Relationship of Delta Cross Channel Gate Operations To Loss of Juvenile Winter-run Chinook Salmon at the CVP/SWP Delta Facilities

Alice F. Low and Jim White
California Department of Fish and Game

Winter-run Chinook salmon are distinguishable from the three other Chinook runs in the Sacramento River system by the timing of their upstream migration and spawning. Due to precipitous decline in the population from the late 1960's through the late 1980's, NOAA Fisheries listed the run as "threatened" in August 1989, and subsequently reclassified the run as "endangered" in 1992. The state of California listed the run as endangered in 1989.

Many factors contributed to the decline in the winter-run Chinook population. Among these factors, operation of the federal Central Valley Project and State Water Project has had continuing impacts on winter-run Chinook. Of particular concern have been the direct entrainment losses of juvenile winter-run Chinook at the project export facilities in the Delta.

There is considerable annual variability in the magnitude of direct winter-run entrainment losses in the Delta. Analysis has shown that this variability is not directly related to the estimated number of juvenile winter-run entering the Delta each year (estimated based on the number of spawners or the number of juveniles emigrating from the upper Sacramento River), nor does it appear to be directly related to the timing or magnitude of project exports. In this analysis, the relationship was evaluated between annual winter-run loss and Delta Cross Channel gate operations during the time period of juvenile emigration to the Delta.

One way juvenile salmon emigrating from the Sacramento River enter the interior Delta, and may be vulnerable to entrainment at the project facilities, is by diversion through the Delta Cross Channel (DCC) and Georgiana Slough. Operation of the DCC gates may significantly affect the survival of juvenile salmon emigrating from the Sacramento River associated with the diversion of a significant proportion of Sacramento water into the interior Delta. The Delta Cross Channel (DCC), completed in 1951, is a controlled diversion channel between the Sacramento River and the interior Delta. Up to 6,000 cfs of water can be diverted through the Channel into Snodgrass Slough (DWR 1991). From Snodgrass Slough, Sacramento River water flows through natural channels of the lower Mokelumne River to the vicinity of the CVP and SWP export facilities (Figure 1).

During the period juvenile winter-run Chinook salmon are emigrating through the lower Sacramento River, approximately 40-50 % of Sacramento River flow is diverted into the interior Delta through DCC when both gates are open; with the gates closed, approximately 15-20 % of Sacramento River flow enters the interior Delta through Georgiana Slough.

Early investigations by Schaffter (1980) suggested that juvenile winter-run may be entrained into the interior Delta in proportion to Sacramento River flow diverted through the DCC. Schaffter (1980) found that densities of salmon in the Sacramento River above the DCC were similar to those in the DCC.

In 2001, the CALFED Science Program initiated a major interdisciplinary study of the effects of DCC gate operations and tides on flow and fish entrainment. Preliminary results indicate that fish are entrained into the DCC primarily on flood tides, in proportion to water velocity vectors. (Add reference)

Coded-wire tag studies of juvenile Chinook migration through the Delta by USFWS have shown that survival is lower for smolts released into the interior Delta than for smolts released into the mainstem Sacramento River. In addition, studies showed that smolts released into the Sacramento River below the open DCC survived better than smolts released above the DCC, although the differences were not significant (USFWS 1992). Once diverted into the interior Delta, juvenile salmon are subject to adverse conditions that decrease their survival. Lower survival rates in the central and southern Delta may be the result of a longer migration route where fish are exposed to increased predation, higher water temperatures, unscreened agricultural diversions, poor water quality, reduced availability of food, and entrainment at the CVP and SWP export facilities.

For fisheries protection, the 1995 Water Quality Control Plan for the Bay-Delta includes specific requirements for DCC gate closures (SWRCB 1995).

The focus of this evaluation was to examine the relationship of Delta Cross Channel gate operations to subsequent direct losses of juvenile winter-run Chinook salmon at the CVP and SWP Delta export facilities. The specific hypothesis tested was as follows:

> The proportion of the juvenile winter-run population lost at the Delta facilities each year is correlated to the proportion of Sacramento River flow diverted into the interior Delta that year during the time juvenile winter-run are emigrating through the lower Sacramento River in the vicinity of the Delta Cross Channel and Georgiana Slough. The proportion of flow diverted into the interior Delta is significantly influenced by the position of the DCC gates. Highest losses of juvenile winter-run at the Delta facilities has occurred in years when the DCC gates were open during the time juvenile winter-run were migrating through the lower Sacramento River.

Conceptual Model

The following conceptual model was developed to guide the analysis of data relevant to the study hypothesis:

1. A large proportion of juvenile winter run migrate downstream to the Delta in December every year, independent of upstream river conditions. If water clarity is high at the time, these fish may not be detected moving past sampling locations just upstream of the Delta (Knights Landing RST, Sacramento trawl).

2. Upon reaching the Delta, salmon in the Sacramento River can follow one of several pathways. These include: Sutter Slough, Steamboat Slough, Delta Cross Channel, Georgiana Slough, Three Mile Slough, and the mainstem Sacramento River to the western Delta.

3. The pathway used by salmon is a function of flow splits at channel junctions when fish encounter them. Tidal stage, river discharge, and DCC gate status all have an effect on the flow splits. Channel configuration also influences the distribution of fish within the channel cross-section (e.g. fish apparently concentrate at the outside of the bend in the Sacramento River channel at Walnut Grove, in the vicinity of the DCC and Georgiana Slough) so in some instances the proportion of fish following a particular pathway may deviate from the proportion of water flowing that way.

4. Whether the Delta Cross Channel gates are open or closed is a key factor. When the DCC gates are open, some Sacramento River water flows into Sutter and Steamboat Sloughs and the rest flows down the Sacramento River to Walnut Grove. There some water flows from the Sacramento River into the DCC, primarily on flood tides. Water flowing past the DCC either flows into Georgiana Slough to a confluence with the Mokelumne River and then to the San Joaquin River in the central Delta or it flows down the Sacramento River to Rio Vista, past Three Mile Slough and to a confluence with the San Joaquin River in the western Delta.

When the DCC gates are closed, the proportion of Sac R flow going into Sutter/Steamboat increases, hence the proportion and (for any given Freeport flow) the amount of flow remaining in the main stem Sacramento River is reduced. No water flows into the DCC with the gates closed, therefore flow increases in both Georgiana Slough and the Sacramento River to Rio Vista. (Blocking all flow into the DCC more than offsets the reduction in Walnut Grove flow due to Sutter/Steamboat flow increase)

5. Juvenile salmon moving downstream will be distributed roughly in proportion to the split in flow at junctions. Thus, more salmon will enter the Sutter or Steamboat slough pathways with the DCC gates closed. Thereafter the migration pathway to the lower estuary is relatively direct. The chance of these fish ending up in the southern Delta is lower, with Three Mile Slough and the Sac-SJ confluence being the only plausible routes.

6. Most juvenile winter run reaching the Delta in December are not physiologically prepared to continue migrating through the estuary to the ocean. They spend 1-3 months growing in the lower Sacramento River and Delta region before resuming their seaward migration as smolts.

7. Habitat selection during this rearing period is influenced by many factors but increasing salinity defines the downstream extent of migration prior to smoltification. Ocean-derived salt defines this boundary in the western Delta/Suisun Bay. Land-derived salt in the relatively high EC water flowing into the Delta from the San Joaquin basin may define this boundary in the southern Delta under some circumstances. Rearing salmon take up residence in the suitable habitat within the Delta.

8. Movement of juvenile winter run in the rearing stage is not affected to any great extent by channel flow. Few are observed at the SWP/CVP. When these juvenile salmon reach a certain age (size?) and are ready to migrate to the ocean they undergo a physiological transformation.

9. Smolting salmon cue on a combination of increasing salinity gradient, downstream flow, and possibly other factors. When this change in behavior occurs winter run size smolts begin to appear in sampling gear at Chipps Island and at the SWP/CVP fish facilities.

10. The direction of water movement when a migrating smolt arrives at a channel junction is an important factor in determining what pathway the fish chooses. Flow direction and velocity at channel junctions throughout most of the Delta is primarily influenced by the tide. Timing of arrival at a junction is critical.

11. Depending on where they were rearing, the pathway to the lower estuary may be either relatively straightforward or complex. Selections resulting in smolts reaching the western Delta and Suisun Bay and the lower estuary lead to improved survival. Selections at one or more junctions resulting in smolts migrating into southern Delta channels lead to decreased survival. Salmon that reared in the northern Delta Channels (Sutter, Steamboat, Cache, Lindsey, lower ship channel) or the main stem Sacramento River have the most direct route to Suisun Bay and the lower estuary, with few channel junctions and hence few opportunities for straying off the correct pathway. Salmon that reared in the interior Delta (Mokelumne forks, Georgiana Slough, lower San Joaquin R.) have a potentially more complex pathway to find Suisun Bay, with numerous channel junctions and many opportunities to select the wrong channel.

12. In the southern Delta, the influence of SWP/CVP export pumping combines with tidal effects to determine channel flow which, in turn, affect the pathways chosen by migrating smolts. The extent of the area where this occurs varies and is determined by pumping rate and river flows. Some salmon respond to false cues and reach the wrong destination (southern Delta instead of the western Delta) where they are likely to be entrained in the SWP and CVP water diversions. Migrating winter run smolts begin to appear in salvage samples at the fish facilities at about the same time as their numbers increase in sampling at Chipps Island.

13. More juvenile winter-run rear in the interior portion of the Delta when the DCC gates are open for more days in December and January. Smolts resuming seaward migration from interior Delta rearing locations are more likely to be entrained at the SWP/CVP facilities.

Methods

To evaluate the timing and relative abundance of juvenile winter-run emigrating downstream through the Sacramento River and the Delta, data from several juvenile monitoring programs were used (Figure 1):

- Rotary screw trapping at Red Bluff Diversion Dam (RM)(USFWS, Red Bluff Fish and Wildlife Office, 2003a)
- Rotary screw trapping at Knights Landing (RM 89) (DFG, Stream Evaluation Program) (DFG 2000)
- Mid-water trawl at Sacramento (RM 55)(USFWS, Sacramento-San Joaquin Estuary Fishery Resource Office, 2003b)
- Beach seining at several sites on the lower Sacramento River, from Sacramento to the vicinity of the Delta Cross Channel (USFWS, Sacramento-San Joaquin Estuary Fishery Resource Office, 2003b)

Data were available from these programs for 1995 through 2003, with the exception of 2000-01 and 2001-02 at Red Bluff Diversion Dam.

To evaluate the annual loss of juvenile winter-run at the Delta export facilities, the estimated annual direct loss density data (fish lost per thousand acre-feet exported) for October 1 through May 31, 1995 – 2003, were obtained from the Department of Water Resources for juvenile Chinook meeting the winter-run length criteria (Delta length curves). To estimate the proportion of the total winter-run juvenile population lost each year at the Delta facilities, the Delta loss density data for each year were divided by each year's Juvenile Production Index (JPI), the estimated number of winter-run fry equivalents passing Red Bluff each year in rotary screw trap sampling (USFWS 2003a).

To determine the proportion of Sacramento River mainstem flow diverted into the interior Delta through the Delta Cross Channel gates and Georgiana Slough during periods of peak winter-run migration, flow formulas in Dayflow (IEP, http://www.iep.water.ca.gov/dayflow/index.html) were used. Dayflow is a computer program developed in 1978 as an accounting tool for determining historical Delta boundary hydrology. The Dayflow program currently provides an estimate of historical mean daily flows through the Delta Cross Channel and Georgiana Slough, past Jersey Point, and past Chipps Island to San Francisco Bay (net Delta outflow). Flows through the Delta Cross Channel and Georgiana Slough were not gaged prior to 2002. Therefore, empirical equations were developed in 1978 using historical data to relate these flows to Sacramento River flow (QSAC) at I Street Bridge in Sacramento. In later years, flow gauging was changed to Freeport. Sacramento River flow at Freeport rather than Sacramento is now used in these equations.

The following equations from Dayflow were used in this analysis:

Both gates closed; flow only through Georgiana Slough:

$$QXGEO = 0.133 (QSAC) + 829$$

Both gates open plus flow through Georgiana Slough:

$$QXGEO = 0.293 (QSAC) + 2090$$

The flow proportion was calculated on a daily basis, and then averaged over monthly and 2-week intervals, for the months of November, December, and January, 1995 – 2004.

Results

Timing of Juvenile Winter-run Emigration and Delta Losses

Winter-run spawn in the upper Sacramento River from Keswick Dam to Red Bluff Diversion Dam from late April through August, with peak spawning occurring in May and June. Juveniles migrate from the upper river beginning in late July. Evidence from downstream sampling sites indicates that winter-run rear in the Sacramento River and Delta for a significant time before emigrating to the ocean.

Juvenile winter-run size fish emigrating from the spawning area in the upper river are sampled in rotary screw trapping at Red Bluff Diversion Dam. The USFWS Red Bluff Fish and Wildlife Office has conducted sampling at this site beginning in 1995, with the exception of 2000 and 2001 (USFWS 2003a). Data indicate the timing and relative abundance of juvenile winter-run size fish emigrating from the upper river. Peak timing of winter-run size emigration past RBDD typically occurs in September (Figure 2). Most winter-run sampled are fry size.

In the lower Sacramento River, juvenile winter-run size fish are sampled in rotary screw traps at Knights Landing (DFG), in the mid-water trawl at Sacramento (USFWS), and in beach seining at several sites between Sacramento and the Delta Cross Channel (Figure 1). These data were evaluated to estimate the timing of winter-run passage through the lower Sacramento River. Winter-run juveniles are distinguished from other Chinook races at these sites using size criteria.

Data from these sites show similar patterns in the timing of winter-run emigration. At Knights Landing, in seven of the nine years sampled (1995 – 2003), peak passage of winter-run size juveniles occurred in late November to mid-December (Figure 3). In the Sacramento River trawl, peak winter-run size passage also occurred in late November to mid-December in seven of the nine years sampled (Figure 4). At the lower Sacramento River beach seining sites, peak winter-run size juvenile passage occurred from late November through late December in seven of the nine years sampled (Figure 5). At each of the sites, catches of winter-run size juveniles in the 1999-2000 and 2000-2001 seasons were relatively low and late (January or later) compared to the pattern seen in the other years.

Timing of Juvenile Winter-run Emigration Compared to Delta Facility Losses

Comparison of the timing of winter-run size passage at Knights Landing and the timing of losses at the Delta facilities indicate that winter-run size juveniles rear in the Delta for significant time periods (one to four months) before entrainment at the project facilities (Figure 6). Peak winter-run size passage at Knights Landing typically occurs in late November to mid-December, while peak losses at the Delta facilities typically occur in March or April. Fish may be vulnerable to entrainment at the project facilities at the time they are ready to migrate from the Delta to the ocean.

Relationship Between Proportion of Flow Diverted into Interior Delta and Direct Losses of Juvenile Winter-run

In this analysis, the proportion of Sacramento River mainstem flow diverted into the interior Delta through the Delta Cross Channel gates and Georgiana Slough was calculated for the November through January period, the typical period of peak winter-run migration, for 1995 - 2003. The relationship was then evaluated between these flow proportions and the estimated proportion of the total winter-run juvenile population lost each year at the Delta facilities from October 1 through May 31 (the estimated Delta direct loss density data for each year, divided by each year's Juvenile Production Index (JPI)) (Table 1).

Significant linear relationships were found between the proportion of Sacramento River flow diverted into the interior Delta in December and January and the proportion of the winter-run size population lost at the Delta facilities from October 1 through May 31 each year (Figures 7 and 8). Evaluating the data by two-week time intervals showed highly significant relationships between these proportions in late December (December 15-31) and early January (January 1-15) periods (Figures 9 and 10).

Conclusions

The proportion of the juvenile winter-run population lost at the Delta facilities each year was found to be correlated to the proportion of Sacramento River flow diverted into the interior Delta that year during the time juvenile winter-run are emigrating through the lower Sacramento River in the vicinity of the Delta Cross Channel and Georgiana Slough (late December and early January). Juvenile winter-run may be entering the interior Delta in December and early January when the DCC gates are open at a higher rate than when the gates are closed, in proportion to the flow diverted. These fish are vulnerable to direct entrainment losses in subsequent months when they attempt to emigrate from the Delta to the ocean.

The proportion of flow diverted into the interior Delta during December and January is significantly influenced by the position of the DCC gates. Prescriptive DCC gate closures during the December 15 through January 15 period may therefore provide increased protection for migrating juvenile winter-run.

However, there may be many other factors influencing the observed relationships between direct winter-run losses and the proportion of flow diverted into the interior Delta. The estimated proportion of winter-run lost at the facilities was much higher in 1999-2000 and 2000-01 than in any of the other years from 1995-2003, making the relationships with diversions significant. In both of these years, Sacramento River flows were low in December, and juvenile winter-run were not observed at the sampling sites in the lower Sacramento River until January or later (Knights Landing, Sacramento trawl, lower Sacramento River beach seine sites). The biological triggers for DCC gate closures were therefore not met in December or early January of those years, and the gates were allowed to remain open until late January. The relatively high proportion of winter-run take in 1999-2000 and 2000-01 therefore may have been due to other factors related to the low Sacramento River flow during December, the time when juvenile winter-run are typically observed migrating through the lower river.

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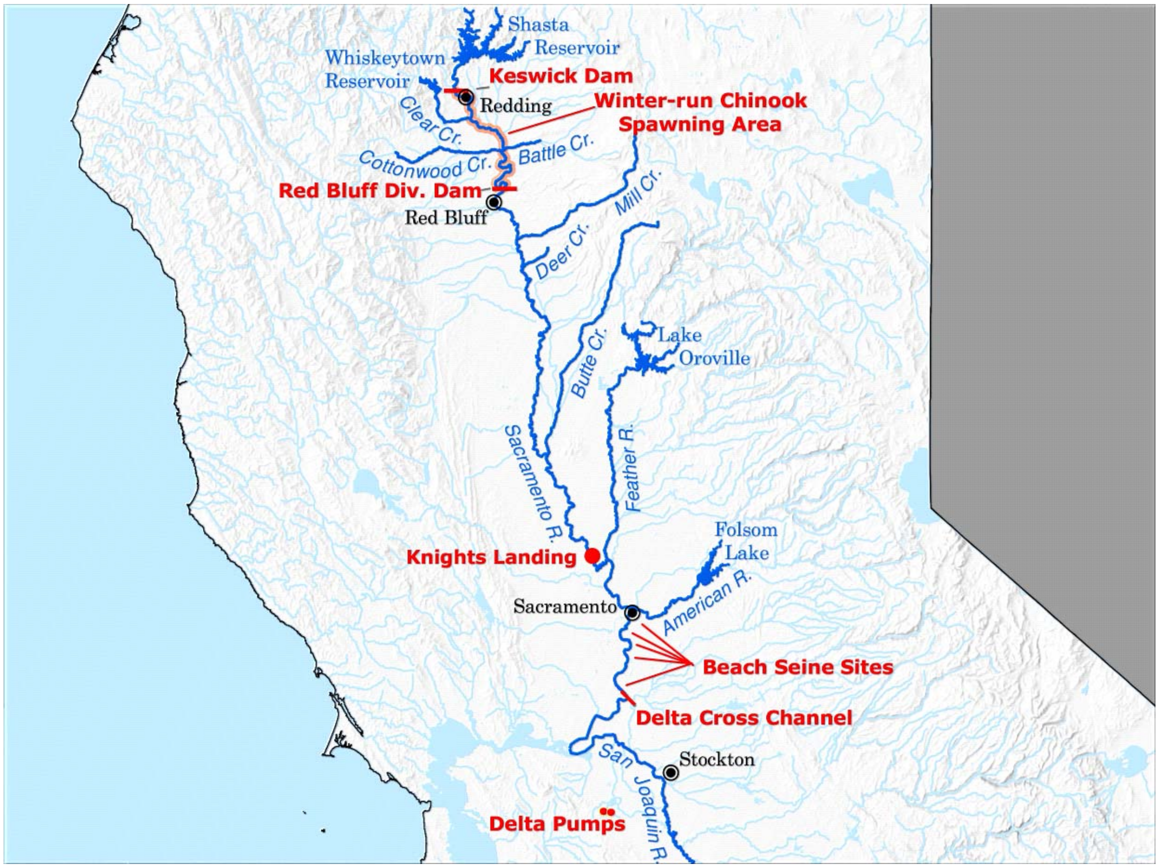


Figure 1. Sacramento River and Sacramento-San Joaquin Delta, indicating winter-run Chinook spawning area and juvenile sampling sites.

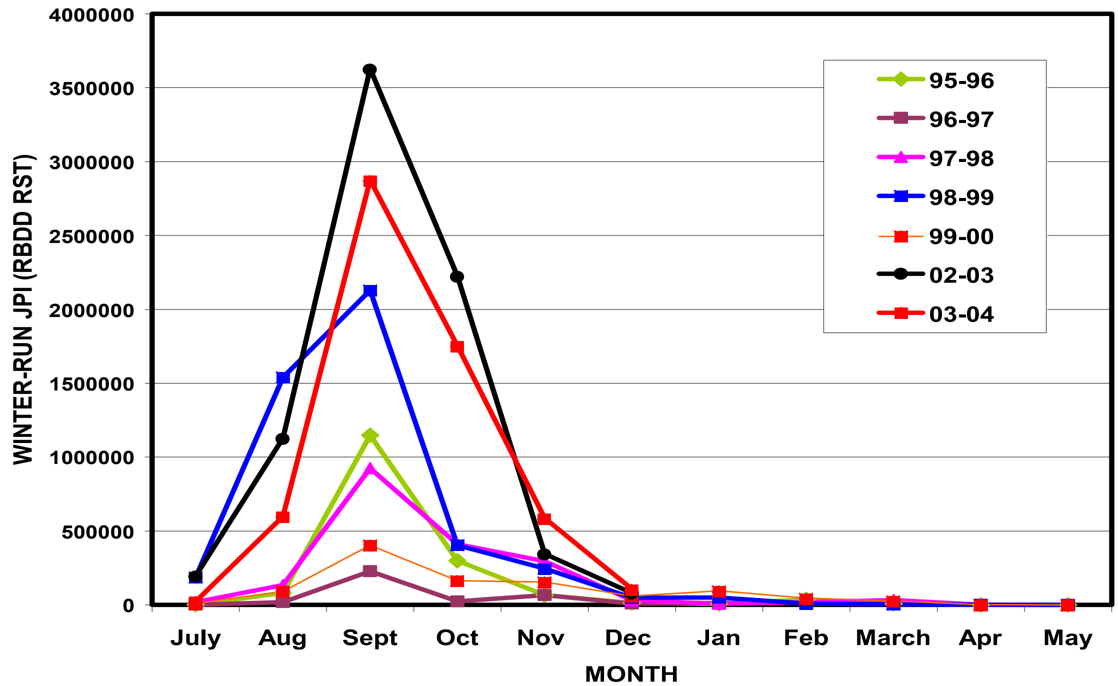


Figure 2. Timing of juvenile winter-run passage at Red Bluff Diversion Dam, rotary screw trap sampling (USFWS 2003a).

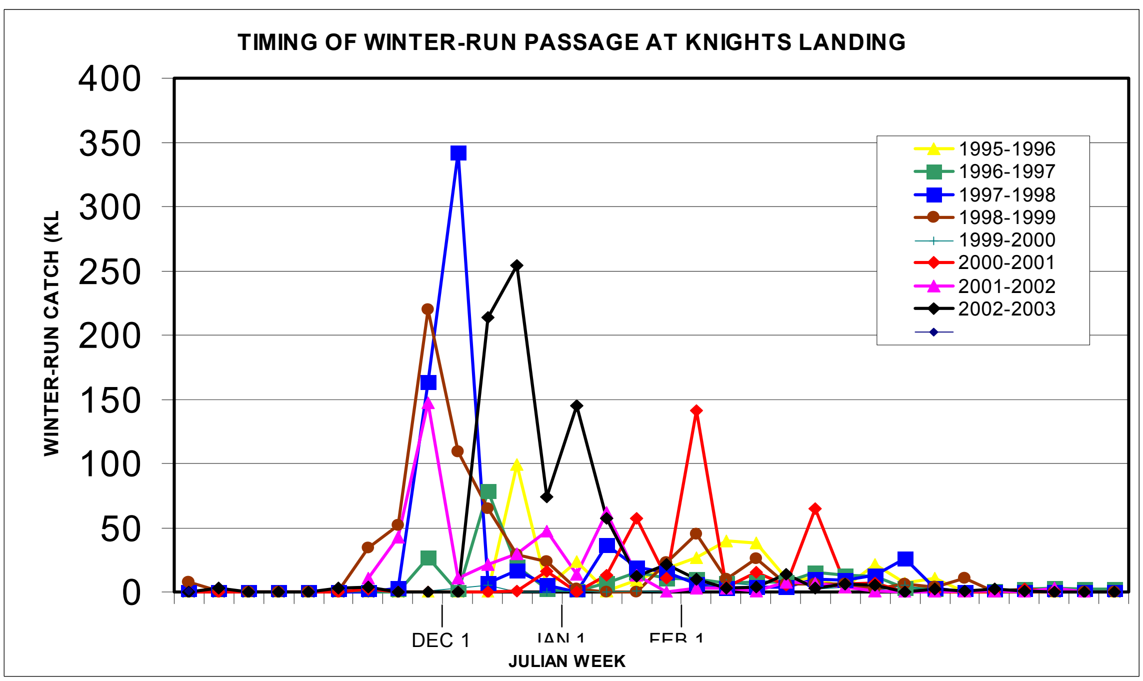


Figure 3. Timing of juvenile winter-run passage at Knights Landing, rotary screw trap sampling (DFG 2000).

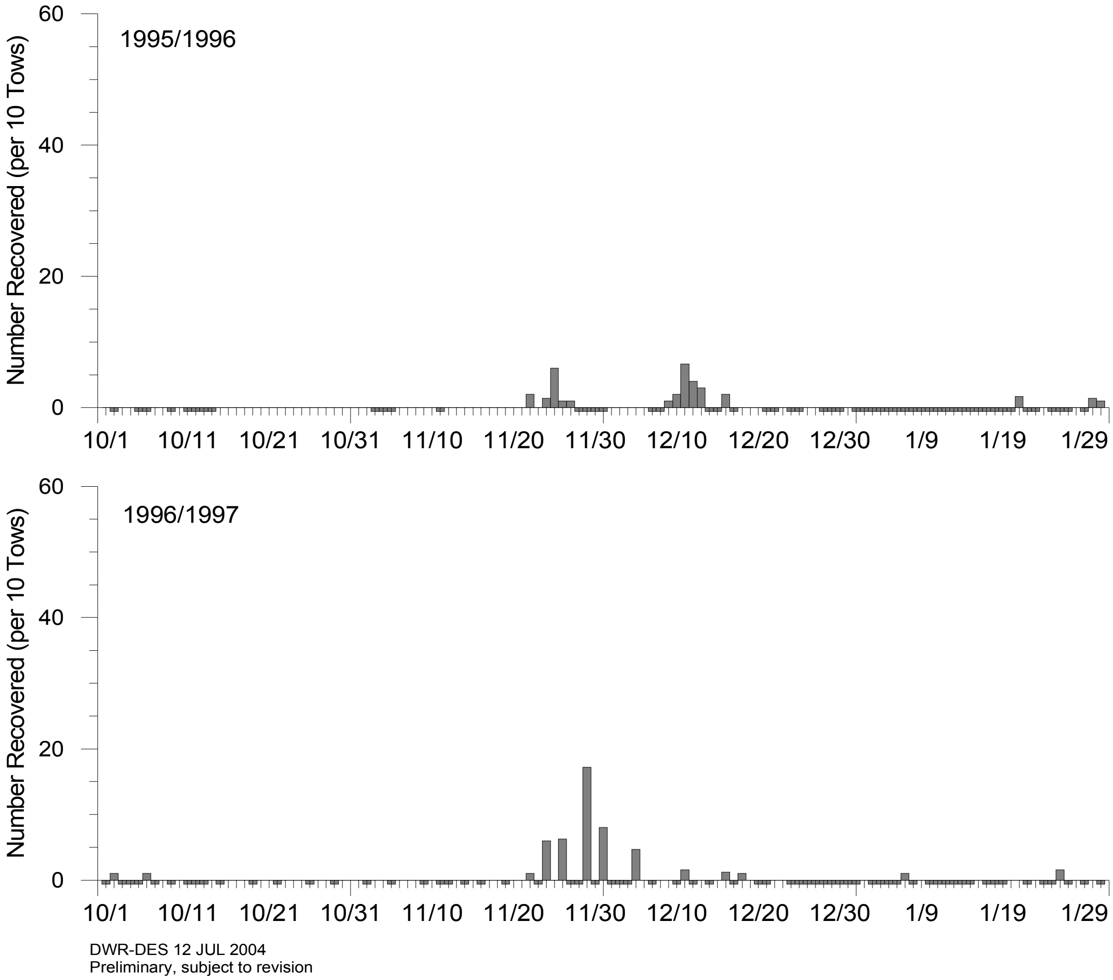


Figure 4. Number of older juvenile Chinook salmon caught in the USFWS Sacramento River trawl (SR055M), October through January, 1995 – 1997.

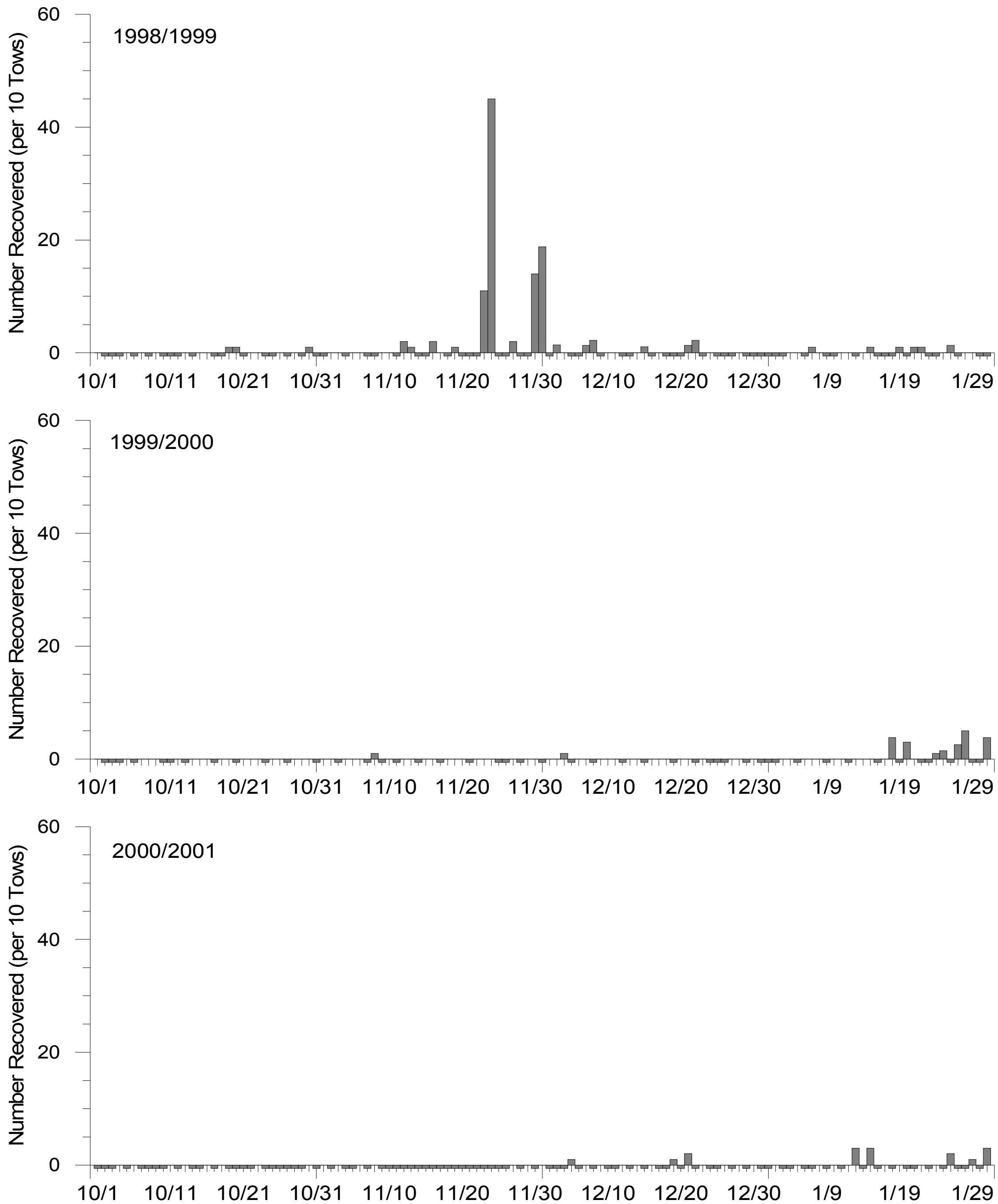


Figure 4 (cont'd). Number of older juvenile Chinook salmon caught in the USFWS Sacramento River trawl (SR055M), October through January, 1998 – 2001.

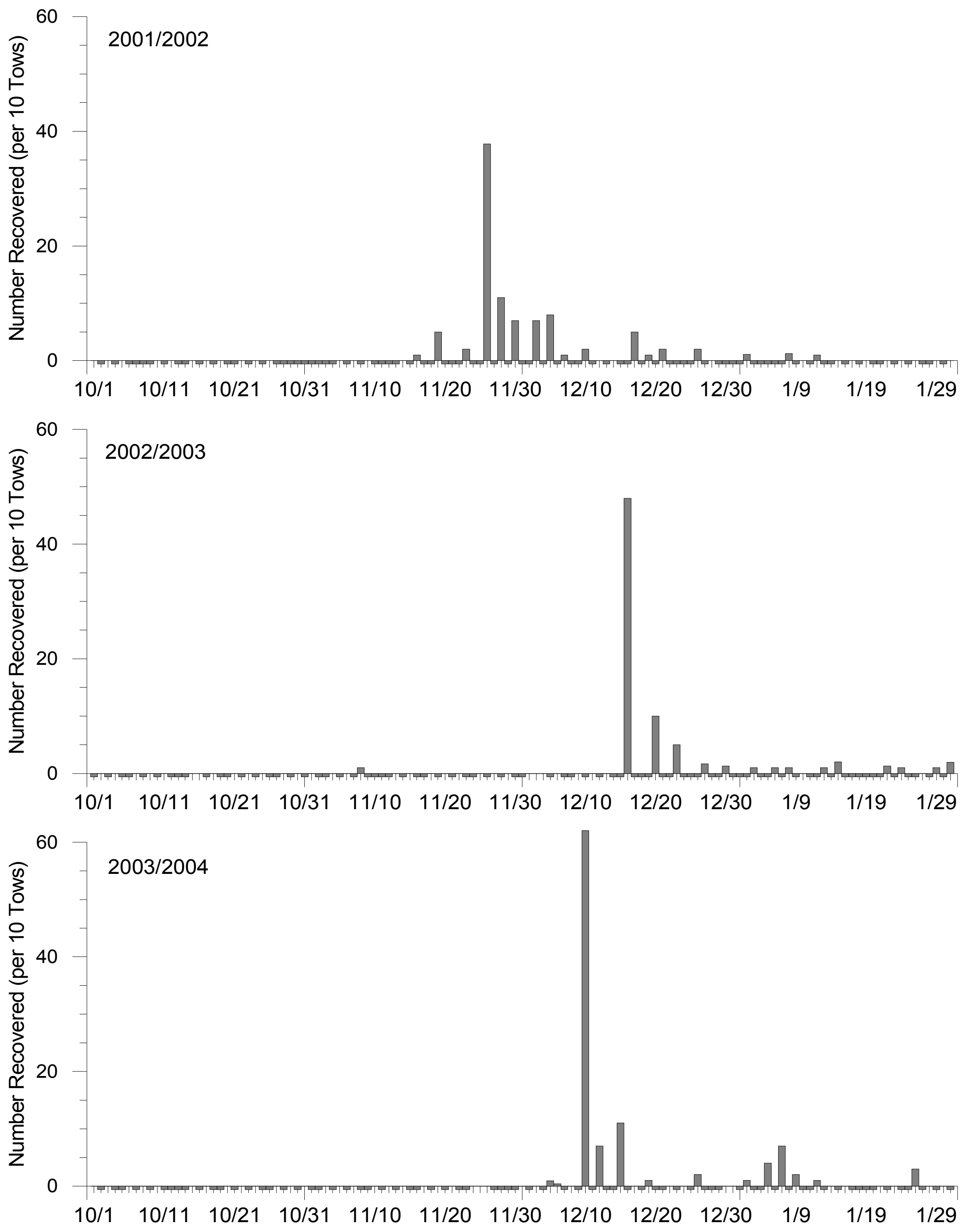


Figure 4 (cont'd). Number of older juvenile Chinook salmon caught in the USFWS Sacramento River trawl (SR055M), October through January, 2001 – 2004.

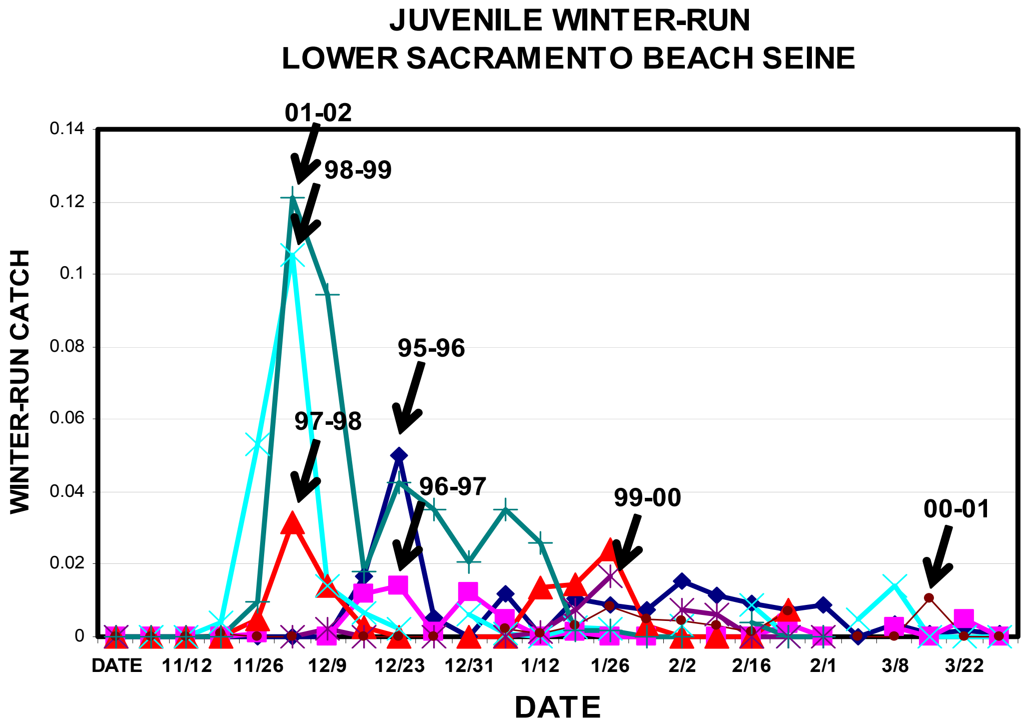
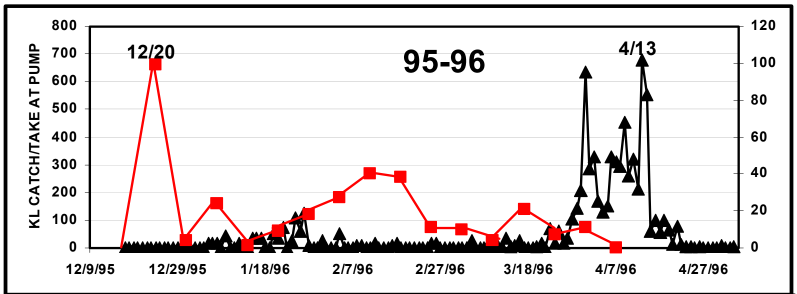
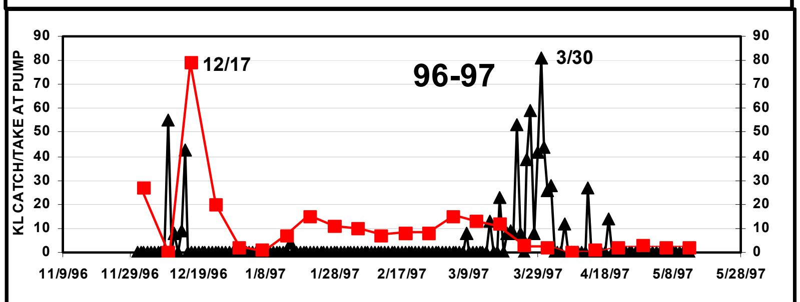


Figure 5. Timing of juvenile winter-run Chinook catches in the lower Sacramento River beach seine (5 sites) (USFWS 2003b).



KL CATCH/TAKE AT PUMP
95-96
12/20
4/13
800
700
600
500
400
300
200
100
0
120
100
80
60
40
20
0
12/9/95
12/29/95
1/18/96
2/7/96
2/27/96
3/18/96
4/7/96
4/27/96



KL CATCH/TAKE AT PUMP
96-97
12/17
3/30
90
80
70
60
50
40
30
20
10
0
11/9/96
11/29/96
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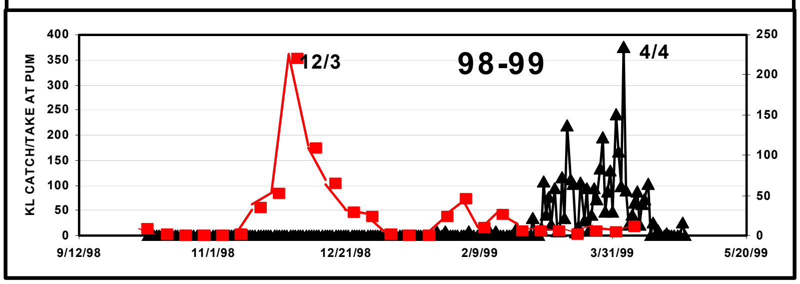
5/8/97
5/28/97



KL CATCH/TAKE AT PUM
98-99
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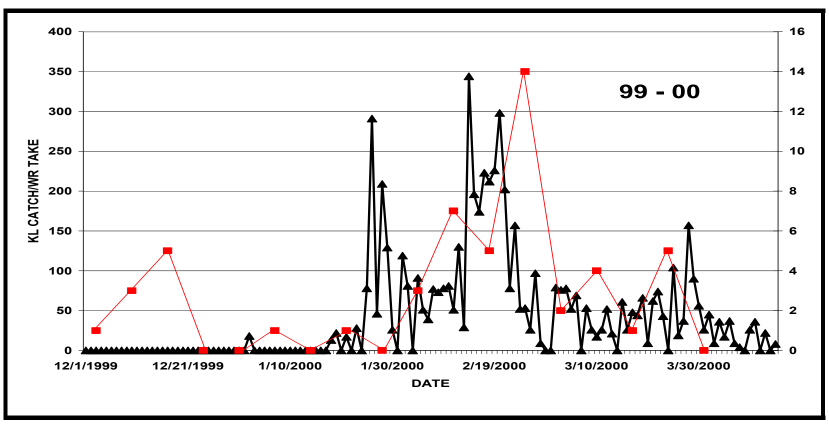
3/31/99
5/20/99



KL CATCH/WR TAKE
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300
250
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100
50
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16
14
12
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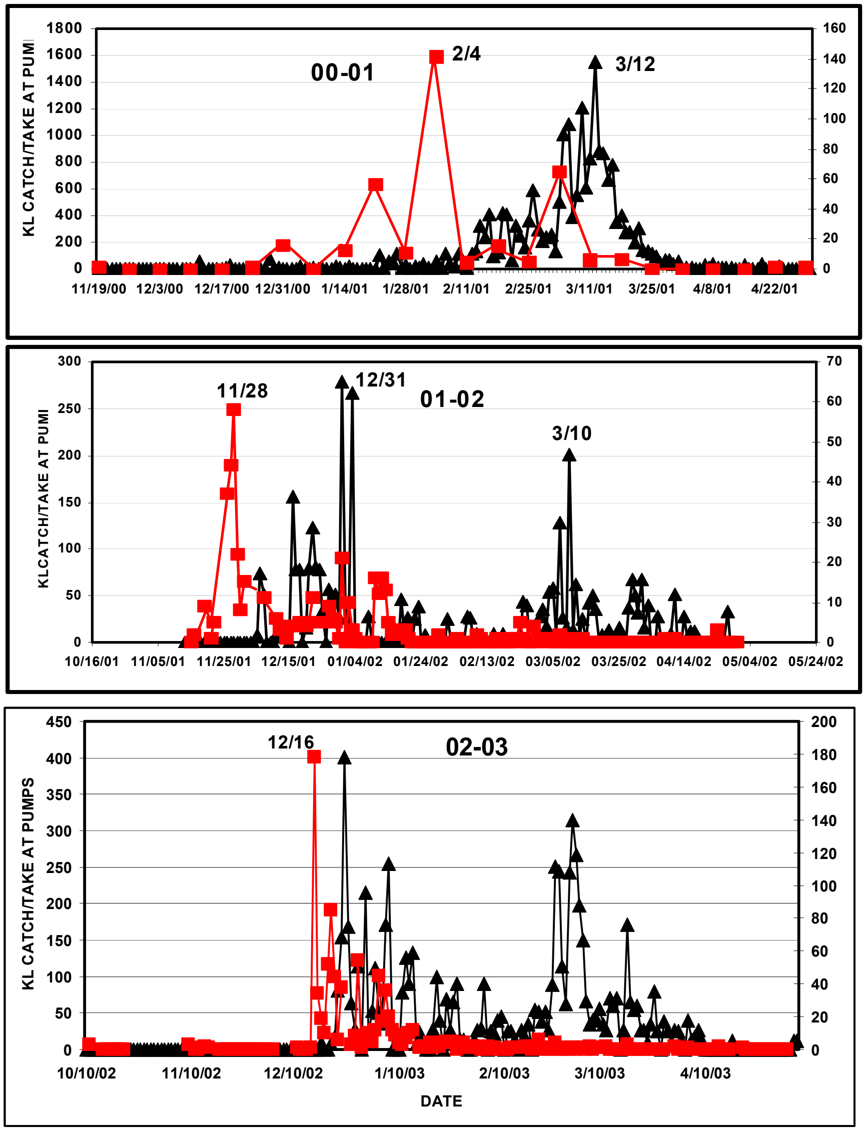

Figure 6. Timing of juvenile winter-run passage at Knights Landing rotary screw trap vs. timing of juvenile winter-run combined loss at the SWP/CVP Delta facilities, 1995 – 2003. Year 1997-98 not shown due to low export rates. (Knights Landing catch shown in red squares, scale on right axis; SWP/CVP losses shown in black triangles, scale on left axis.)

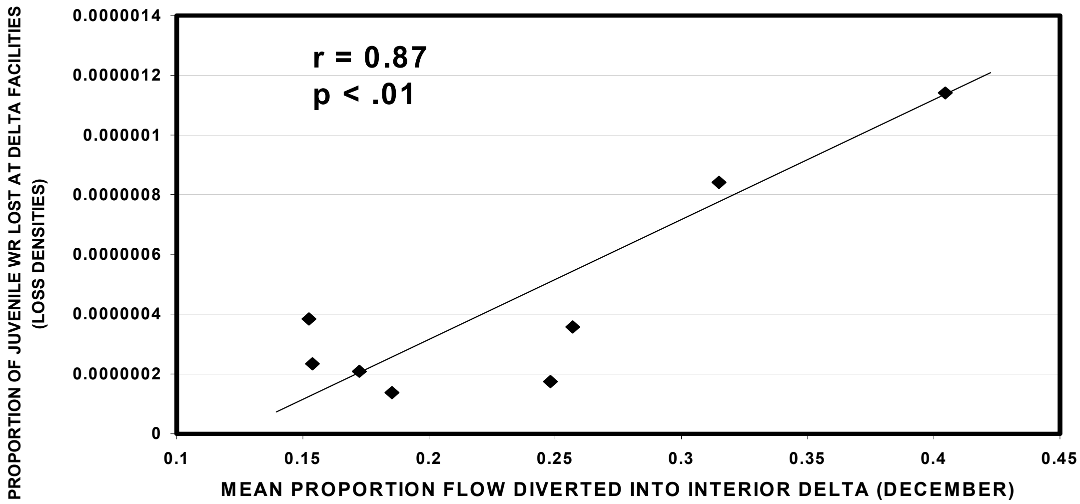

Figure 7. Relationship between the mean proportion of flow diverted into the interior Delta in December and the proportion of juvenile winter-run lost at the SWP/CVP Delta facilities (loss densities divided by the Juvenile Production Index), October 1 through May 31, 1995 – 2004.

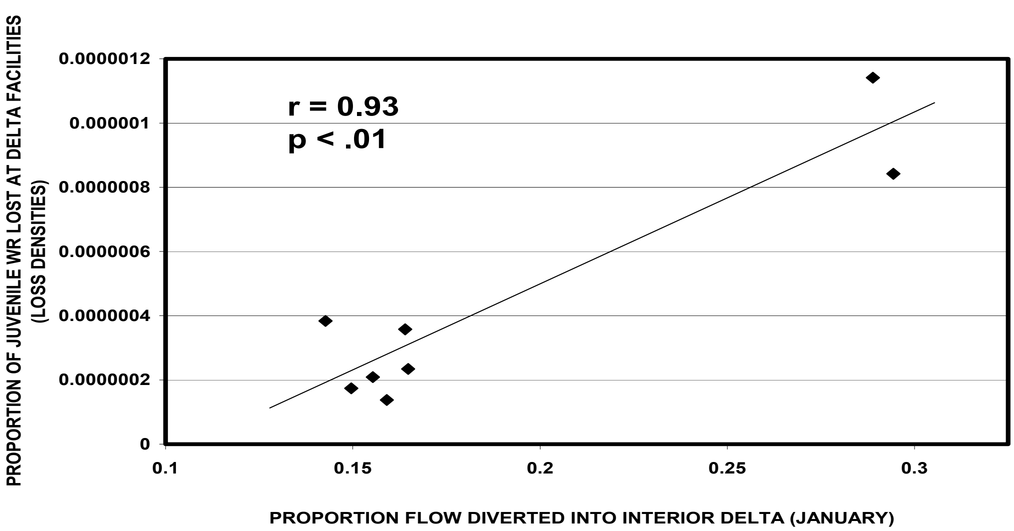

Figure 8. Relationship between the mean proportion of flow diverted into the interior Delta in January and the proportion of juvenile winter-run lost at the SWP/CVP Delta facilities (loss densities divided by the Juvenile Production Index), October 1 through May 31, 1996 – 2004.

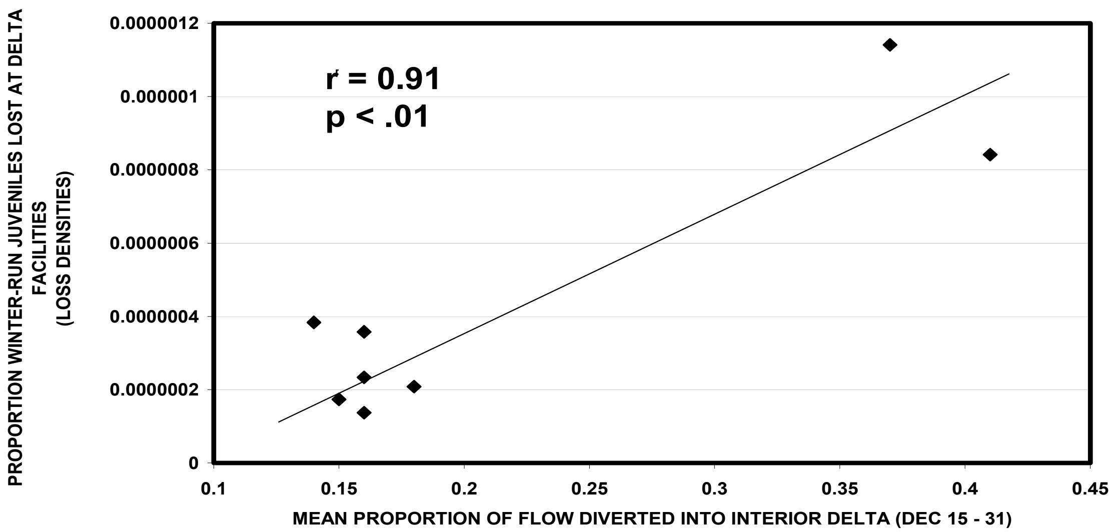

Figure 9. Relationship between the mean proportion of flow diverted into the interior Delta from December 15 - 31 and the proportion of juvenile winter-run lost at the SWP/CVP Delta facilities (loss densities), October 1 through May 31, 1995 – 2004.

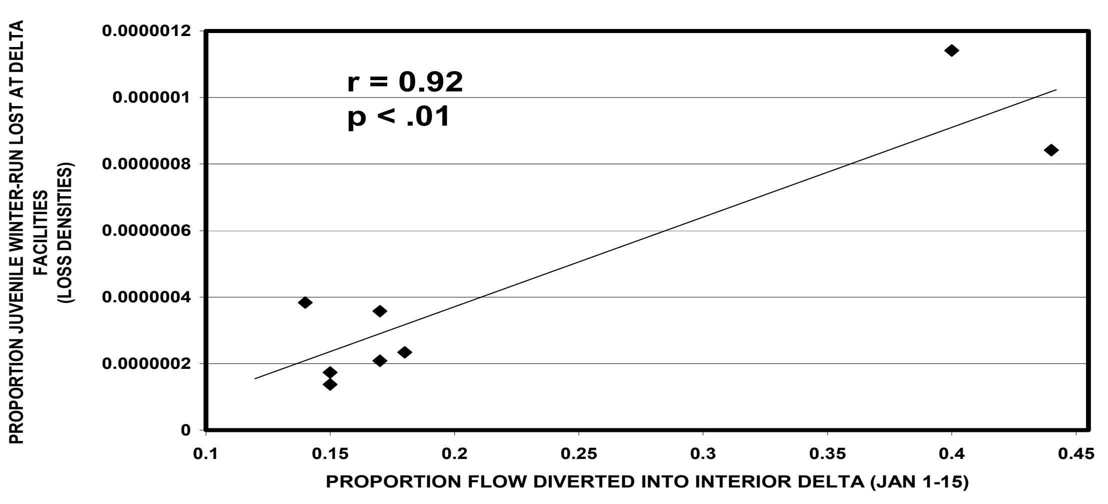

Figure 10. Relationship between the mean proportion of flow diverted into the interior Delta from January 1 - 15 and the proportion of juvenile winter-run lost at the SWP/CVP Delta facilities (loss densities), October 1 through May 31, 1996 – 2004.

Table 1.

Winter-run Broodyear	Winter-run Loss Density (Fish/TAF)	Winter-run JPI (RBDD RST)	Proportion Winter-run Lost at Delta facilities	Mean Proportion of Flow Diverted into Interior Delta			
				Dec.	Dec. 15-31	Jan.	Jan. 1-15
1995	0.65	1816984	0.0000003577	0.257001	0.16	0.163998	0.17
1996	0.18	469183	0.0000003836	0.152351	0.14	0.14267	0.14
1997	0.46	2205163	0.0000002086	0.172476	0.18	0.15536	0.17
1998	1.17	5000416	0.0000002340	0.153867	0.16	0.16478	0.18
1999	1.15	1366161	0.0000008418	0.314976	0.41	0.294347	0.44
2000	5.42	4750000[1]	0.0000011411	0.404534	0.37	0.288855	0.4
2001	0.81	5900000[1]	0.0000001373	0.185328	0.16	0.159099	0.15
2002	1.41	8114841	0.0000001738	0.248132	0.15	0.149555	0.15
2003	-	5571319	-	0.167013	0.16	0.158654	0.15

[1] Data for 2000-2001 and 2001-2002 JPI estimated based on relationship between winter-run adult escapement and JPI, 1995 – 2003.