.



**Figure 9 Daily smolt densities from 1996 real-time monitoring program from April 1 to May 6.** These are unmarked natural smolts. If the proportion of smolts in each channel exactly followed flow, the data would all lie on the diagonal line. The data tend to lie well above the line, however, suggesting a preference on the part of the smolts for the Old River channel. The two open diamonds were well off-scale at 12.5 for the upper one and 18.7 for the one on the left axis, so we left them off to better visualize the majority of the data.

### In-Delta Flows and Smolt Survival

Most of the USFWS CWT experiments in recent years have attacked the problem of relating survival along a given migration route to Delta hydrodynamics. In these experiments, two basic migration routes are recognized: down Lower San Joaquin River (past Stockton), or down Old and Middle rivers (past the export pumps). Delta hydrodynamics are represented by calculated net flows in Lower San Joaquin River at Stockton, and in Old River between its head and the split with Middle River, respectively.

This work has so far been inconclusive. There is a significant ( $P = 0.049$ ) correlation between survival in Lower San Joaquin River and San Joaquin flow at Stockton. This relationship is no better (or worse) than that with San Joaquin flow at Vernalis, and thus sheds little light on what the underlying mecha-



nisms for such a relationship could be. There is no empirical correlation at all between survival in Lower San Joaquin River and the rate of CVP-SWP export.

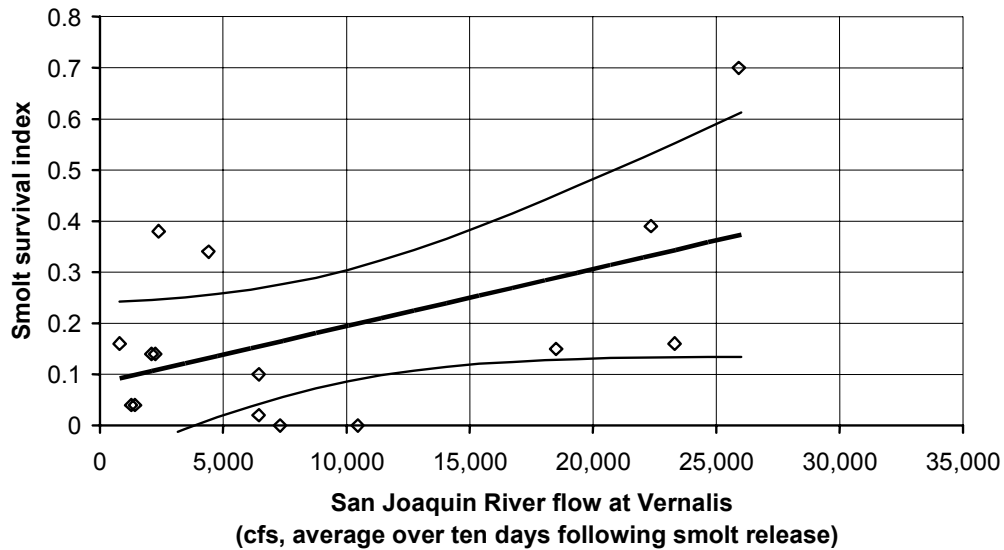
Results so far on survival in Old River have been even more unsatisfactory. Taken at face value, multiple regression of survival vs. flow in Old River and CVP-SWP export leads to the conclusion that increased export would improve smolt survival along this route (presumably an artifact of the strong contribution of export to Old River flow). As with the Lower San Joaquin River, the problem is that the degree of scatter, and lack of good controls, makes interpretation difficult.

Beginning in 1997, major changes have been made to the design of South Delta CWT experiments. These changes are expected to result in higher recapture numbers (leading to more precise estimates of survival), better control of flow and export conditions during individual experiments, and some degree of statistical design in the combinations of flow and export to be tested. It is too soon to tell whether these improvements will lead to a clearer understanding of the effects of flow and export on survival, but results so far are encouraging.

### **Vernalis Flows and Smolt Survival**

Figure 10 shows the relationship between the USFWS smolt survival index for CWT tagged fish and the flows in the San Joaquin River at Vernalis, just before the flow split between the lower San Joaquin River and Old River. Shown on the figure is a simple linear regression and the 95% confidence intervals. The data points are grouped in the regions of moderately low flow and quite high flow, with no data at all between 11,000 cfs and 18,000 cfs. The flows over 18,000 represent periods when the tributaries are spilling from the dams, and are essentially at flood stage; such conditions are probably very important to fish, but cannot be provided on demand by reservoir operators. When only the data below 10,000 cfs are considered, there appears to be a negative relationship between flow and smolt survival.

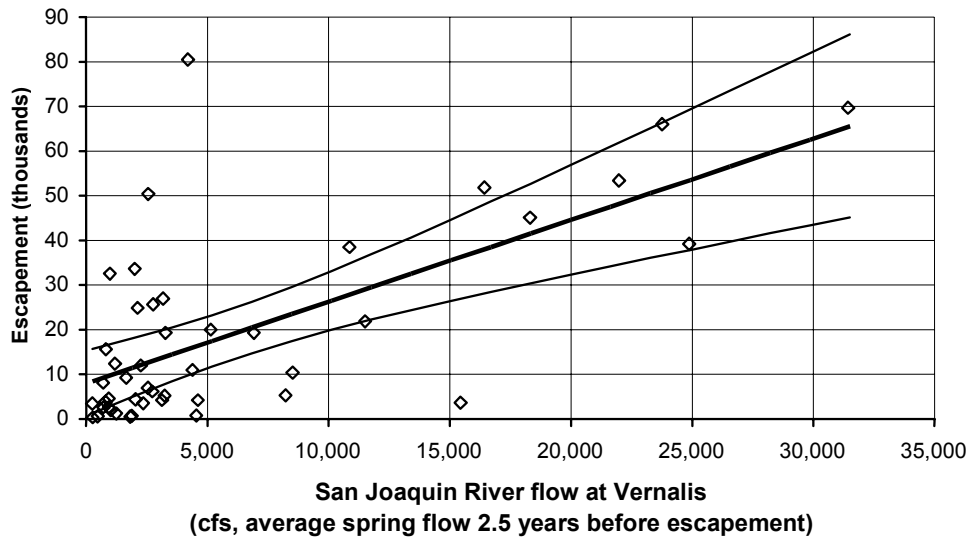
There are two ways to think about these data. One school believes that there is, in fact, a linear positive relationship between flow and smolt survival and that, on average, one could expect to get a survival improvement through the Delta corresponding to the slope of the regression line in Figure 10. The other school suspects that different mechanisms are at work at flood flows than low or moderate ones, and there is little reason to believe that altering flows within the lower range will have much effect on smolt survival through the Delta. Data from the middle range of flows will help, but the data are very scattered and factors other than flow are obviously influential.



**Figure 10 USFWS smolt survival index for tagged smolts released in the lower San Joaquin River at Dos Reis and average flow in the San Joaquin River at Vernalis over the 10 days following tag release. Fitted regression line and envelope of 95% confidence region for fitted line are shown.**

### Vernalis Flows and Escapement

Another way to look at the effects of flow at Vernalis is to examine the escapement as a function of flows when the escapees were smolts. Figure 11 shows such a result, based on the simplifying assumptions that all adults returned 2.5 years after their emigration as smolts and that in every year there were the same number of smolts. The results are similar to those for the smolt survival relationship with Vernalis flow, but with considerably more data and consequently, with narrower confidence limits. As with the smolt data, there is a clear relationship when high flows are included in the analysis, but at flows below 10,000 cfs there is very little correlation between flows at Vernalis and escapement, and there is a very large amount of scatter in the data. The scatter is undoubtedly partly attributable to failure of the two assumptions, but efforts to correct for these assumptions have not been particularly successful, so there are likely to be other issues as well.



**Figure 11** Total escapement to San Joaquin tributaries, 1951 through 1996, and spring flow in the San Joaquin River at Vernalis 2.5 years earlier. Fitted regression line and envelope of 95% confidence region for fitted line are shown.

## Conclusions

Smolt survival through the Delta may be influenced to some extent by the magnitude of flows from the San Joaquin River, but this relationship has not been well quantified yet, especially in the range of flows for which such quantification would be most useful. Salvage records show clearly that export-related smolt mortality is a major problem, but no relationship between export rate and smolt mortality, suitable for setting day-to-day operating levels, has been found. Survival measured in the Delta using paired releases of tagged smolts shows a twofold better survival for individuals that travel past Stockton via San Joaquin River rather than past the export facilities via Old River. Since more than 60% of the smolts usually go down Old River, any measure that decreased this percentage would be expected to benefit smolts, however such a benefit has yet to be demonstrated empirically.

In general, current methods used to explore smolt survival in the Delta have not succeeded in clarifying basic technical and biological issues. Some of these methods are contributing useful information, but very slowly. New kinds of studies are needed, focussed on fundamental questions of salmon biology and survival methods, and designed with more concern for issues of statistical power and refutability.

## References

- Brandes P, McLain J. 2001. Juvenile chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In: Brown RL, editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. Sacramento (CA): California Department of Fish and Game.
- [DWR] California Department of Water Resources. 1993. Sacramento San Joaquin Delta Atlas. Sacramento (CA): California Department of Water Resources. 121 p.
- [EA] EA Engineering, Science, and Technology, Inc. 1991. San Joaquin River system chinook salmon population model documentation and validation. Prepared for Turlock Irrigation District and Modesto Irrigation District, California. 80 p.
- [Flow Science] Flow Science, Inc. 1998. Determination of the sources of water arriving at Clifton Court Forebay and Bethel Island. Task 1 of Delta Flow Determination Project. Prepared for San Joaquin River Group, Modesto, California. 9 p.
- [SWRCB] State Water Resources Control Board. 1995a. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 95-1 WR. Sacramento (CA): State Water Resources Control Board. 45 p.
- [SWRCB] State Water Resources Control Board. 1995b. Environmental report. Appendix 1 to Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 95-1 WR. Sacramento (CA): State Water Resources Control Board. 494 p.

## Additional References

- [DFG] California Department of Fish and Game. 19- (Series). San Joaquin River chinook salmon enhancement project. Sport Fish Restoration Act. Annual Progress Reports. Fresno (CA): California Department of Fish and Game, Region 4.
- [IEP] Interagency Ecological Program for the Sacramento-San Joaquin Estuary. 19- (Series). IEP Newsletter. Sacramento (CA): California Department of Water Resources.
- [USFWS] US Fish and Wildlife Service. 19- (Series). Survival and productivity of juvenile chinook salmon in the Sacramento-San Joaquin Estuary. Annual Progress Reports. Stockton (CA): US Fish and Wildlife Service, Fisheries Assistance Office.