Chapter 6 Factors That May Influence Abundance and Distribution of Winter-Run and Spring-Run Chinook Salmon and Coho Salmon

This chapter describes the factors that may affect winter-run and spring-run Chinook salmon and critical habitat in the action area. A significant factor affecting all listed salmonids in the Central Valley is the loss of spawning and rearing habitat upstream of the major dams. Major limiting factors that affect survival of Chinook and Coho salmon include, but are not limited to, high water temperatures, low flows and flow fluctuations, and fish passage. Other factors that may affect various runs of Chinook salmon include changes in the Delta ecosystem. These changes that are of concern in the Delta include: altered flow patterns, varying salinity, contaminants, limited food supplies, and predation. In addition, ocean conditions and harvest, hatchery operations and disease can affect winter- and spring-run Chinook salmon.

Factors That May Influence Abundance and Distribution of Winter-Run and Spring-Run Chinook Salmon

Water Temperature

California's Central Valley is located at the extreme southern limit of Chinook salmon distribution (Moyle 2002). In particular, low water temperatures (< 5°C) are rarely of concern in the Sacramento – San Joaquin system because of the low frequency of periods of extreme cold in areas used by salmonids (Cech and Myrick 2001). However, because of the occurrence of temperatures stressful to salmonids in parts of the system, warm water temperatures are a critical management issue. Water temperatures in the lower Sacramento River mainstem regularly exceed 20°C by late spring (City of Sacramento water treatment plant, unpublished data); and statistical studies of coded-wire-tagged juvenile Chinook show that high temperatures are an important factor in mortality (Baker et al. 1995 as cited in Cech and Myrick 2001). Water temperatures that are too low or too high can kill Chinook salmon directly by impairing metabolic function or indirectly by increasing the probability of disease, predation, or other secondary mortality factors (Boles et al. 1988). Chinook salmon temperature tolerances vary by life stage, and may also vary among stocks, but the latter is not well studied. The recommendations included in this Biological Assessment (BA) were developed by Boles et al. (1988) based on previous temperature studies of Chinook salmon and other salmonids. An overview of temperature effects on Chinook salmon follows.

Table 6-1 Recommended water temperatures for all life stages of Chinook salmon in Central Valley streams as presented in Boles et al. (1988).[a]

Life stage	Temperature (°F)
Migrating adult	<65
Holding adult	<60
Spawning	53 to 57.5[b]
Egg incubation	<55
Juvenile rearing	53 to 57.5[c]
Smoltification	<64[d]

[a] The lower thermal limit for most life stages was about 38°F.

[b] Can have high survival when spawned at up to 60°F, provided temperatures drop quickly to less than 55°F.

[c] Temperature range for maximum growth rate based on Brett (1952, as cited in Boles et al. 1988).

[d] Marine and Cech 2004

Note: °F = degrees Fahrenheit.

The temperature recommendation for migrating adults was based on Hallock et al. (1970, as cited in Boles et al. 1988) who found Chinook immigration into the San Joaquin River was impeded by temperatures of 70°F, but resumed when the temperature fell to 65°F. There was also a low dissolved oxygen correlation in timing.

The temperature recommendations for adult holding and spawning, and for egg incubation were based on laboratory studies of Sacramento River Chinook egg survival (Seymour 1956, as cited in Boles et al. 1988). Egg mortality was high at constant temperature of 60°F, but was considerably reduced at temperatures between 55°F and 57.5°F. However, sac-fry mortality remained very high (greater than 50 percent) at temperatures above 56°F, presumably due to “aberrations in sequential physiological development.” These were long-duration experiences that are not representative of river conditions. Table 6-2 shows the relationship between water temperature and mortality of Chinook eggs and pre-emergent fry compiled from a variety of studies. This is the relationship used for comparing egg mortality between scenarios. FWS (1998) conducted studies to determine Sacramento River winter run and fall run Chinook early life temperature tolerances. They found that higher alevin mortality can be expected for winter-run between 56°F and 58°F. Mortality at 56°F was low and similar to fall-run Chinook mortality at 50°F. Their relationships between egg and pre-emergent fry mortality and water temperature were about the same as that used in the mortality model in this BA (Table 6-2).

Table 6-2 Relationship between water temperature and mortality of Chinook salmon eggs and pre-emergent fry used in the Reclamation egg mortality model.

Water Temperature (EF)[a]	Egg Mortality[b]	Instantaneous Daily Mortality Rate (%)	Pre-Emergent Fry Mortality[b]	Instantaneous Daily Mortality Rate (%)
41-56	Thermal optimum	0	Thermal optimum	0
57	8% @ 24d	0.35	Thermal optimum	0
58	15% @ 22d	0.74	Thermal optimum	0
59	25% @ 20d	1.40	10% @ 14d	0.75
60	50% @ 12d	5.80	25% @ 14d	2.05
61	80% @ 15d	10.70	50% @ 14d	4.95
62	100% @12d	38.40	75% @ 14d	9.90
63	100% @11d	41.90	100% @ 14d	32.89
64	100% @ 7d	65.80	100% @10d[c]	46.05

[a] This mortality schedule was compiled from a variety of studies each using different levels of precision in temperature measurement, the lowest of which was whole degrees Fahrenheit (±0.5°F). Therefore, the level of precision for temperature inputs to this model is limited to whole degrees Fahrenheit.

[b] These mortality schedules were developed by the FWS and DFG for use in evaluation of Shasta Dam temperature control alternatives in June 1990 (Richardson et al. 1990)

[c] This value was estimated similarly to the preceding values but was not included in the biological assumptions for Shasta outflow temperature control FES (Reclamation, 1991b).

A number of factors affect water temperatures, including meteorological conditions, air-water surface area of the stream, water-bed area, temperatures of inflows into storage, temperature at release to river, river flows, tributary inflows, river diversions, and the amount of river shading. To help address Sacramento River water temperature concerns, the Bureau of Reclamation (Reclamation) installed a temperature control device on Shasta Dam in 1997 to allow cool water releases to meet winter-run Chinook salmon life history needs.

Yearly water temperatures downstream at Balls Ferry and Bend Bridge are shown in Figure 6-1 through Figure 6-4. Temperature compliance points (Bend Bridge and Balls Ferry) vary by water year type and date between April 15 and October 31 for winter-run spawning, incubation, and rearing. The objective is to meet a daily average temperature of 56°F for incubation and 60°F for rearing. After October 31, natural cooling generally provides suitable water temperatures for all Chinook life cycles.

Rearing juvenile Chinook salmon can tolerate warmer water than earlier life stages. Nimbus Hatchery fall-run were able to feed and grow at temperatures up to at least 66°F (Cech and Myrick 1999), but this is not reflected in the Boles et al. (1988) temperature recommendation for juveniles. The relationship between temperature and growth rate seen in Cech's and Myrick's (1999) data parallels that observed in northerly salmon runs. Northern salmon (ie. Washington and north) exhibit maximum growth at 66°F when fed satiation rations. Nimbus Chinook had maximum growth rates at 66°F and lower rates at 59°F and 52°F (Myrick and Cech 2001).

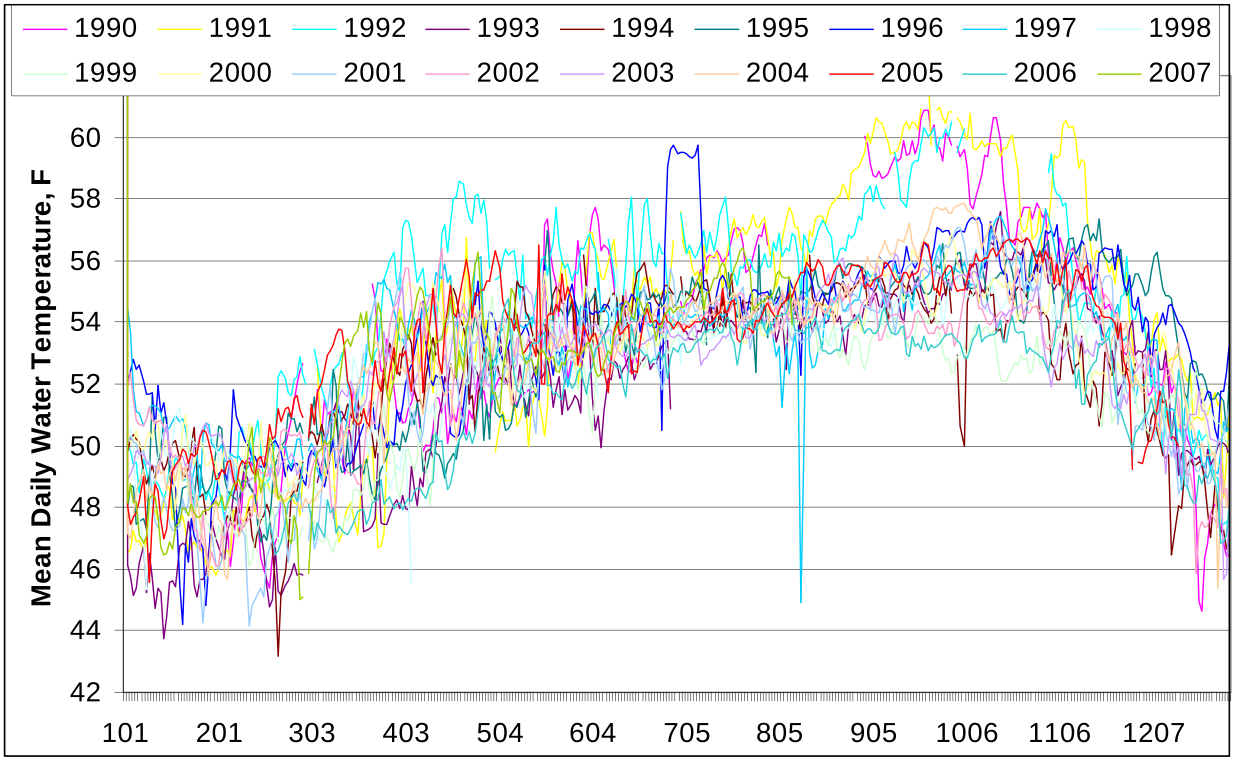

Figure 6-1 Sacramento River at Balls Ferry mean daily water temperatures, 1990 – 2007. Dates on the x-axis expressed like 101 = Jan 1, 303 = March 3, etc. (Source: cdec data)

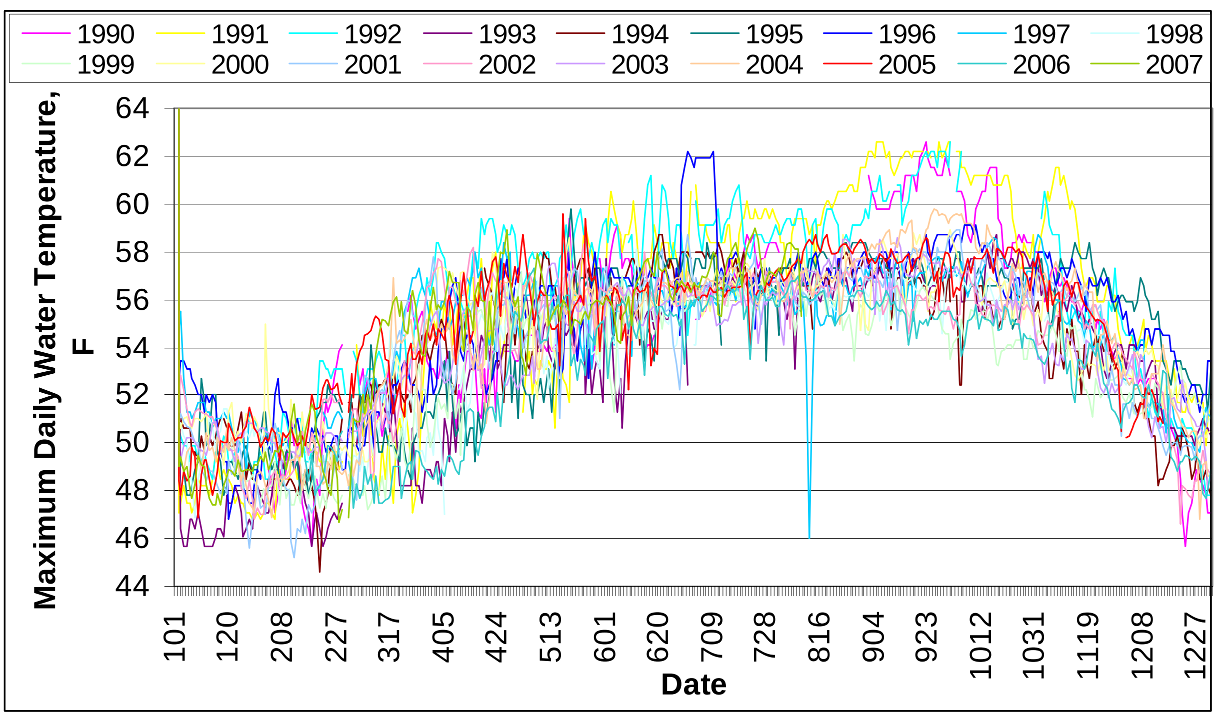

Figure 6-2 Sacramento River at Balls Ferry maximum daily water temperatures, 1990 – 2007. (Source: cdec data)

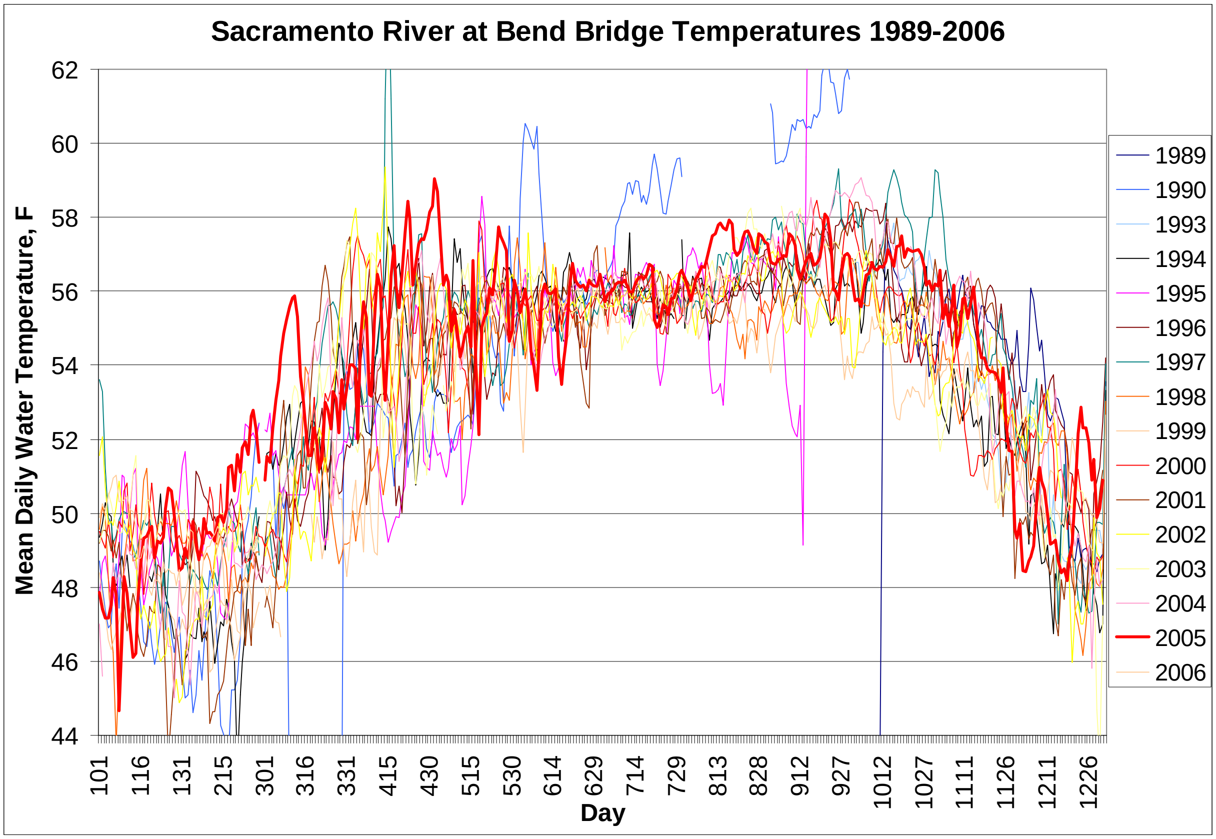

Figure 6-3 Sacramento River at Bend Bridge Water Temperatures 1989–2006. (Source: cdec data)

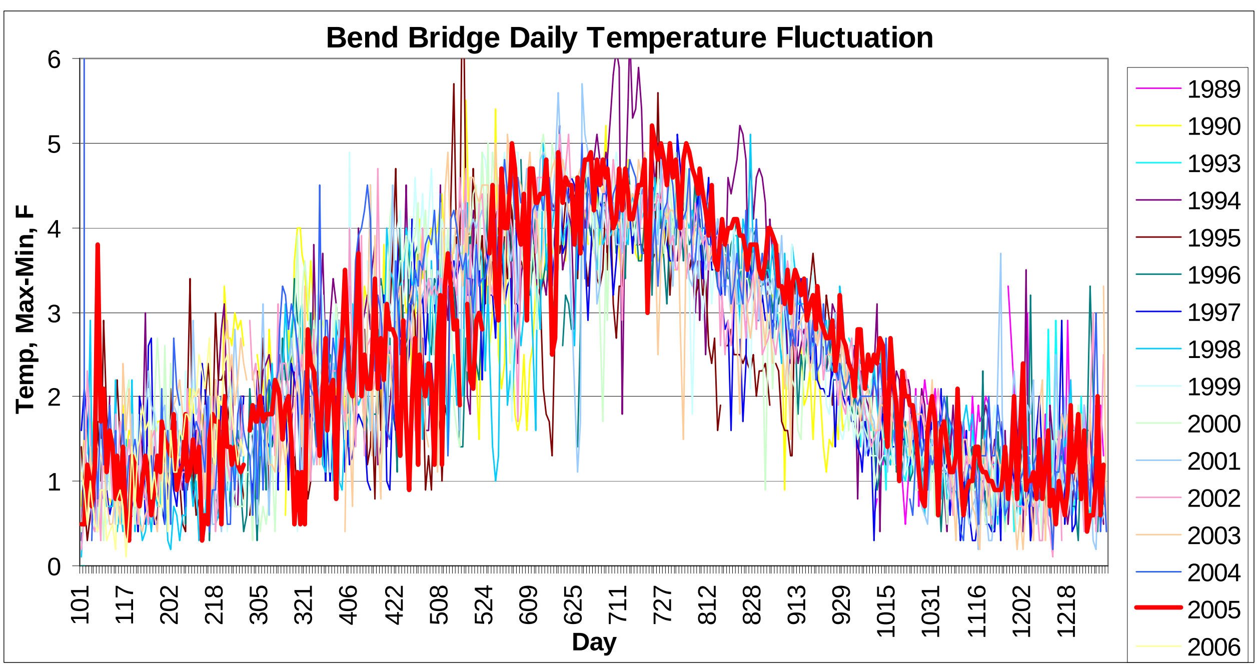

Figure 6-4 Bend Bridge Daily Temperature Fluctuation 1989–2006. Dates on the x-axis expressed like 101 = Jan 1, 303 = March 3, etc. (Source: cdec data)

The theoretical upper lethal temperature that Sacramento River Chinook salmon can tolerate has been reported as 78.5°F (Orsi 1971, as cited in Boles et al. 1988). However, this result must be interpreted with several things in mind.

First, the theoretical maximum corresponds to the most temperature-tolerant individuals. It is not a generality that can be applied to an entire stock. Second, it is only a 48-hour LT 50 (lethal time for 50 percent mortality). This means it is a temperature that can only be tolerated for a short period. It does not indicate a temperature at which a Chinook could feed and grow. Third, indirect mortality factors (for example, disease and predation) would likely lead to increases in total mortality at temperatures well below this theoretical laboratory-derived maximum. For example, Banks et al. (1971, as cited in Boles et al. 1988) found Chinook growth rates were not much higher at 65°F than at 60°F, but the fish had higher susceptibility to disease at 65°F. Subacute and sublethal temperature thresholds have been identified for Central Valley Chinook salmon by Marine and Cech (2004). Sublethal impairment of predator avoidance, smoltification, and disease begins in the range of about 64° to 68°F.

Myrick and Cech (2001) show that Chinook salmon that complete juvenile and smolt phases in the 50 to 62°F range are optimally prepared for saltwater survival. Marine and Cech (2004) identified a smoltification threshold of <64 F for Central Valley Chinook salmon.

Newman (2000) modeled the effect of temperature on coded wire-tagged (CWT) fall-run smolt survival from Fish and Wildlife Service (FWS) paired Delta release experiments. Newman's analysis indicated smolt survival would decrease by 40 percent as temperatures rose from 58 to 76°F. This result indicates that water temperature would be unlikely to affect spring-run smolt survival until it exceeded 58°F. On average, Delta temperatures have exceeded 58°F during April or May (Figure 6-5), when subyearling spring-run are emigrating. Newman's analysis is consistent with the lab findings of Marine and Cech 2004, where sublethal physiologic performance impairments were measured for CV Chinook salmon beginning at about 64° to 68°F. The level of resolution in Newman's data sets may not distinguish between 58-63°F, or there is an additional stressor in the Delta that further lowers temperature mortality relationship thresholds. Water project operations cannot effectively control water temperatures in the Delta.

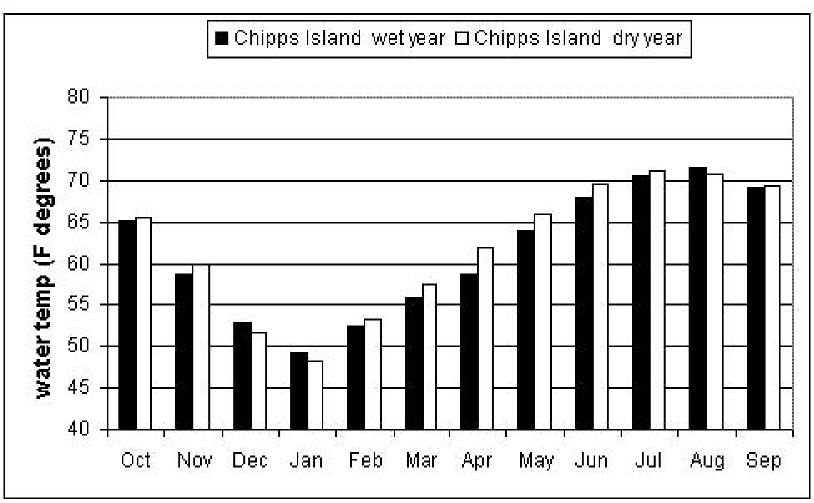

Figure 6-5 Monthly mean water temperatures for the Sacramento River at Chipps Island for water years 1975–1995.

It is also important to note that operation of CVP and SWP facilities cannot influence (1) the water temperatures on many of the tributaries to the Sacramento and San Joaquin Rivers or (2) those other factors that affect water temperatures that are unrelated to the appropriation of water for use by the CVP and SWP. Reclamation is not aware of any actions taken by others to address those other factors that are beyond the control of Reclamation and DWR that influence water temperatures.

Flow and Spawning

In-stream flow recommendations have been developed for Chinook salmon for most major Central Valley streams by AFRP and others. Many of the recommendations are intended to optimize habitat area for salmon spawning and egg incubation. High flows can affect redds by scouring the gravel away down to the depth of the eggs and washing the eggs out or by piling more gravel and fines on top of redds so that alevins are unable to emerge or are suffocated. Lowering flows to below the depth of the egg pockets following spawning can kill incubating eggs and alevins.

In-stream Flow Studies

Sacramento River

The FWS (2003) developed spawning flow-habitat relationships for winter, fall, and late-fall Chinook salmon and steelhead spawning habitat in the Sacramento River below Keswick Dam using the Physical Habitat Simulation (PHABSIM) component of the instream flow incremental methodology (IFIM). Relationships were developed by cross section and by stream segments but were not aggregated into river-wide flow-habitat relationships.

Winter-run Chinook salmon weighted usable spawning area (WUA) peaked at around 10,000 cubic feet per second (cfs) in the upstream reach above the Anderson-Cottonwood Irrigation District (ACID) Dam when the dam boards are in. With the boards out, the peak was around 4,000 to 5,000 cfs. In the next reach downstream (ACID Dam to Cow Creek) habitat peaked at 8,000-9,000 cfs. In the lower reach (Cow Creek to Battle Creek) spawning habitat peaked at around 4,000 cfs but had low variability in wetted usable spawning habitat area in the flow range analyzed (3,250-30,000 cfs). The highest density redd counts for winter-run occur in the upper and middle reach, although since the ACID fish ladder was built there has been a substantial increase in spawning upstream of the dam (Killam 2002). ACID puts the boards in during early April and they stay in until fall, so the flows dictated by water use would be compatible with maximization of habitat area during that time.

Fall-run and late-fall-run had different weighted usable spawning area values but the flow versus habitat relationship was about the same for the two runs. Upstream of the ACID Dam, spawning habitat peaked at 3,250 cfs with the dam boards out and at about 6,000 cfs with the boards in. Between ACID and Cow Creek spawning habitat peaked at around 4,000 cfs. Between Cow Creek and Battle Creek habitat peaked at about 3,500 cfs. The highest density redd counts for fall and late-fall-run occur in the middle reach.

Feather River

Chinook salmon spawning distribution in the Feather River has been studied in detail by Sommer et al. (2001a), although the data are not specific for spring-run. Approximately three-quarters of spawning occurs in the low flow channel, where the heaviest activity is concentrated in the upper three miles. By contrast, spawning activity below Thermalito Afterbay Outlet is fairly evenly distributed. The proportion of salmon spawning in the low flow channel has increased significantly since the completion of the Oroville Complex and Feather River Hatchery (FRH). The significant shift in the distribution of salmon spawning in the Feather River to the upper reach of the low flow channel is perhaps one of the major factors affecting any in-channel production of spring-run as a result of redd superimposition mortality. Since they spawn later in the fall, fall-run fish may destroy a significant proportion of the redds of earlier spawning spring-run.

The major factors that had a statistically significant effect on spawning location were flow distribution and escapement (Sommer et al. 2001a). Significantly more salmon spawned in the low-flow channel when a higher proportion of flow originated from that reach. Attraction flows are known to change the spawning distribution of salmon in other rivers. Higher escapement levels were also weakly associated with increased spawning below Thermalito Afterbay Outlet. Since salmon are territorial, increasing densities of salmon would be expected to force more fish to spawn downstream. As will be discussed in further detail in the “Hatchery” section of this chapter, Feather River Fish Hatchery (FRF) operations may also affect salmon spawning location.

In 2002, DWR conducted an IFIM habitat analysis for the lower Feather River (DWR 2004). This analysis drew on the earlier IFIM work of Sommer et al. (2001), but added an additional 24 transects, and included additional spawning observations. The river segments above the low-flow channel (LFC) and below the high-flow channel (HFC) were modeled separately due to their distinct channel morphology and flow regime. The weighted usable area (WUA) for Chinook salmon spawning in the LFC increased from 150 cfs to a peak at 800 cfs. Beyond the peak, the WUA index falls sharply again. Although the WUA curve peaks at 800 cfs, the current base flow in the LFC (600 cfs) represents 90 percent of the highest habitat index value. In the HFC, the WUA rises from the lowest modeled flow (500 cfs) and peaks near 1,700 cfs, above which it again declines out to 7,000 cfs.

Redd Scouring

High flows, such as those released from dams to draw down storage for flood control during heavy runoff periods, have the potential to scour salmon and steelhead redds and injure eggs or sac-fry in the gravel. These same flows are important for maintaining rearing habitat and high-quality spawning gravel. River-specific geomorphic studies evaluated the bedload mobilization flow for the affected rivers. The future probability of occurrence of flow releases exceeding the bedload mobilization flow is based on the historic hydrograph since the respective dam was constructed. This is because scouring flows are generally a result of flood control operations during high runoff periods, which will not likely change in the near future.

Clear Creek

Sampling was conducted in Clear Creek at the U.S. Geological Survey (USGS) Clear Creek near Igo gauge during high flows in January and February 1998 to estimate a flow threshold that initiated coarse sediment transport (McBain & Trush and Matthews 1999). Sampling bedload movement during a 2,600 cfs flow showed that mainly sand was being transported. During a 3,200 cfs flow, medium gravels were being transported. Particles slightly greater than 32 millimeters (mm) were being transported by the 3,200 cfs (D_{84} = 7.5 mm) flow while no particles larger than 11 mm were sampled during the 2,600 cfs flow (D_{84} = 1.8 mm). Their initial estimate for a coarse sediment transport initiation threshold is in the 3,000 to 4,000 cfs range. Marked rock experiments at Reading Bar, the first alluvial reach downstream of the Clear Creek canyon, suggest that large gravels and cobbles (the D_{84}) are not significantly mobilized by a 2,900 cfs flow.

The majority of post-Whiskeytown Dam floods are produced from tributaries downstream of Whiskeytown Dam, but floods larger than about 3,000 cfs are caused by uncontrolled spillway releases from Whiskeytown Dam, as happened in WY 1983 (19,200 cfs, the largest post-regulation flood), 1997 (15,900 cfs), and 1998 (12,900 cfs) floods. These flows are the result of heavy runoff from the upper Clear Creek watershed and are not affected by Reclamation water release operations. Reclamation does not make releases into Clear Creek that exceed the bedload mobilization point unless recommended by fishery agencies for the benefit of fish. A probability of exceedance plot for Whiskeytown Dam is shown in Figure 6-6. Instantaneous flows of 3,000 cfs occur on average about once every 2 years and flows of 4,000 cfs occur about once every 3 years (Figure 6-7). One-day average flows of 3,000 cfs occur about once every 5 years.

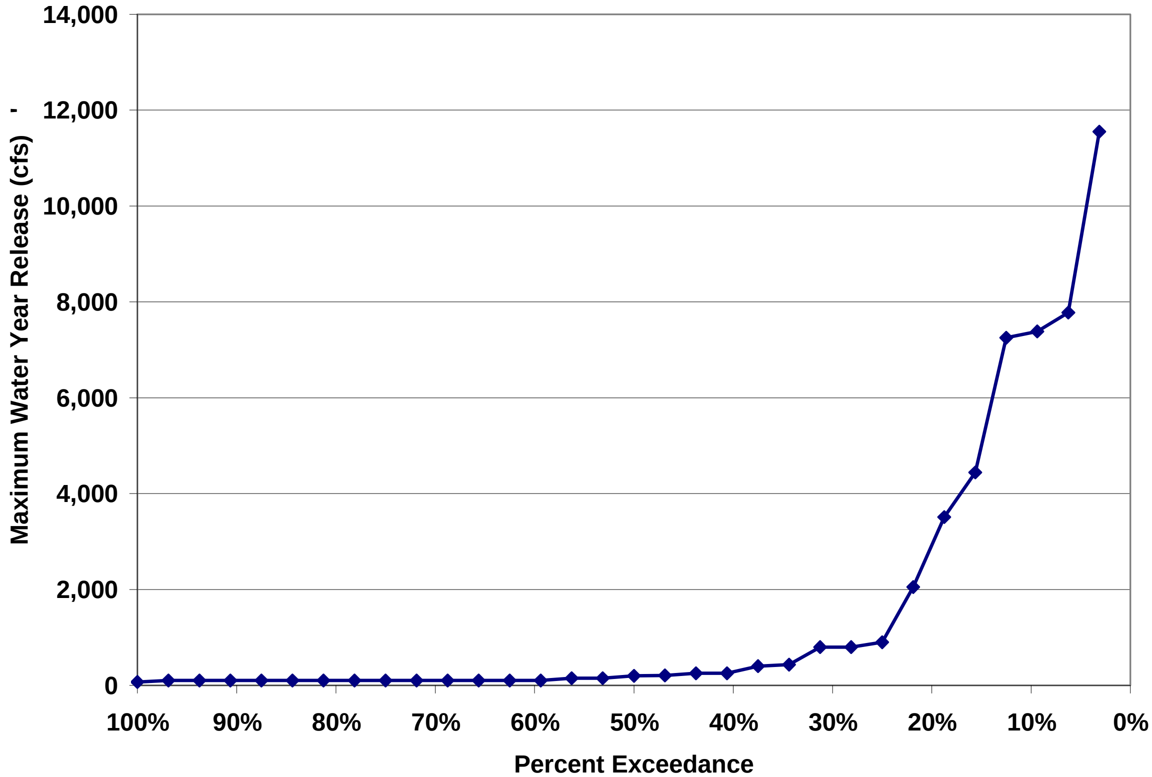

Figure 6-6 Yearly probability of exceedance for releases from Whiskeytown Dam on Clear Creek based on historical dam operations records.

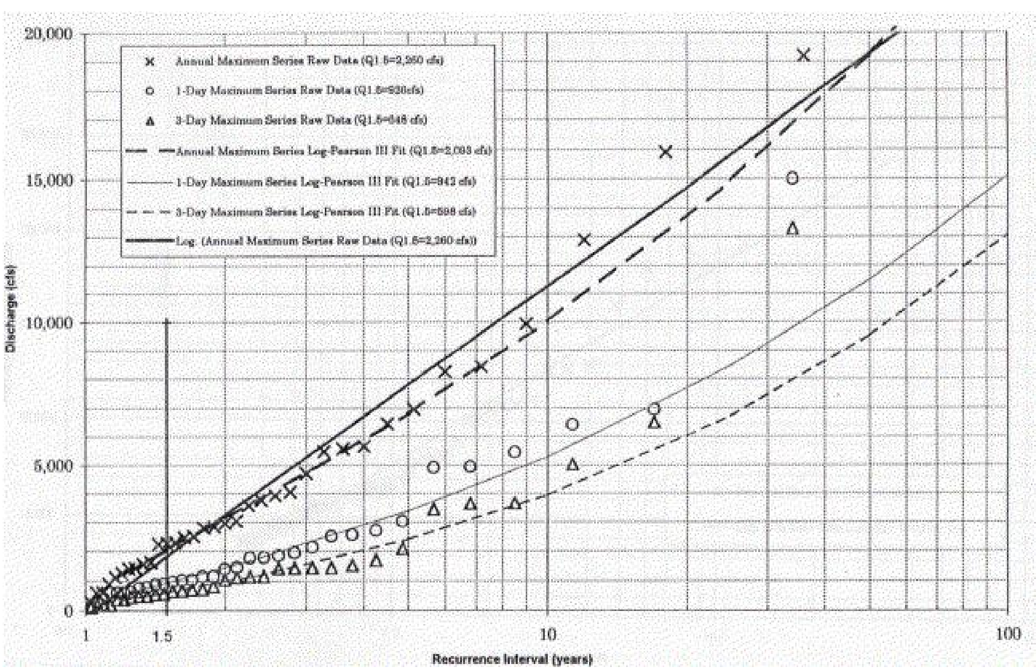

Figure 6-7 Clear Creek near Igo (Station 11-372000) flood frequency analysis of annual maximum, 1-day average, and 3-day average flood series for post-dam (1964–97) data.

Sacramento River

Buer (1980) conducted bedload movement experiments by burying a 50-gallon drum in a riffle below Redding. Gravel up to 3 inches in diameter began to accumulate in the barrel at about 25,000 cfs, indicating initiation of surface transport. Painted rocks moved 200 to 300 feet down the riffle at 25,000 cfs. Flows of 40,000 to 50,000 cfs would likely be required to move enough bedload to scour redds (Koll Buer, pers. comm. 2003.). The coarse riffles (small boulders and large cobbles), are probably armored from release of sediment-free flows from Shasta Dam. These armored riffles appear not to change and thus probably remain immobile even at flows exceeding 100,000 cfs (CALFED 2000). A bed mobility model was applied to four of the Army Corps of Engineers Comprehensive Study cross sections as another bed mobility estimate to compare to the empirical bed mobility observations. The bed mobility model suggests bed mobility thresholds between 15,000 and 25,000 cfs between River Miles 169 and 187, although the model is not considered appropriate for the Sacramento River (Calfed 2000).

Probability of occurrence for a release exceeding 25,000 cfs at Keswick Dam is approximately 50 percent each year and flows in the 40,000 to 50,000 cfs range occur in about 30 to 40 percent of years (Figure 6-8). Some redds could potentially be scoured in 10 – 25% of years when flows over 50,000 cfs occur while eggs are in the gravel. This would most likely occur during fall- and late-fall-run incubation. The significance to the population is difficult to determine, but based on the amount of scouring that occurs in unregulated rivers with large salmon runs compared to regulated rivers such as those in the Central Valley, long-term negative population effects from redd scouring are probably not very significant. On the Sacramento River, the 2-year return interval flood has been reduced from 119,000 cfs to 79,000 cfs since construction of Shasta Dam (as measured at Red Bluff, Figure 6-9).

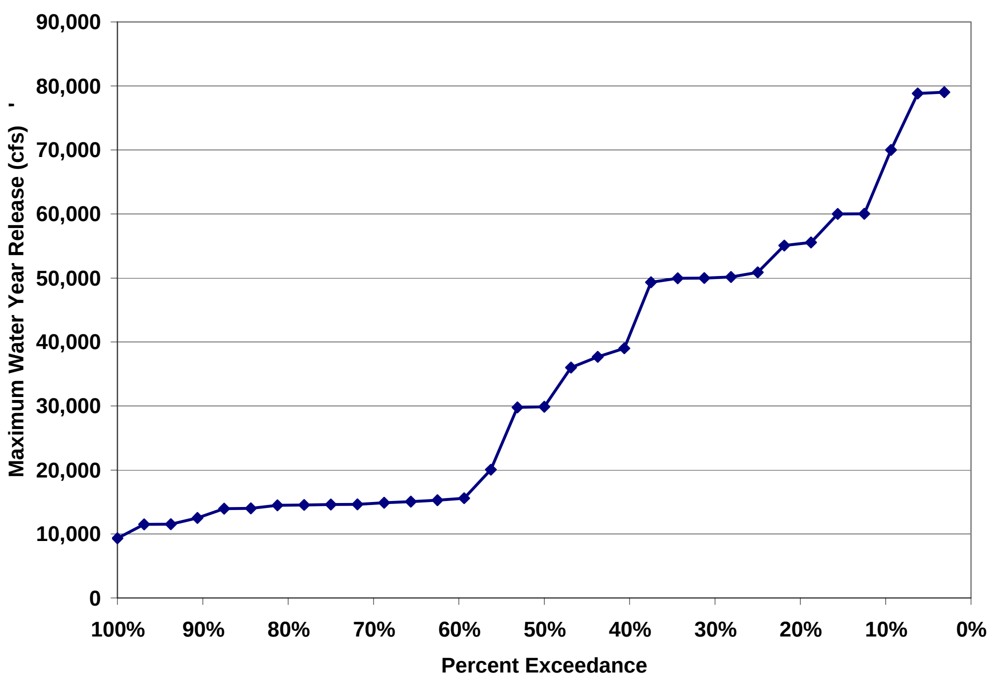

Figure 6-8 Yearly probability of exceedance for releases from Keswick Dam on the Sacramento River from historical dam operations records.

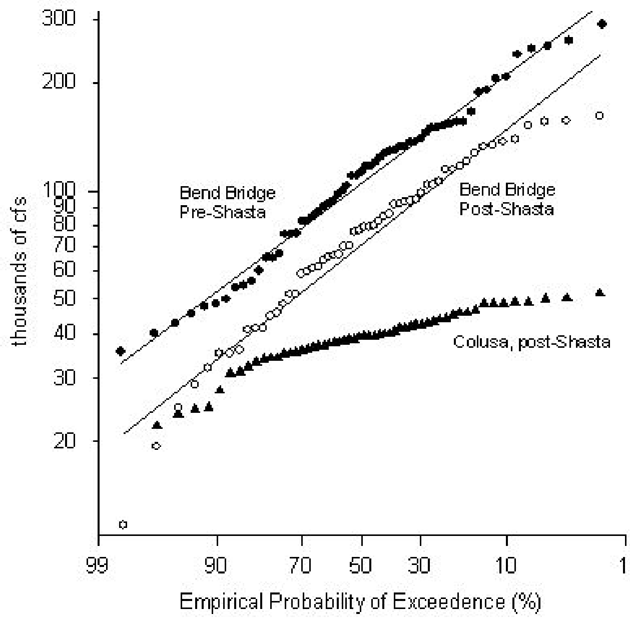

Figure 6-9 Empirical flood frequency plots for the Sacramento River at Red Bluff (Bend Bridge gauge) for pre- and post-Shasta periods, and downstream at Colusa for the post-Shasta period.

The reduced peak flows at Colusa reflect diversions into the Butte Basin between the two gauges. Data from U.S. Geological Survey internet site (www.usgs.gov), Red Bluff (Bend Bridge) and Colusa gauges. Chart from Calfed (2000).

American River

Ayres Associates (2001) used a two-dimensional model of the lower American River constructed on 2-foot topography to determine at what flows spawning beds would be mobilized. Their modeling results indicated that the spawning bed materials are moving for flows of 50,000 cfs or greater, although some movement may occur for flows between 30,000 and 50,000 cfs. Shear stress conditions tend to be highest upstream of Goethe Park, where the majority of salmon and steelhead spawning occurs.

Flood frequency analysis for the American River at Fair Oaks gauge shows that, on average, flows will exceed 30,000 cfs about once every 4 years and exceed 50,000 cfs about once every 5 years (Figure 6-10). Fair Oaks gauge flows result almost entirely from Folsom and Nimbus releases.

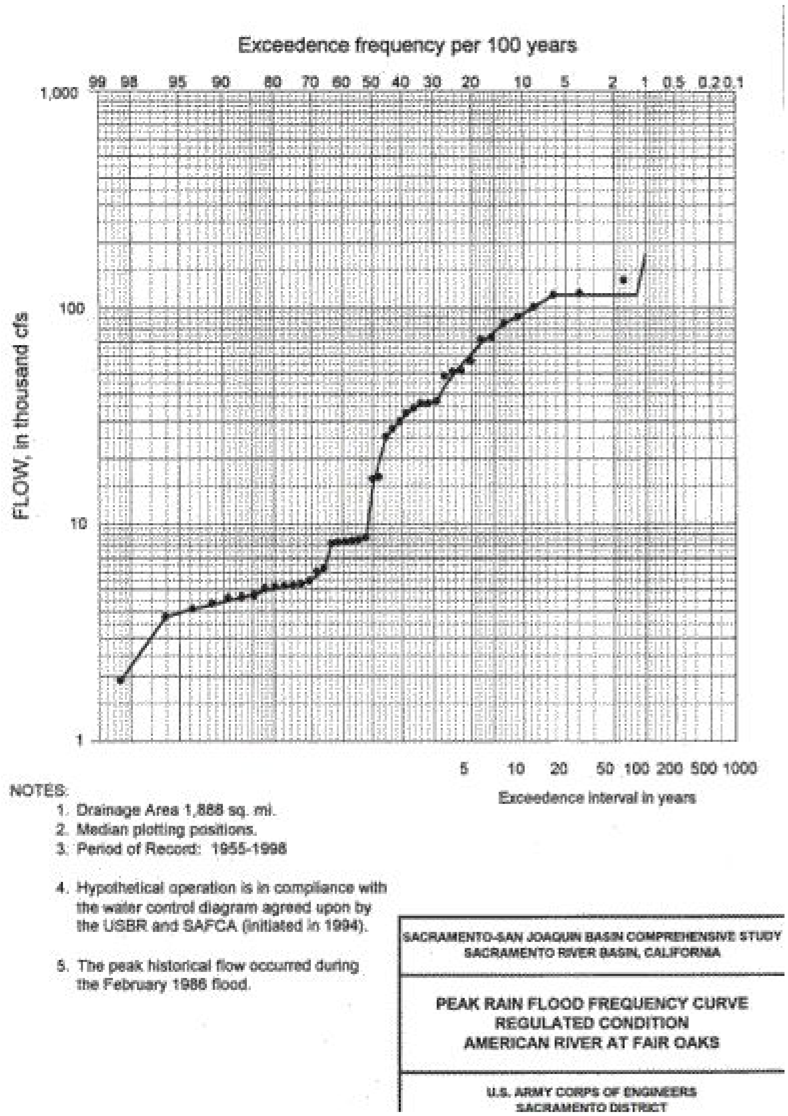

Figure 6-10 Flood frequency analysis for the American River at Fair Oaks Gauge (U.S. Army Corps of Engineers 1999).

Stanislaus River

Kondolf et al. (2001) estimated bedload mobilization flows in the Stanislaus River to be around 5,000 to 8,000 cfs to mobilize the D_{50} (median particle size) of the channel bed material. Flows necessary to mobilize the bed increased downstream from a minimal 280 cfs near Goodwin Dam to about 5,800 cfs at Oakdale Recreation Area.

Before construction of New Melones Dam, a bed mobilizing flow of 5,000 to 8,000 cfs was equivalent to a 1.5 to 1.8 year return interval flow. On the post dam curve, 5000 cfs is approximately a 5-year return interval flow, and 8,000 cfs exceeds all flows within the 21-year study period, 1979–99 (max flow = 7,350 cfs on January 3, 1997). The probability of occurrence for a daily average flow exceeding 5,330 cfs (the pre-dam bankfull discharge) is 0.01 per year. Figure 6-11 shows the yearly exceedance probability for Goodwin Dam releases.

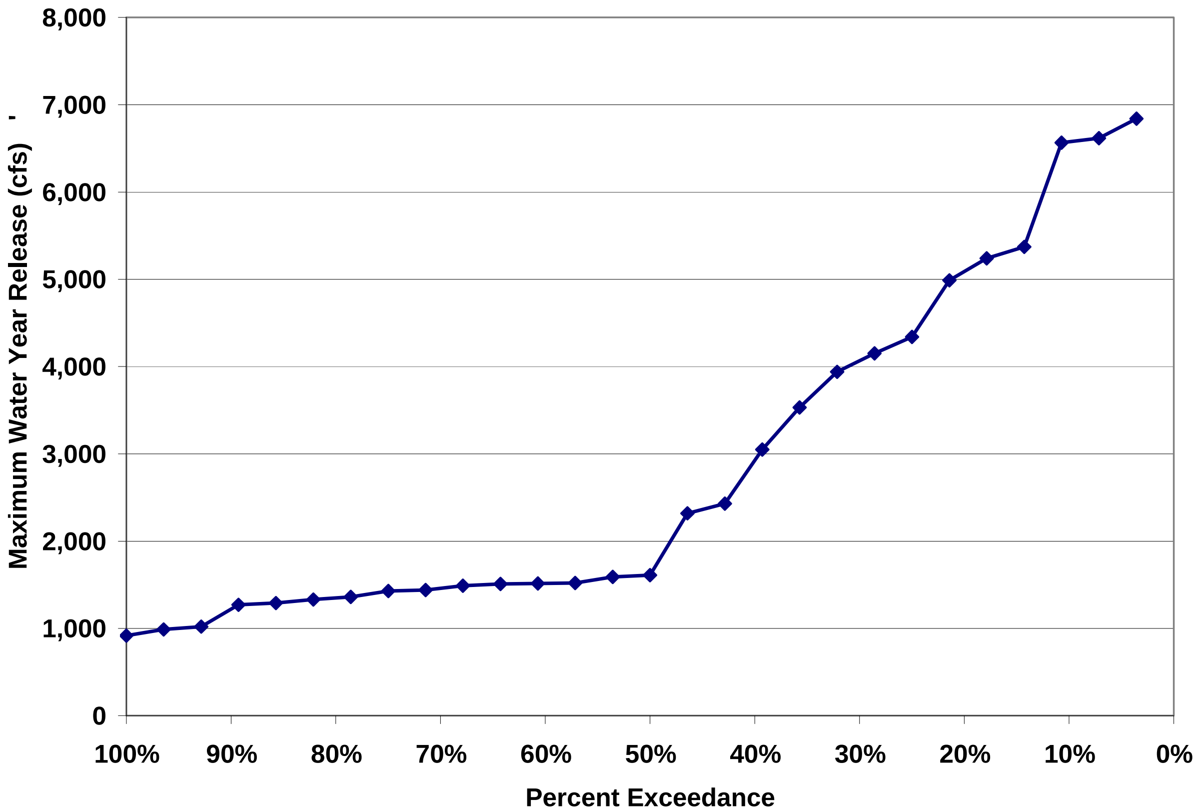

Figure 6-11 Exceedance probability for yearly Goodwin Dam releases from historical dam operations records.

Flow Fluctuations/Stranding

Flow fluctuations have the potential to dewater salmon and/or steelhead redds or isolate and strand juvenile salmonids below project reservoirs. Depending on the frequency and timing of flow fluctuations within and between years, salmon and steelhead populations can be affected.

Clear Creek

Table 6-3 shows the stage discharge relationship in Clear Creek at Igo. Using the 5-inch redd depth as the threshold for redd dewatering, a 100-cfs flow drop in the 100 to 300 cfs range could start to dewater the shallowest redds. A flow drop of 150 cfs in the 300 to 800 cfs range could start to dewater redds, and a flow drop of 300 cfs between 800 and 1,800 cfs could start to dewater redds. Flows over 500 cfs in Clear Creek are the result of uncontrolled runoff or pulse flows prescribed through collaboration with fishery agencies for the benefit of fish and habitat.

Table 6-3 Stage discharge relationship for the Clear Creek at Igo USGS gauge, Station 11372000.

Stage, inches	Discharge, cfs
33.12	101
38.52	200
42.72	301
46.2	400
49.32	501
52.2	602
54.72	702
57	803
59.16	903
61.08	1000

Sacramento River

Based on the Sacramento River at Bend Bridge gauge, drops in flow of approximately 800 cfs in the low end of the flow range up to about 20,000 cfs have the potential to start drying the shallowest redds 5 inches deep (Table 6-4). Areas of the river away from stream gauges where there is not as much confinement and more spawning activity probably experience less change in stage for a given flow change but the data were not available to evaluate other locations.

Table 6-4 Stage discharge relationship in the Sacramento River at Bend Bridge, gauge 11377100.

Stage, inches	Discharge, cfs
8	4190
10	4500
12	5020
15	5490
18	5990
21	6490
24	6990
27	7490
31	7990
34	8500
38	9000
41	9510
45	10000
48	10500

Stage, inches	Discharge, cfs
52	11000
55	11500
59	12000
62	12500
65	13000
68	13500
71	14000
74	14500
78	15000
81	15500
84	16000
87	16500
90	17000
92	17500
95	18000
98	18500
101	19000
103	19500
106	20000
110	21000
114	22000
118	23000
122	24000
126	25000
129	26000
133	27000
137	28000
140	29000
144	30000

American River

Snider et al. (2001) evaluated flow fluctuations relative to stranding in the American River and made the following recommendations for operations of the Folsom project. Reclamation implements the recommendations where feasible after consultation with the American River Operations Group. This has reduced instances of stranding.

- Ramping rates should not exceed 100 cfs per hour when flows are less than 4,000 cfs;
- Flow increases to 4,000 cfs or more should be avoided during critical periods (January through July for young of the year salmon and steelhead and October through March for yearling steelhead and non-natal rearing winter-run Chinook salmon) unless they can be maintained throughout the entire period; and
- Flow fluctuations that decrease flow below 2,500 cfs during critical spawning periods should be precluded: October through December for Chinook salmon and December through May for steelhead. They define flow fluctuations as unnatural rapid changes in stream flow or stage over short periods resulting from operational activities of dams and diversions.
- Reclamation implements the recommendations where feasible after consultation with the American River Operations Group. This has reduced instances of stranding.

The shallowest salmon redds observed prior to any flow changes were under 5 inches of water referenced to the original bed surface (Hannon, field observations 2002) and the shallowest steelhead redds observed were over 7-inches deep (Hannon and Healey 2002). Steelhead could likely spawn in water as shallow as Chinook, so this analysis is based on water depth reductions of 5 inches that could drop the water level to even with the top of the shallowest redds. Evenson (2001) measured Chinook egg pocket depth in the Trinity River. The shallowest egg depth found was 2.2 inches under the gravel referenced to the original bed surface and the mean depth to the top of the egg pocket was 9 inches. Ninety-three percent of the top of egg pockets were buried at least 5 inches under the gravel. Five-inch-deep eggs would not become dewatered until water drops at least 10 inches, but fry emergence could be prevented if no water is over the surface of the redd. Based on cross sections measured in 1998 by the FWS, flow changes of 100 cfs generally change the water depth by about 1 inch in a flow range of 1,000 to 3,000 cfs and by about 0.5 inch in a flow range from about 3,000 to 11,000 cfs. Therefore, when flows are 3,000 cfs or lower, flow drops of 500 cfs or more can begin to dewater redds. When flow is over 4,000 cfs, flow drops of 1,000 cfs or more can begin to dewater redds. Figure 6-12 shows the number of times by month that flow was raised above 4,000 cfs and then dropped back below 4,000 over a 30 year period. The annually maximum daily Nimbus release exceedance is shown in Figure 6-13.

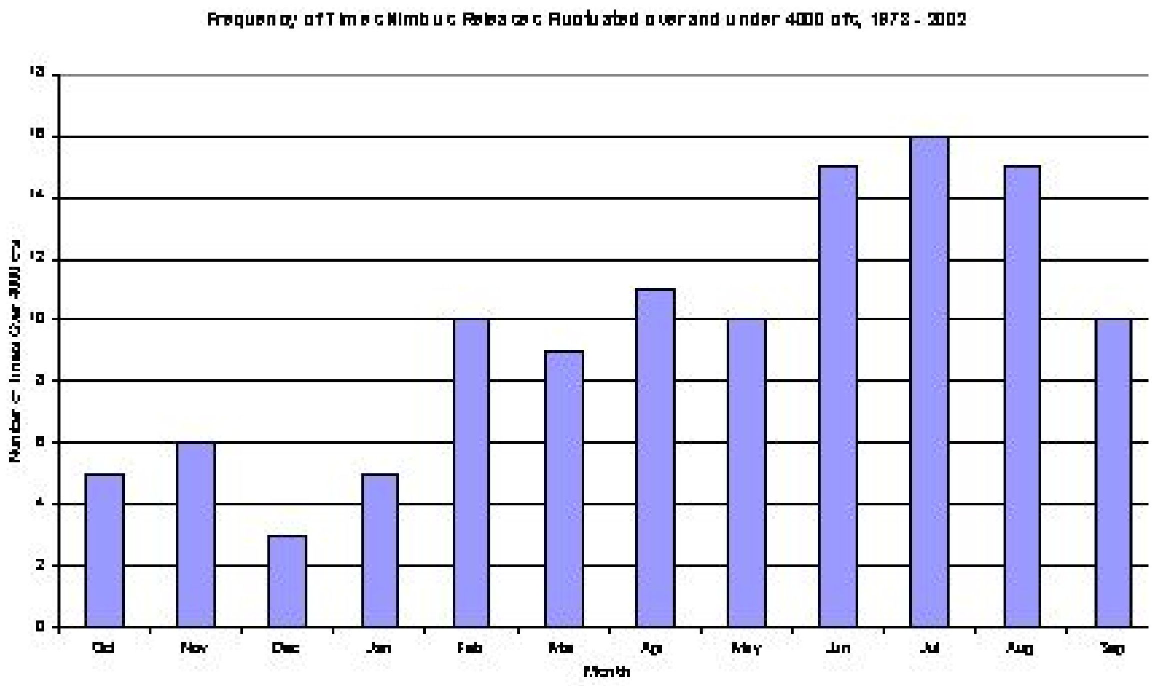

Figure 6-12 Frequency of times Nimbus releases fluctuated over and under 4000 cfs, 1972-2002.

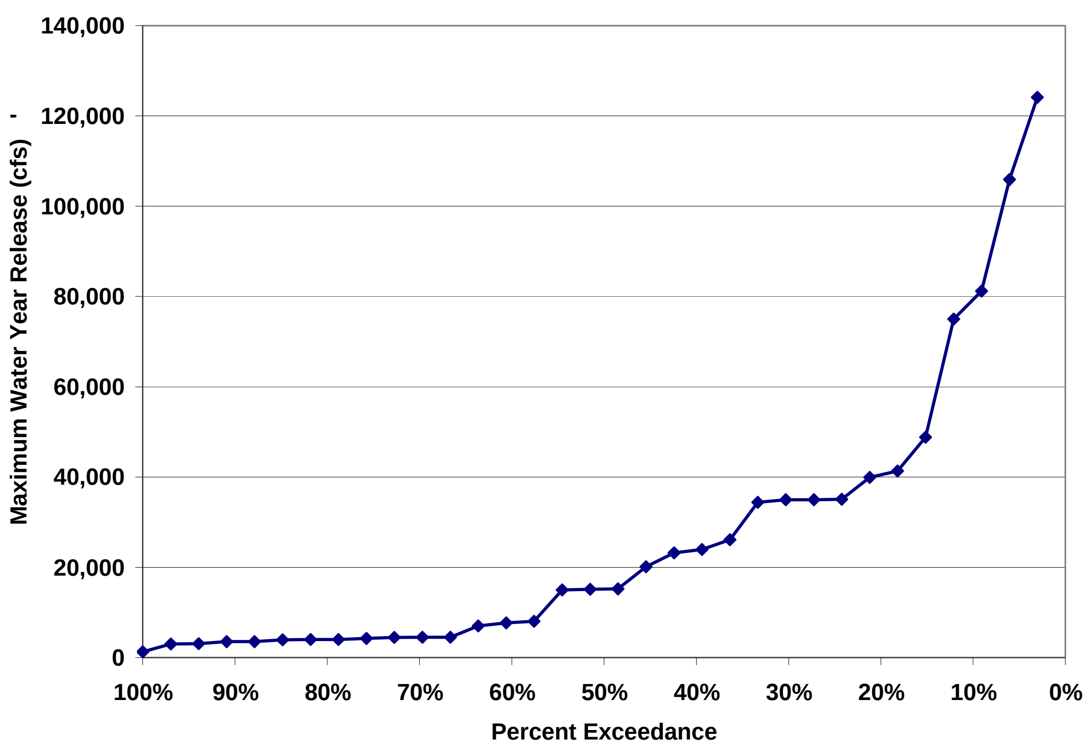

Figure 6-13 Annual Maximum Daily Nimbus Release Exceedance.

Stanislaus River

Based on the Stanislaus River at Ripon gauge, reductions in flow of approximately 50 cfs in the flow range of 100 to 300 cfs have the potential to start to dewater the shallowest redds 5-inches deep (Table 6-5). Although the Ripon gauge is downstream of spawning areas, the channel morphology at the gauging station is similar to that through much of the spawning area so the stage discharge relationship should be similar. Reductions in flow of 100 cfs in the flow range of about 150 to 1,000 cfs will cause a 5-inch drop in water surface elevation. Reductions in flow of about 175 cfs in the flow range of 1,000 to 2000 cfs will cause about a 5-inch drop in water level.

Table 6-5 Stage discharge relationship in the Stanislaus River at Ripon, gauge 11303000.

Stage, inches - 440	Discharge, cfs
3	100
5	125
8	150
10	174
13	200
17	251
21	300
24	350
27	400
32	501
37	601
43	700
49	800
54	900
58	1000
67	1200
76	1400
84	1600
92	1800
100	2000
120	2500
139	3000
175	4000
199	5000
215	6000

Flow and Its Importance to Sub-adult Chinook Salmon

Streamflow is important to subadult Chinook salmon (Healey 1991). Larger salmon populations tend to occur in larger river systems, suggesting a direct effect of discharge on the amount of suitable habitat area. River flows directly affect through-gravel percolation rates, which are very important to egg survival, and may help disperse swim-up fry to suitable rearing habitats.

Streamflows indirectly affect other environmental conditions, which in turn affect Chinook survival. Flow rates can affect instream temperatures downstream of reservoirs. For example, releases from Shasta Dam affects temperature for up to 200 miles downstream but can only effectively "control" temperature in the top 40 or so miles. In natural stream systems, flow is correlated with turbidity. Turbidity may be important in juvenile life stages. Juvenile salmon losses to predators may be reduced by at least 45 percent in turbid-water stream reaches relative to clear-water reaches (Gregory and Levings 1998). Turbid water may also stimulate faster migration rates, which reduces the time young fish are exposed to freshwater mortality risks. The relative survival benefits of longer versus shorter freshwater residence time in juvenile Chinook has not been determined for Central Valley stocks. Pink salmon, the most abundant of the salmon species, emigrate to the ocean immediately upon emergence from the gravel and presumably derive survival benefits from this trait, although pink salmon are generally less abundant in watersheds requiring freshwater migrations over longer distances. High outflows and sediment loads can increase egg mortality through scouring and suffocation (Healey 1991).

In the upper Sacramento River Basin, problems of flow and temperature are closely associated during the summer and fall. Low flows and limited cold water supplies make spring-run habitat in tributaries like Clear Creek, Cottonwood Creek, and Antelope Creek marginally usable, or even unsuitable. Problems with low flow and high temperature may also occur in current spring-run habitat like Butte and Big Chico Creeks. The likelihood that survival will be reduced in low-flow years could be greater in unregulated tributaries than in regulated tributaries where stored water can sustain releases longer through dry periods.

Fish Passage

As with steelhead and other salmon races, migration impediments and barriers are a problem for winter-run and spring-run Chinook (Table 4-5) as well as other salmonids. Spring-run Chinook salmon formerly spawned in the upper reaches of at least 22 major rivers and tributaries in the Central Valley. However, the construction of dams has blocked access to historical upstream spring-run Chinook salmon habitat in Central Valley rivers and streams.

The presence of dams also has resulted in the probable hybridization of some spring- and fall-run Chinook salmon stocks. Historically, stocks occupying the same stream were separated in space and time because adult spring-run Chinook salmon migrated earlier in the year, and to spawning grounds farther upstream compared to fall-run Chinook salmon. Presently, both spring- and fall-run Chinook salmon spawn together downstream of dams. Hybridization has the potential to occur because the spawning periods for spring- and fall-run Chinook salmon overlap and the fish intermingle while they spawn. In addition, migration may be slowed or prevented in smaller tributary streams by numerous smaller agricultural diversion facilities.

ACID Diversion Dam

The ACID diversion dam created fish passage problems that required a substantial reduction in Keswick Reservoir releases to adjust the dam flashboards, which resulted in dewatered redds, stranded juveniles, and higher water temperatures. Reclamation assisted in the redesign and renovation of the flashboards and related ACID facilities in the 1990s to reduce the risks of dewatering redds. New fish ladders and fish screens were installed around the diversion and were operated starting in the summer 2001 diversion period. During the spawning runs in 2001 and 2002, spawning upstream of the diversion dam substantially increased, which was attributable to the access provided by the fish ladders (Table 5-5 winter-run redd chart).

Red Bluff Diversion Dam

Problems in salmonid passage at Red Bluff Diversion Dam (RBDD) provide a well-documented example of a diversion facility impairing salmon migration (Vogel and Smith 1984; Hallock 1989; FWS 1987, 1989, 1990a; Vogel et al. 1988, all as cited in DFG 1998). The implementation of gates-out operations and construction of the rotary-drum screen facility have substantially improved fish passage conditions at RBDD (see discussion of RBDD in Chapter 4). All spring-run juvenile emigrants pass RBDD during the gates-out period based on historical average run timing at RBDD. However, only about 30 percent of adult spring-run immigrants that attempt to pass Red Bluff encounter gates-out conditions (FWS 1998, as cited in DFG 1998). The current gates-down operation potentially delays 15 percent of the adult winter-run, and 35 percent of the juveniles going downstream in July, August, and September encounter the lowered gates (NOAA Fisheries 2003). Based on winter-run population increases that have occurred since the current gate operations were initiated, the population seems capable of increasing under current operations.

Aerial redd surveys conducted for winter-run and spring-run spawning since 1987 by DFG show that since the gates-out period was moved to September 15 to May 15 in 1993, few winter-run have spawned below RBDD (Table 6-6). During 1994 and 1995, higher percentages of spring-run spawned below RBDD than in other years. The majority of spring-run production in recent years has continued to occur in Sacramento River tributaries downstream of RBDD (Mill Creek, Deer Creek, Big Chico Creek, Butte Creek, and Feather River) despite the partial elimination of migration delays. Not counting Feather River spring-run, which are primarily considered to be of hatchery origin, 92 percent of spring-run since 1992 occurred in the tributaries downstream of RBDD. The proportion of spring-run using these tributaries was not affected by migratory delays at RBDD. The 8 percent of spring-run in the Sacramento River and tributaries upstream of RBDD were potentially affected by migratory delays at RBDD.

Table 6-6 Percent of winter-run and spring-run redds counted below Red Bluff Diversion Dam, 1987-2005. Data from Doug Killam, DFG.

Year	Winter-Run % Spawning Below RBDD	Spring-Run % Spawning Below RBDD	Months RBDD Gates Raised
1987	5	no survey	December - March
1988	25	3	December - mid-February

Year	Winter-Run % Spawning Below RBDD	Spring-Run % Spawning Below RBDD	Months RBDD Gates Raised
1989	2	0	December - mid-April; gates in 11 days in February
1990	7	0	December - March
1991	0	0	December - April
1992	4	0	December - April
1993	2	0	September 15 - May 15
1994	0	15	September 15 - May 15
1995	1	9	September 15 - May 15
1996	0	0	September 15 - May 15
1997	0	1	September 15 - May 15
1998	3	0	September 15 - May 15
1999	0	no survey	September 15 - May 15
2000	0	0	September 15 - May 15
2001	0.4	3	September 15 - May 15
2002	0.2	0	September 15 - May 15
2003	0.3	0.6	September 15 - May 15
2004	0	0	September 15 - May 15
2005	0.1		September 15 - May 15

New redds constructed in the Sacramento River during the typical spring-run spawning period (late August and September) since redd surveys began have shown low numbers of new redds relative to new redds counted during winter-run spawning timing and fall-run spawning timing. Peaks in redd count numbers are evident during winter-run spawning and fall-run spawning but not during spring-run spawning. The number of new redds has decreased through July and then increased at the end of September before the large increase that occurs after October 1 when they become classified as fall-run. This suggests that the number of spring-run spawning in the Sacramento River is low (average of 26 redds counted) relative to the average spring-run escapement estimate between 1990 and 2001 in the main stem Sacramento River of 908. The additional fish have not been accounted for in the tributaries upstream of RBDD. The additional fish appear to spawn in October and get counted as fall-run redds.

Additional analysis of effects of RBDD on salmon and steelhead was analyzed in an Environmental Impact Statement (CH2M HILL 2002).

Suisun Marsh Salinity Control Gates

The Suisun Marsh Salinity Control Gates (SMSCG) can affect immigration of all four Chinook races as adults move upstream through Montezuma Slough. Edwards et al. (1996) and Tillman et al. (1996) reported that operation of the SMSCG delays and/or blocks the upstream migration of adult salmon. The studies were unable to provide an accurate estimate of the magnitude of the delay or blockage due to variable results, but a potential minimum delay of about 12 hours per tidal day is possible when the gates are closed. The biological significance of this potential increase in migration time to spring-run populations is unknown because DFG staff estimates that it takes a salmon 30 days to reach its spawning area from the bays (DFG 1998). Further, Montezuma Slough is only one path through the estuary, and its relative importance to the overall immigration of adult spring-run has not been studied.

Limited information is available regarding the behavior of adult Chinook in estuaries. Information from the literature indicates that tidal phase, natal origin, water temperature, dissolved oxygen, and changes in flow can all affect upstream immigration. Stein (2003) tracked 480 adult salmon, tagged with ultrasonic transmitters, through the Delta as part of multi-agency DCC studies. Salmon movements varied among individuals. Many salmon crossed back and forth between different channels for weeks while some moved upstream quickly. Transit times in the Delta ranged from 3-48 days.

Generally, adult spring-run may be present in Suisun Marsh from February through June, with peak occurrence in May. The SMSCG are operated only to meet salinity standards. Therefore, avoidance measures (flashboards and gates out of water) are already in place to minimize effects during months when specific conductance is below standards by more than 2 mS/cm. Measures to improve passage for adult spring-run would be most effective if implemented when adult spring-run are moving upstream in late March through May of dry and critical water years, and mid-April through May in above and below normal water years. In recent years DWR has substantially reduced the frequency and duration that the gates are closed, thereby reducing the potential to impact fish passage.

DWR (1997) discussed several specific measures to mitigate gate operation effects on immigrating salmon. The measures examined included: (1) structural modifications to the flashboard section of the control gate facility in the form of openings or passages in individual flashboards; (2) lowering the height of the flashboard structure; and (3) altering the timing of gate closure on flood tides.

The Suisun Marsh Salinity Control Gates Steering Group reviewed the results from the examination of mitigation alternatives and requested an evaluation of the potential effects of structural modifications to the flashboards. Under this evaluation, the flashboard structure was modified by removing one of the four, 6-foot-tall flashboards and creating two, 3-foot horizontal slots at two depths to potentially provide continuous unimpeded passage for adult salmon. To test the effectiveness of this modification, a three-year evaluation was initiated in the fall of 1998 by DFG and DWR to sonic tag adult fall-run Chinook and monitor their movement through the gate structure during three phases of operation: (1) when the gates are open; (2) during full-bore gate operation; and (3) during full-bore gate operation with the modified flashboard structure installed. The evaluation was repeated in two consecutive control seasons with the fish tagging and tracking occurring from approximately September 15 through October 31 of both years. The fish-tagging period was limited to the time when fall-run Chinook were present in Suisun Marsh. The Suisun Marsh Salinity Control Gates Steering Group decided, based on preliminary results from the modified SMSCG tests that the slots resulted in less adult passage than the original flashboards. The steering group decided to postpone the third year of the test until September 2001 and to reinstall the original flashboards when gate operation was needed during the 2000-2001 control season. DWR and Reclamation focused on data analysis from August 2000 through February 2001, and conducted the third year of the study during the 2001-2002 Control Season. Based on these results, another approach to improve passage was investigated, involving opening the boat lock and using full flashboards when gates are operational.

Results in 2001, 2003, and 2004 indicate that leaving the boat-lock open during the migration period when the flashboards are in place at the SMSCG and the radial gates are tidally operated provides a nearly equivalent fish passage to the Non-migration period configuration when the flashboards are out and the radial gates are open. This approach minimizes delay and blockage of adult Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, and Central Valley steelhead migrating upstream during the migration season while the SMSCG is operating. However, the boat-lock gates may be closed temporarily to stabilize flows to facilitate safe passage of watercraft through the facility.

Reclamation and DWR are continuing to coordinate with the SMSCG Steering Group in identifying water quality criteria, operational rules, and potential measures to facilitate removal of the flashboards during the migration period that would provide the most benefit to migrating salmonids. However, the flashboards would not be removed during the migration period unless it was certain that standards would be met for the remainder of the period without the flashboards installed.

See “Suisun Marsh Salinity Control Gates” in Chapter 12 for more information.

Bank Modification and Riparian Habitat Loss

Sacramento River winter-run Chinook salmon are affected by bank modification and riparian habitat loss in the same manner as Central Valley spring-run Chinook salmon. Because adverse modification of shaded river aquatic cover may impede the recovery of winter-run Chinook salmon, NOAA Fisheries (1993) included nearshore rearing areas and adjacent riparian habitats of the Sacramento River in its determination of critical habitat for the winter-run Chinook salmon.

Delta Emigration

The following discussion emphasizes spring-run yearling emigrants, which have been of particular management concern since spring-run were listed. This primarily addresses emigration from Mill and Deer Creeks (DFG 1998), which have a higher proportion of spring-run emigrating as yearlings than either Butte Creek (Brown 1995) or the Feather River (DWR 1999a, 1999b, 1999c). Sub-yearling spring-run emigrate during winter and spring when protections for delta smelt and winter-run Chinook salmon are in place. There is significant uncertainty regarding timing of emigration of yearling spring-run Chinook. Because a relatively small number of yearlings are emigrating, they are difficult to detect in the monitoring programs.

Yearlings are relatively large, strong swimmers, so they may also more easily avoid the monitoring gear (McLain 1998). Other juvenile Chinook in the main stem Sacramento River are in the same size range used to define yearling spring-run Chinook, confounding data interpretation.

Marked releases of Coleman Hatchery yearling late-fall-run (hereafter Coleman late-fall-run Chinook) juveniles have been used as surrogates to estimate the timing of yearling spring-run emigration and incidental take at the SWP and CVP export facilities for the Salmon Decision Tree process and the OCAP biological opinions. Since 1994, FWS has released approximately 17 percent of the Coleman Hatchery late-fall production in each of November, December, and January to evaluate hatchery operations. The fish were adipose fin-clipped and coded-wire tagged before release allowing identification of the members of individual release groups when they are recaptured downstream. The regulatory agencies considered Coleman late-fall-run Chinook salmon appropriate surrogates for yearling spring-run because they were reared to a similar size as spring-run yearlings and were released in the upper Sacramento River. Because they were large, they were expected to emigrate quickly. Some patterns have recently been revealed through the Butte Creek CWT program on naturally spawned spring-run. In particular, the potential effects of the Sutter Bypass (lower Butte Creek) potentially effects residence time for these fish in the Sutter Bypass seems to be 60 to 120 days and dependent on water levels in the bypass resulting from Sacramento River flows (DFG 2003).

Coleman late-fall Chinook released in November were captured at Red Bluff and the Glenn-Colusa Irrigation District (GCID) facility within 2 or 3 days of release. However, they were not captured downstream in the lower Sacramento River or the Delta, until about 3 days after the first significant, precipitation-induced flow event in November or December (Figure 6-14 through Figure 6-22). This suggests Chinook yearlings may use these flow events as migration cues. Based on captures in the FWS Chipps Island midwater trawl and salvage at the Central Valley Project's (CVP) and State Water Project's (SWP) Delta export facilities, some individuals may continue to emigrate for up to 5 months.

The Coleman late-fall Chinook released in December (Figure 6-14 through Figure 6-22) were released after the first significant, precipitation-induced flow event in the fall. However, they were not captured in the Delta until after a second significant precipitation event occurred unless there was significant Sacramento River flow associated with the earlier precipitation-induced events. Since precipitation events occurred sooner after the December releases than the November releases, these fish may have remained in the upper Sacramento River for a relatively short time (several days up to a week), then taken several more days to reach the Delta following a precipitation-induced flow event. Some emigration continued for up to 4 months.

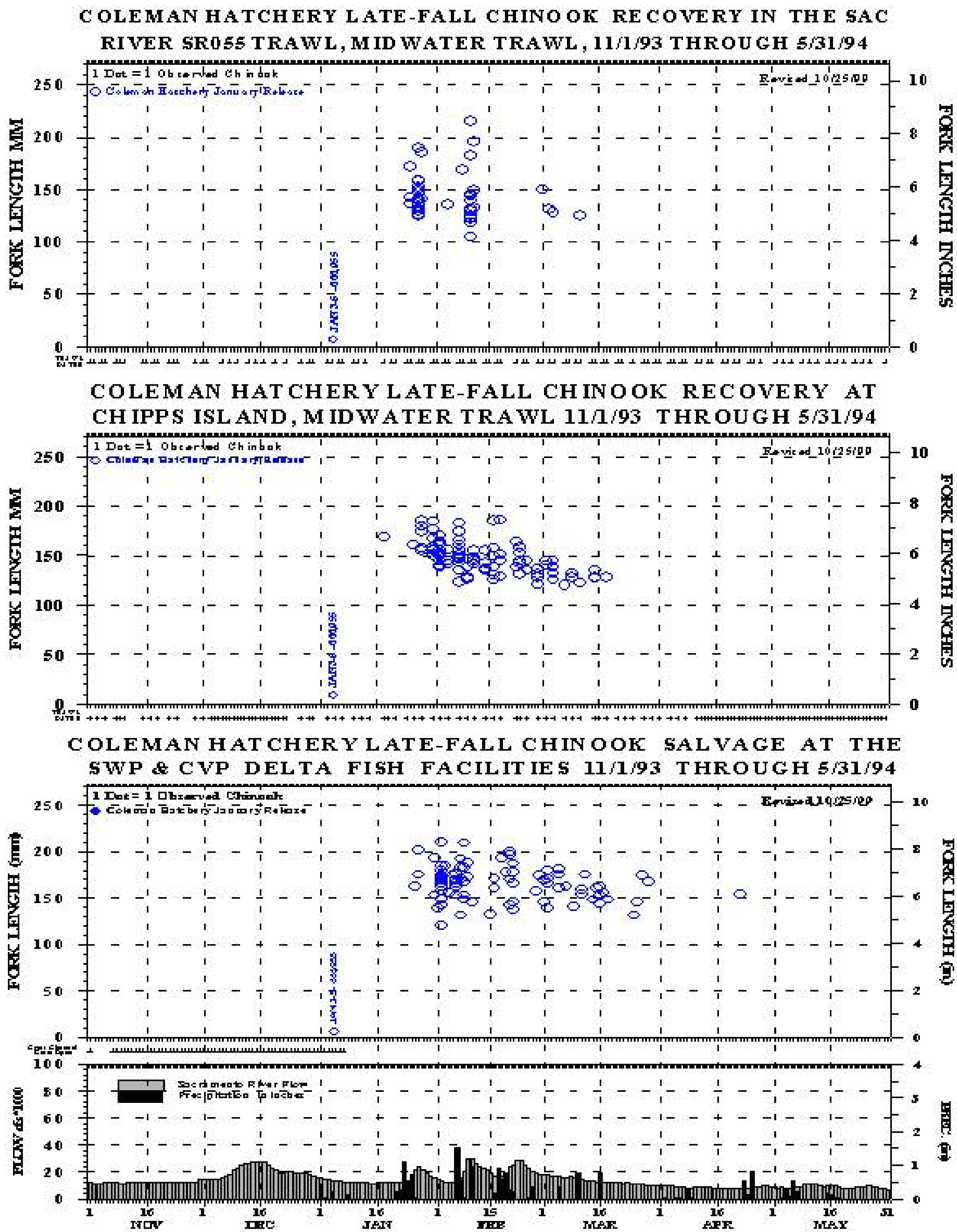

Figure 6-14 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1993–1994.

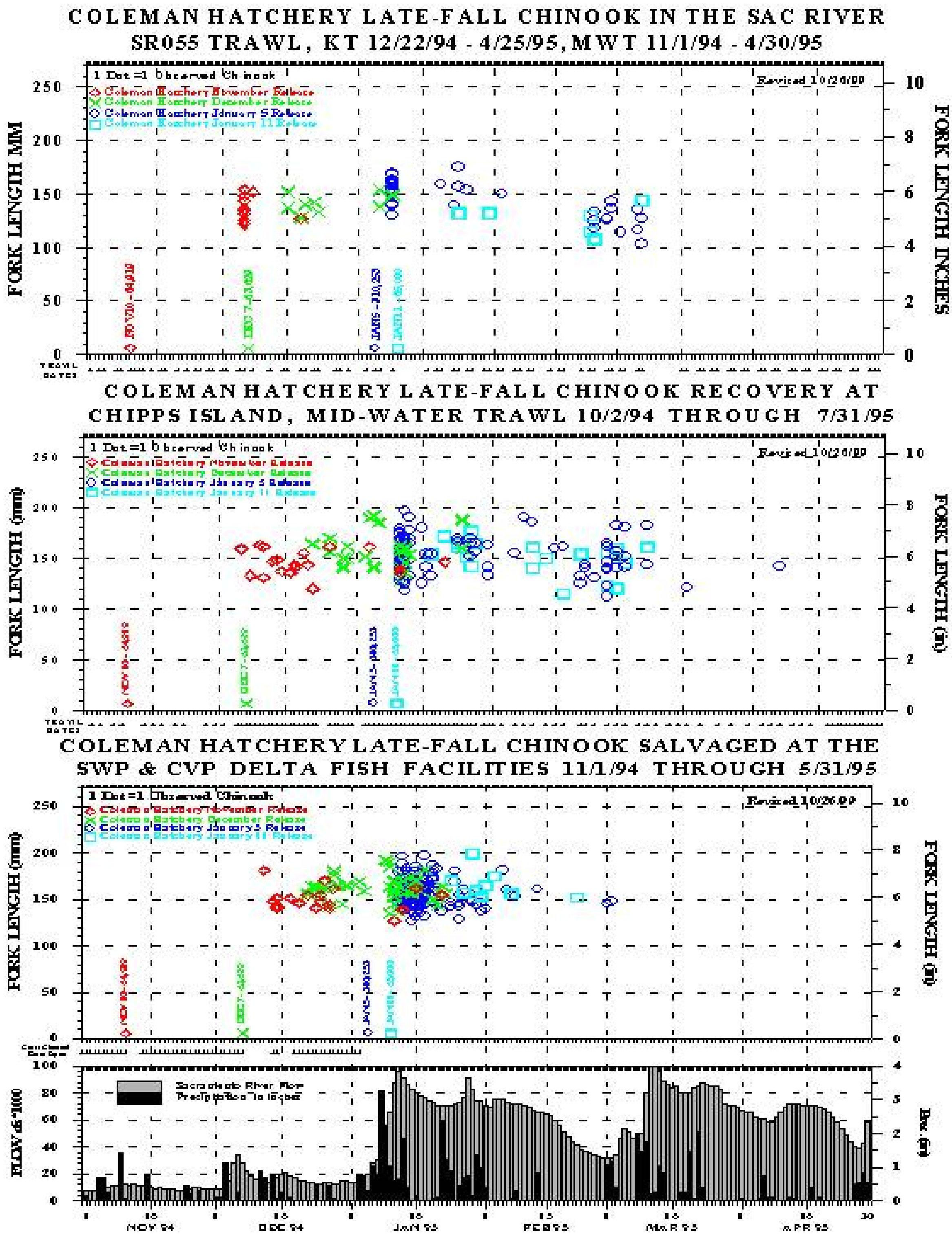

Figure 6-15 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1994–1995.

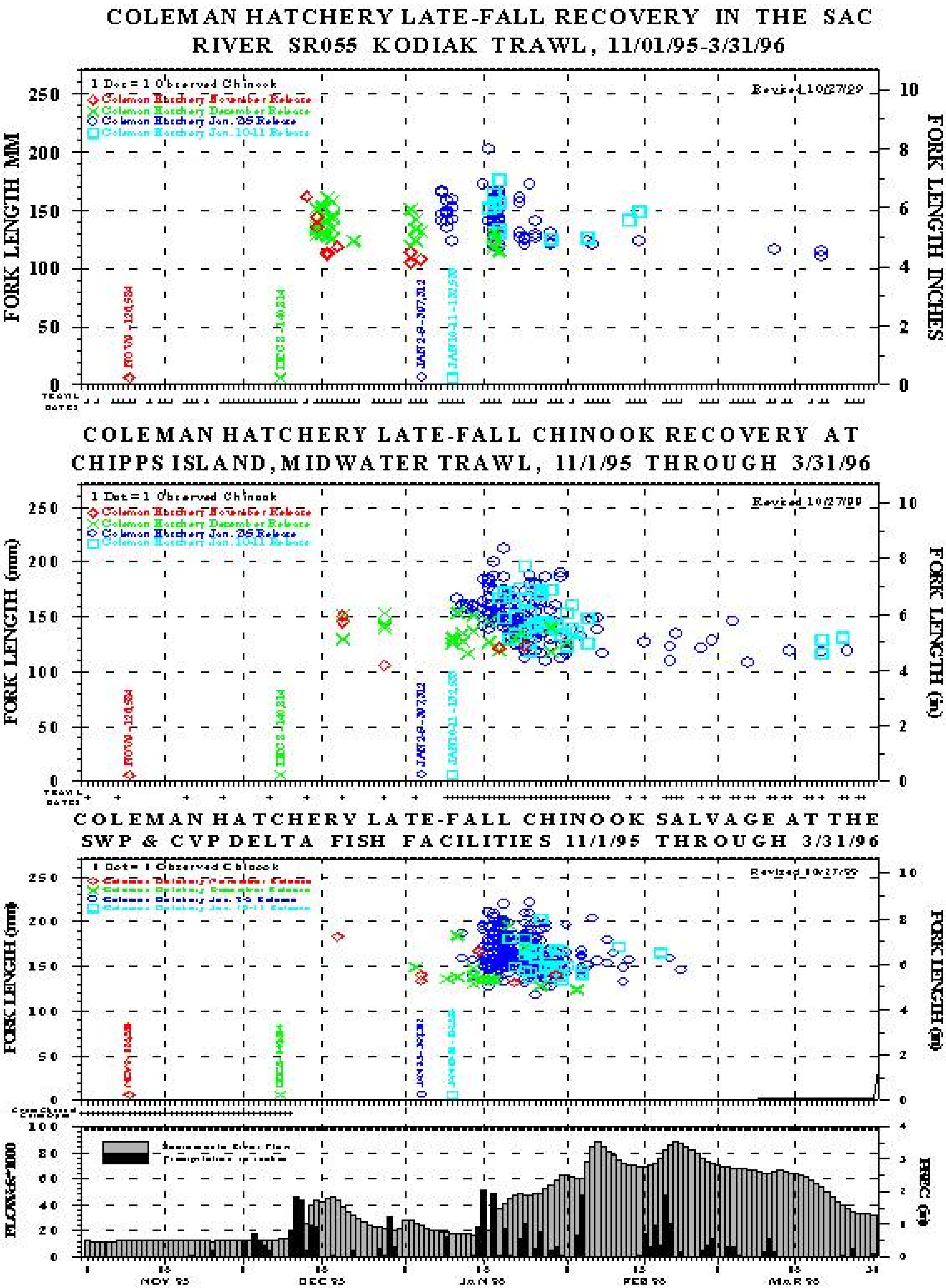

Figure 6-16 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1995–1996.

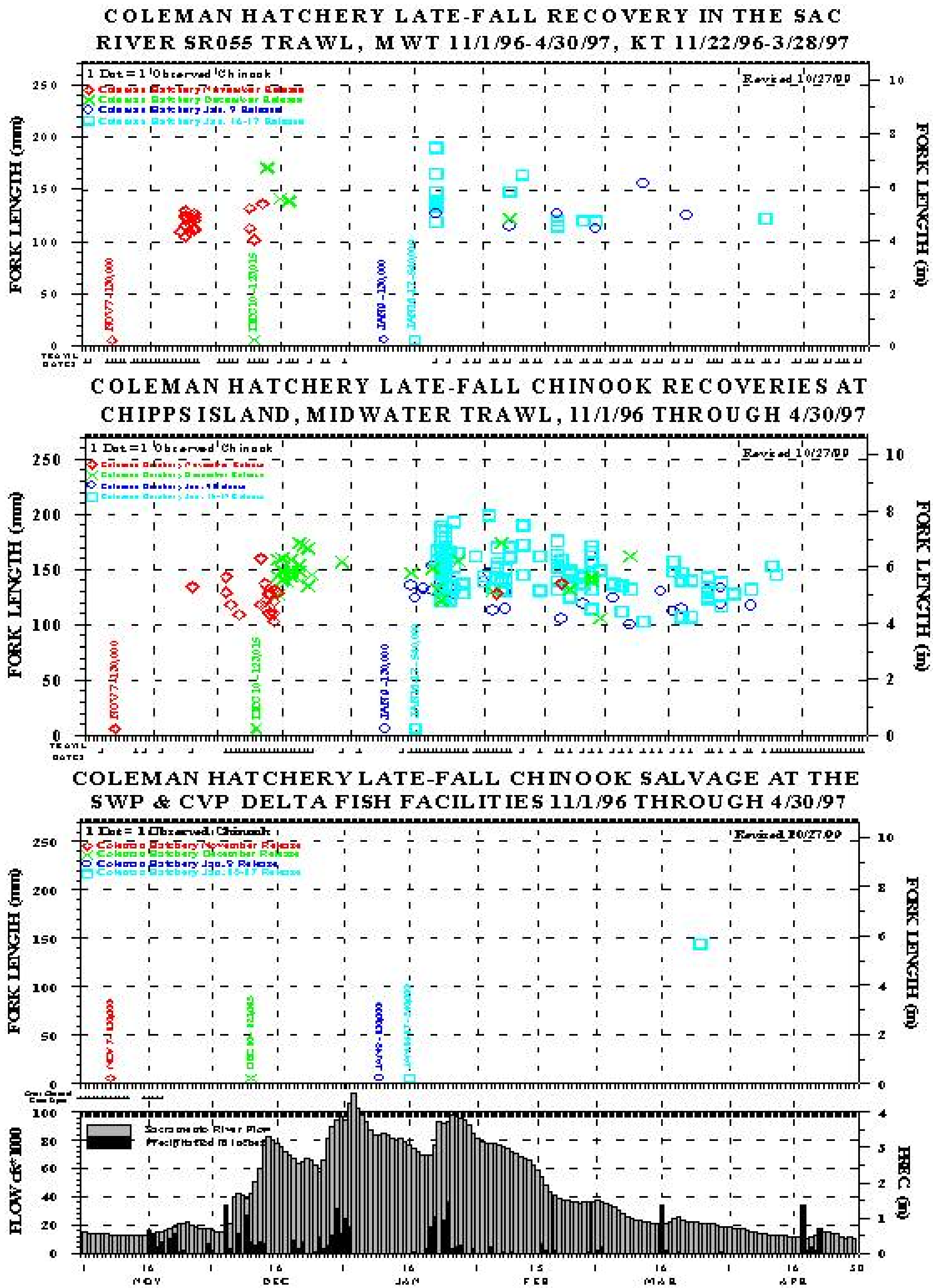

Figure 6-17 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1996–1997.

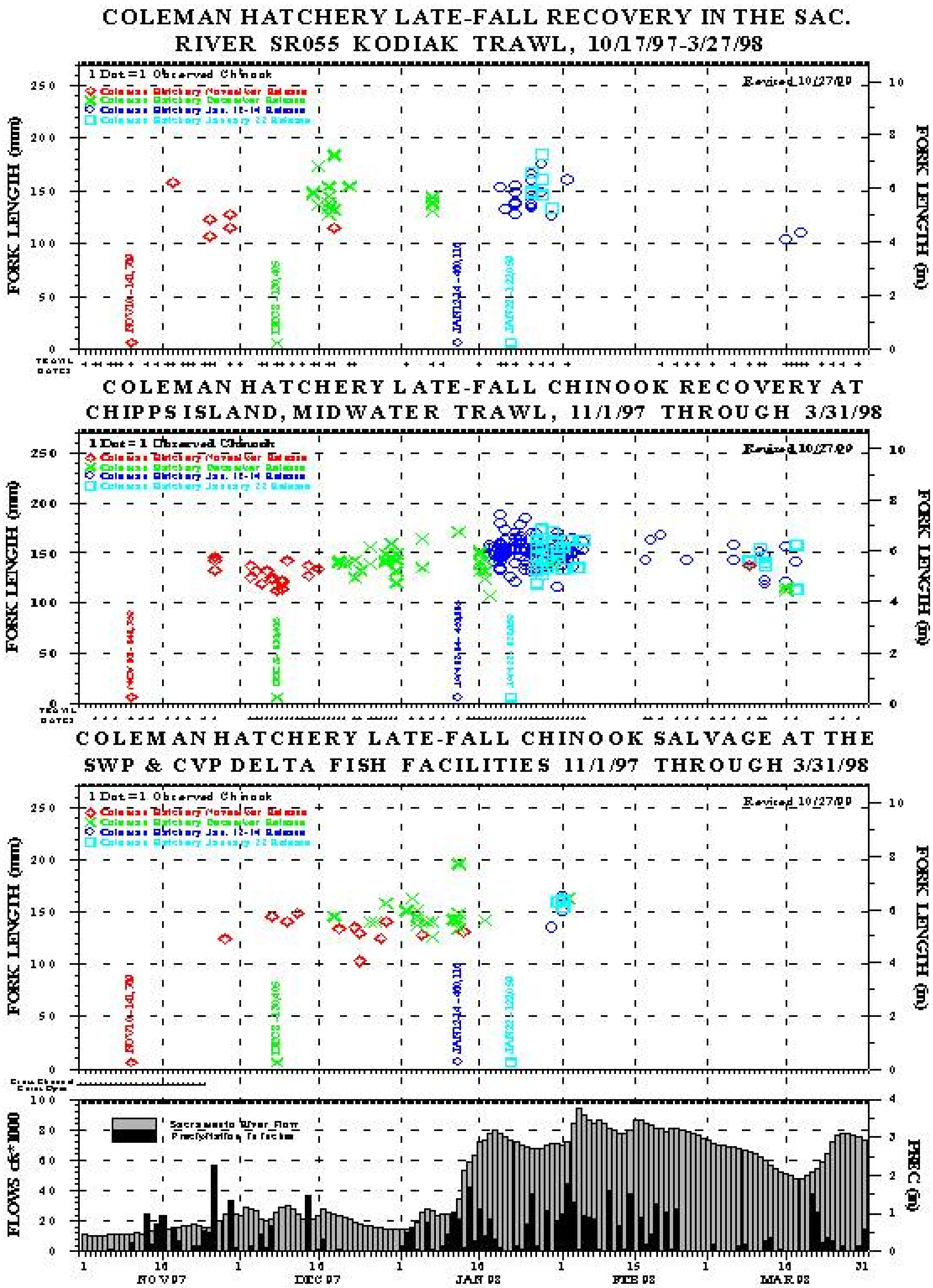

Figure 6-18 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1997–1998.

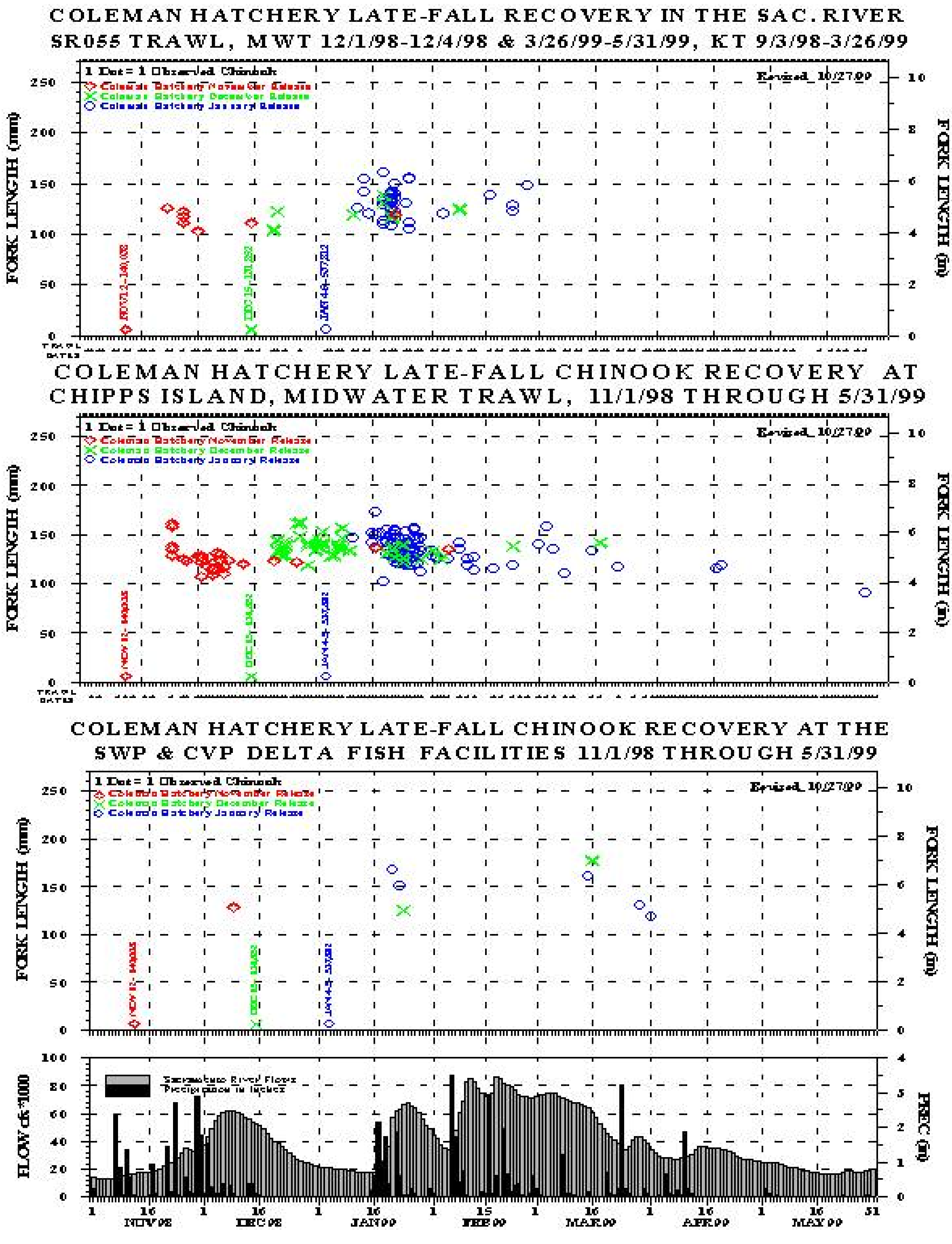

Figure 6-19 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1998–1999.

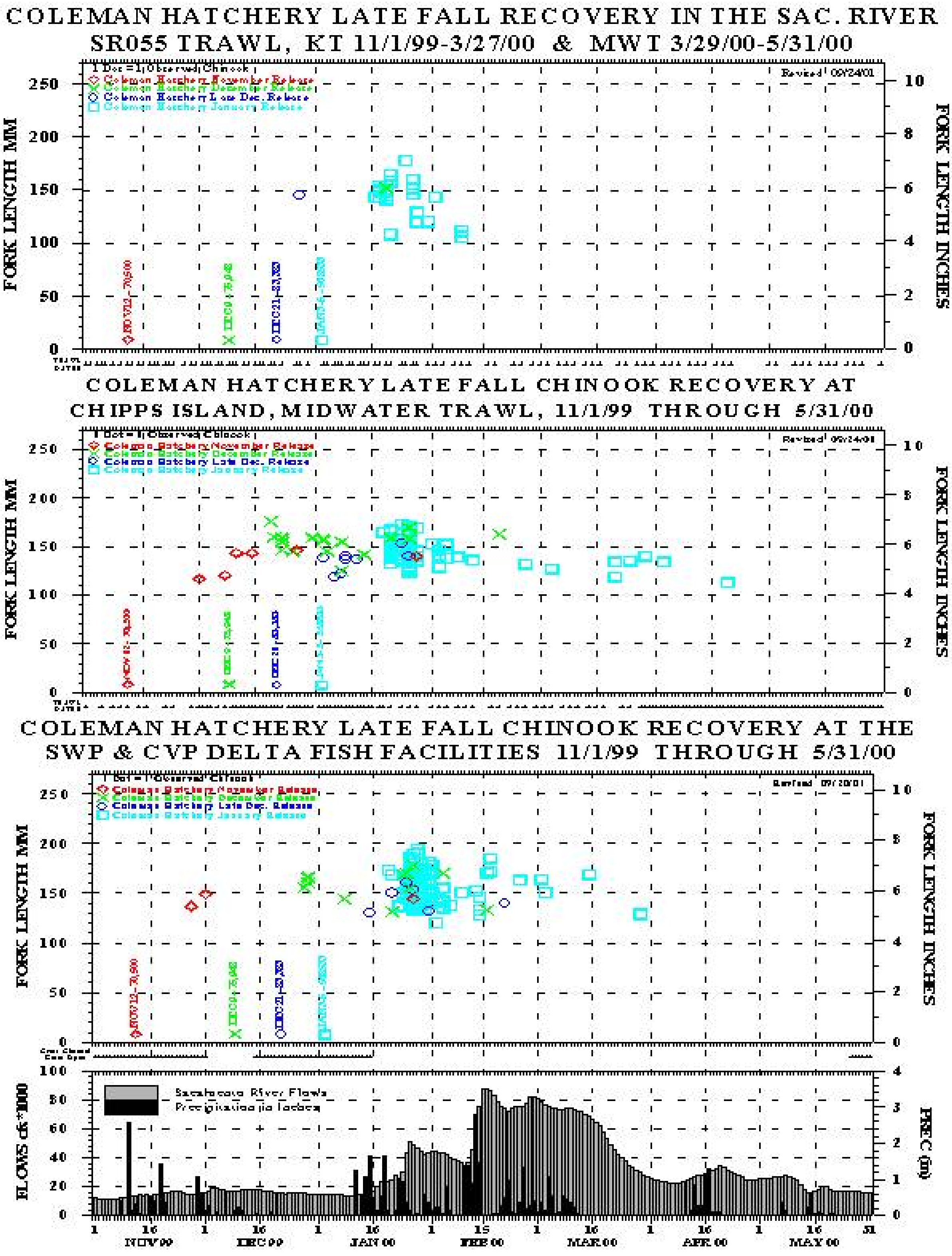

Figure 6-20 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 1999–2000.

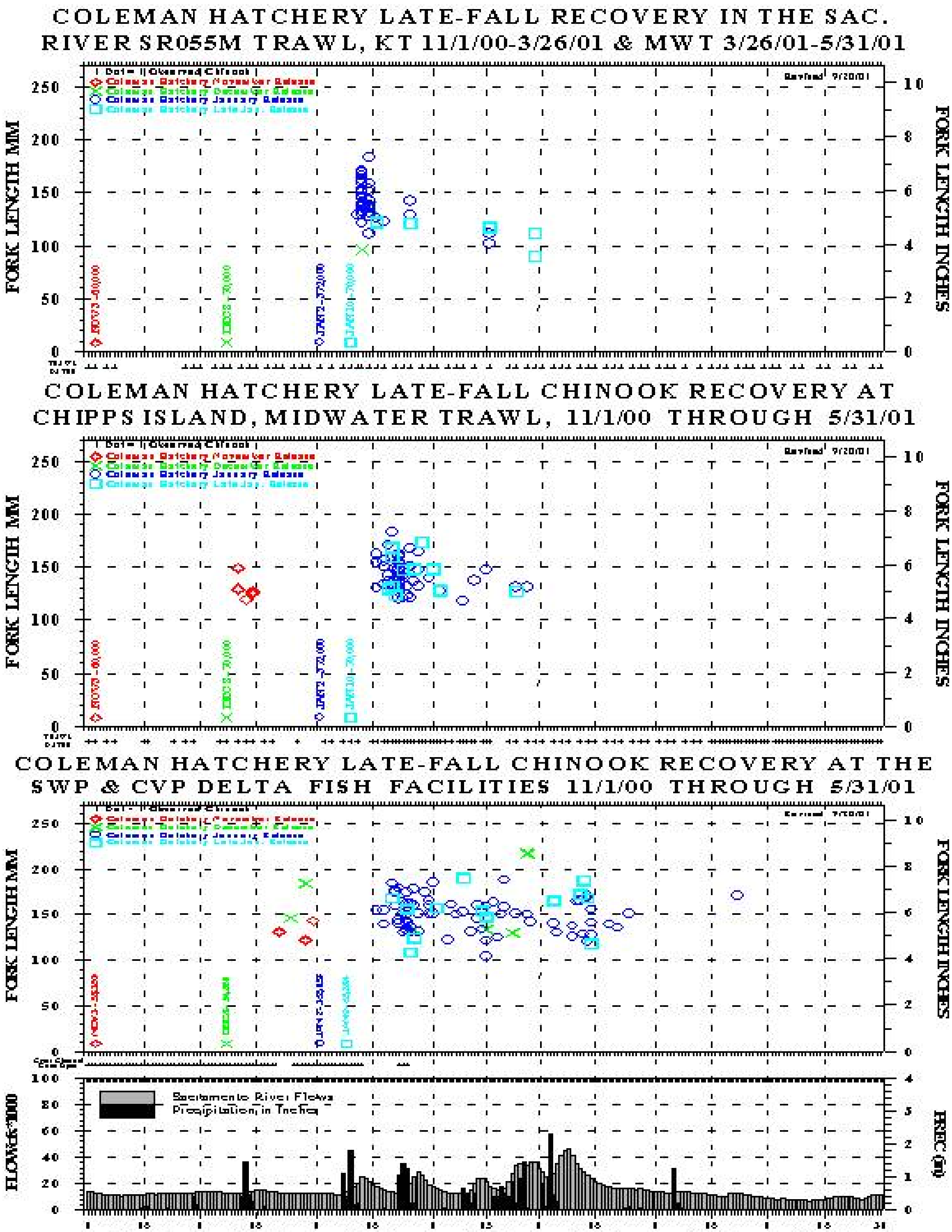

Figure 6-21 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 2000–2001.

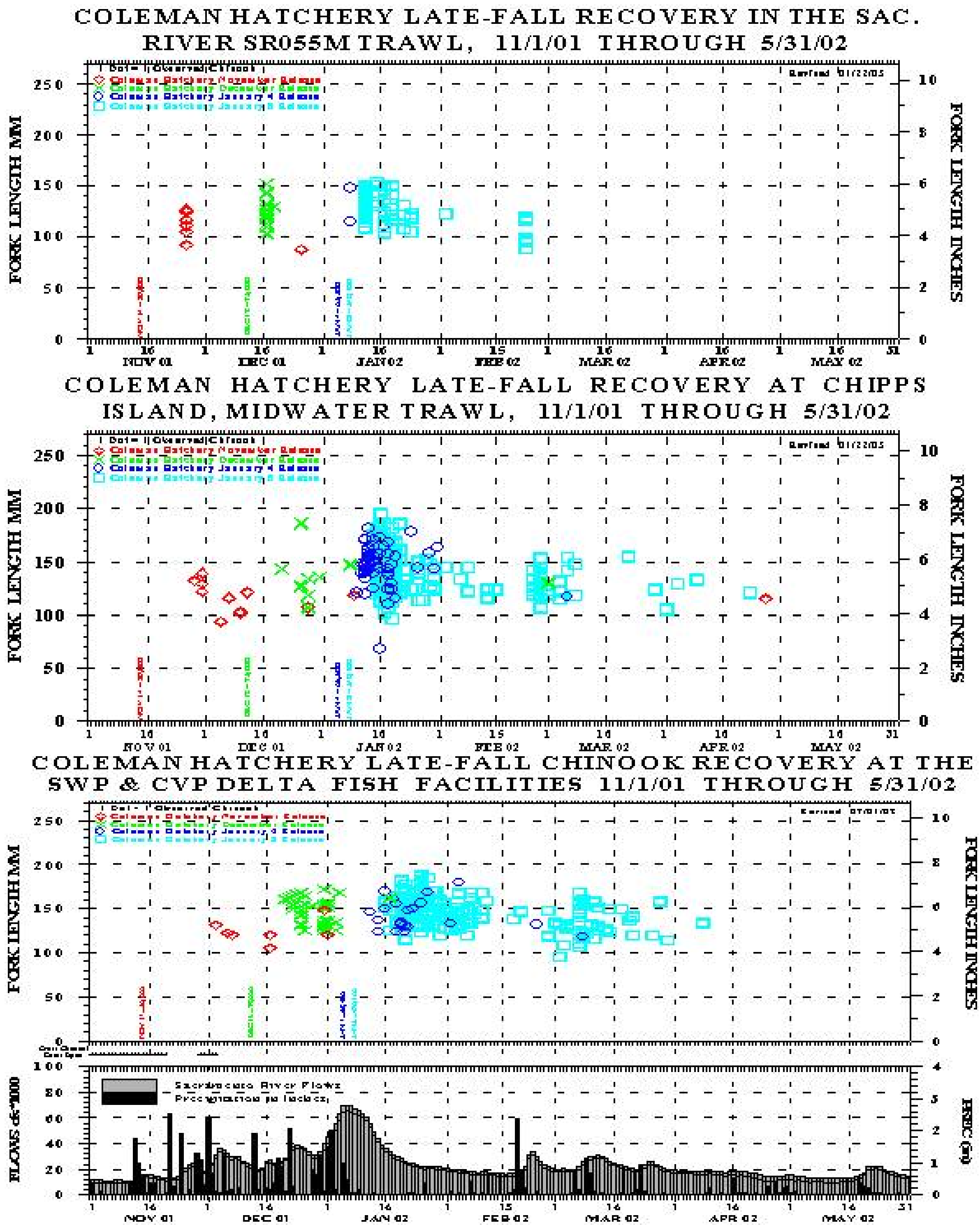

Figure 6-22 Timing of recoveries of coded-wire-tagged Coleman National Fish Hatchery late-fall-run Chinook salmon smolts, Sacramento River flow at Freeport, and precipitation at Red Bluff Airport, winter 2001–2002.

The emigration of Coleman late-fall Chinook released in January (Figure 6-14 through Figure 6-22) was not as closely related to precipitation-induced flow events as the November or December releases; perhaps because significant precipitation and high flows had generally occurred prior to their release. The relationship between emigration and flow associated with precipitation events is variable, although the 1994 dry water year (Figure 6-14) is an example of January releases emigrating on precipitation-induced flow events throughout the winter and spring. Again, some emigration continued for up to 4 months.

Because Coleman late-fall and spring-run yearlings are similar in size and rear in the upper Sacramento River, their emigration patterns should be similar. Therefore, Sacramento River flow associated with precipitation events, along with related tributary flow events, probably provides the major cue for yearling spring-run emigration.

Pooling data for all late-fall-run yearling releases since November 1993, the average travel time from Coleman Hatchery to Sacramento has been 19 days, with a standard deviation of 12 days. The average travel time from the hatchery to Chipps Island has been 26 days (standard deviation = 11 days) and the average travel time from the hatchery to the Delta fish facilities has been 33 days (standard deviation = 18 days). The median travel times to Sacramento and the facilities are significantly different; other combinations are not (ANOVA $F = 4.33$; $p = 0.02$, + post hoc multiple comparison tests). Sacramento River flow for 30 days following release from the hatchery explains some of the variability in median travel time to Chipps Island (Figure 6-23)

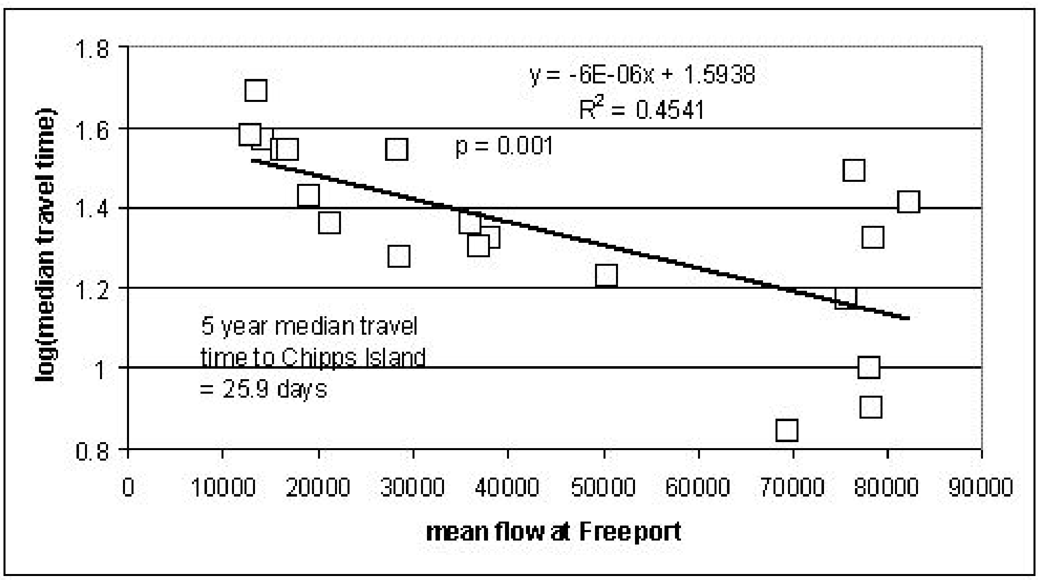

Figure 6-23 Relationship between mean flow (cfs) in the Sacramento River and the log10 time to recapture in the FWS Chipps Island Trawl for Coleman Hatchery late-fall-run Chinook salmon smolts. The explanatory variable is mean flow at Freeport for 30 days beginning with the day of release from Coleman Hatchery. The response variable is an average of median days to recapture for November through January releases during winter 1993–94 through 1998–99.

Winter-run migrate through the Delta primarily from December to April. NOAA Fisheries develops an estimate of winter-run juvenile production each year based on the estimated escapement and applying a set of standard survival estimates including prespawning mortality, fecundity, egg-to-fry survival, and survival to the Delta (Table 6-7). Figure 6-24 shows Winter-run and older juvenile Chinook loss at Delta fish facilities, October 2005-May 2006 and Figure 6-25 shows observed Chinook salvage.(the ones salvaged and measured in sampling counts) during the 2005-2006 outmigration.

Table 6-7 Example of how the winter-run Chinook juvenile production estimate, and take levels are calculated using 2001-02 adult escapement data.

2001-2002 Winter-Run Chinook Juvenile Production Estimate (JPE)	
Total Spawner escapement (Carcass Survey)	7,572
Number of females (64.4% Total)	4,876
Less 1% pre-spawn mortality	4,828
Eggs (4,700 eggs/female)	22,689,740
Less 0.5% due to high temp	113,449
Viable eggs	22,576,291
Survival egg to smolt (14.75%)	3,330,003
Survival smolts to Delta (56%)	1,864,802
Livingston Stone Hatchery release	252,684
Yellow light(1% natural + 0.5 hatchery)	19,911
Red Light (2% natural + 1% Hatchery)	39,823

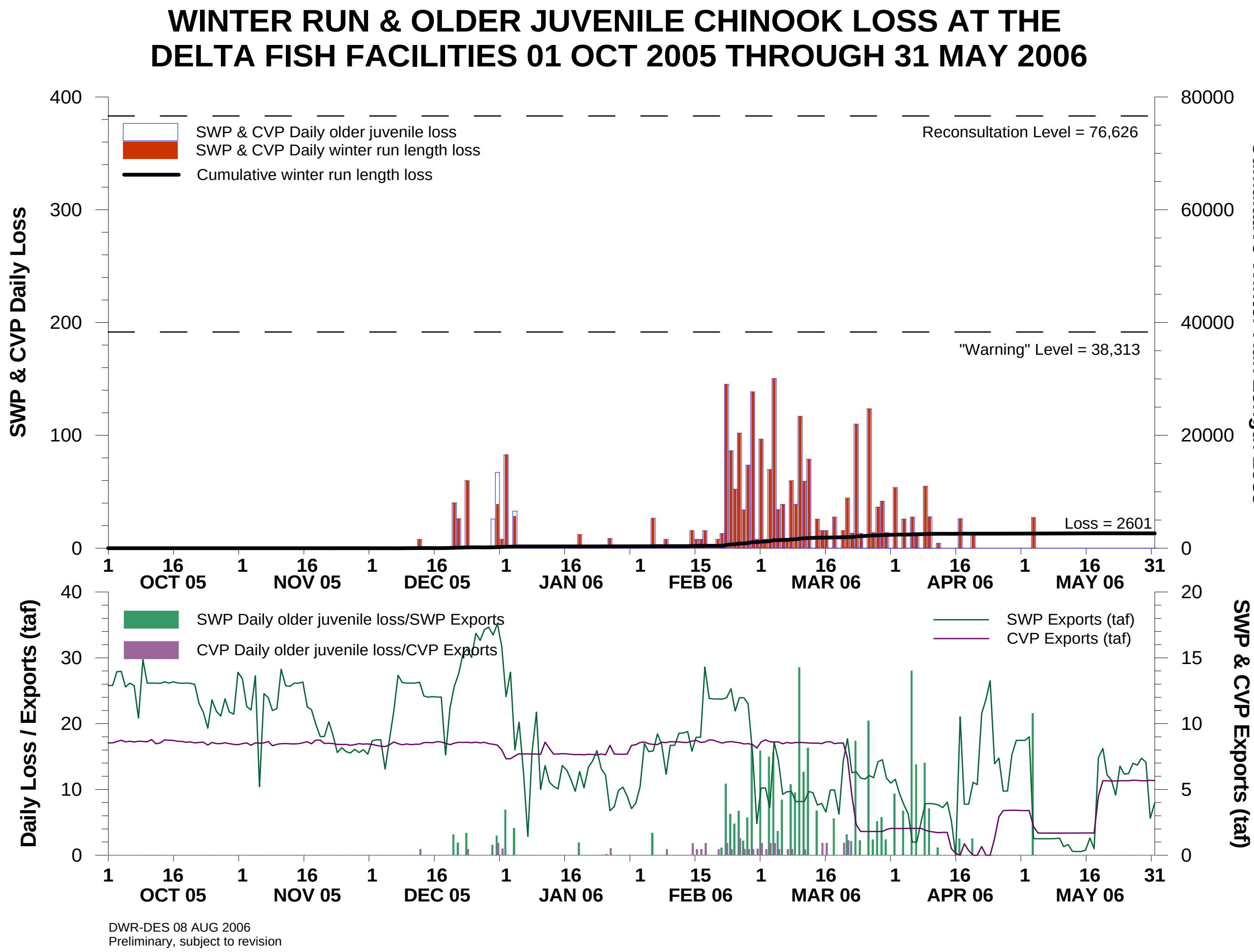

Figure 6-24 Winter-run and older juvenile Chinook loss at Delta fish facilities, October 2005-May 2006.

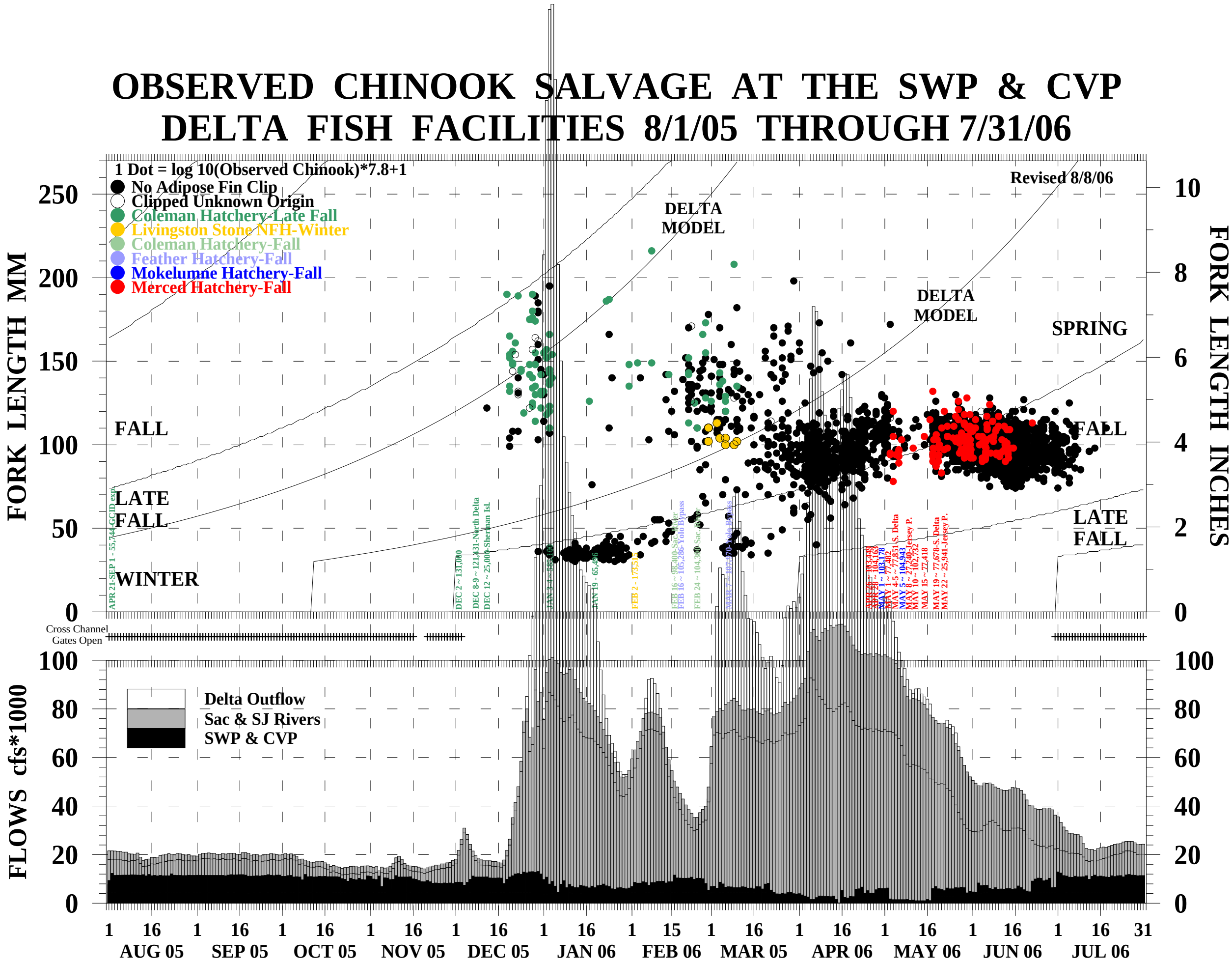

Figure 6-25 Observed Chinook salvage at the SWP and CVP delta fish facilities, 8/1/05 – 7/31/06.

Changes in the Delta Ecosystem and Potential Effects on Winter-Run, Spring-Run and Fall/Late-Fall-Run Chinook Salmon

Changes in estuarine hydrodynamics have adversely affected a variety of organisms at all trophic levels, from phytoplankton and zooplankton to the young life stages of many fish species (Jassby et al. 1995; Arthur et al. 1996; Bennett and Moyle 1996). Ecological processes in the Delta have also been affected by interactions among native and introduced species (Bennett and Moyle 1996; Kimmerer and Orsi 1996), the various effects of water management on Delta water quality and quantity (Arthur et al. 1996), and land use practices within the watershed (Simenstad et al. 1999). Cumulatively, these changes may have diminished the suitability of the Delta as a juvenile salmon rearing habitat and may have reduced the survival of young salmon migrating through the Delta to the Pacific Ocean. Population level effects of changes in the Delta are complex and have not been quantified.

As juvenile salmon from the Sacramento basin migrate through the Delta toward the Pacific Ocean, they encounter numerous junctions in the river and Delta channels (both natural and human-made). Two such junctions are located near Walnut Grove at the Delta Cross Channel (DCC) (a man-made channel with an operable gate at the entrance) and Georgiana Slough (a natural channel). Both channels carry water from the Sacramento River into the central Delta. The relatively high-quality Sacramento River water flows into the central Delta, mixes with water from the east-side tributaries (Mokelumne, Cosumnes and Calaveras Rivers) and the San Joaquin River. This mixture, which much of the time is predominantly Sacramento River water, flows westward through the estuary or is pumped from the Delta water in-Delta water users or for use south of the Delta.

Significant amounts of flow and many juvenile salmon from the Sacramento River enter the DCC (when the gates are open) and Georgiana Slough. Mortality of juvenile salmon entering the central Delta is higher than for those continuing downstream in the Sacramento River. This difference in mortality could be caused by a combination of factors: the longer migration route through the central Delta to the western Delta, exposure to higher water temperatures, higher predation rates, exposure to seasonal agricultural diversions, water quality impairments due to agricultural and municipal discharges, and a more complex channel configuration making it more difficult for salmon to successfully megrate to the western Delta and the ocean.

Water is drawn from the central Delta through lower Old River and Middle River to the export pumps when combined CVP/SWP pumping exceeds the flow of the San Joaquin River water down the upper reach of Old River and Middle Rivers. This situation likely increases the risk of juvenile salmon migrating to the south Delta and perhaps being entrained at the SWP and CVP facilities. This condition can be changed either by reducing exports or increasing Delta inflows or the use of physical barriers and gates. Decreasing exports to eliminate net upstream flows (or, if net flows are downstream, cause an increase in positive downstream flows) may reduce the chances of migrating juvenile salmonids moving up lower Old River towards the CVP/SWP diversions. Tidal flows, which are substantially greater than net flows, play an important role in salmon migrations.

Juvenile salmon, steelhead and other species of fish in the south Delta are directly entrained into the SWP and CVP export water diversion facilities (Table 6-8, Table 6-9, Table 6-10,Figure 6-26, Figure 6-27). Many juvenile salmon die from predation in Clifton Court Forebay before they reach the SWP fish screens to be salvaged (80 percent mortality currently used in loss calculations based on Gringas 1997) and approved by the fishery agencies. Loss at the SWP is thought to vary inversely with the pumping rate because when water is drawn through Clifton Court Forebay faster, salmon are not exposed to predation for as long (Buell 2003). At the CVP pumping facilities the loss rate through the facility for Chinook is about 33 percent.

Salmon from the San Joaquin Basin, and those migrating from the Sacramento River or east Delta tributaries through the central Delta are more directly exposed to altered channel flows due to exports and to entrainment because their main migration route to the ocean puts them in proximity to these diversions. Some juvenile salmon migrating down the main stem Sacramento River past Georgiana Slough may travel through Three-Mile Slough or around Sherman Island and end up in the southern Delta. There is a lack of understanding about how or why salmon and steelhead from the north Delta end up at the diversions in the south Delta, particularly regarding the influence of the SWP and CVP export pumping. Nevertheless it is clear that once juvenile salmon are in the vicinity of the pumps, they are more likely to be drawn into the diversion facilities with the water being diverted. By reducing the pumping rate, entrainment of fish, and therefore loss (loss = number of fish salvaged multiplied by prescreen loss from predation, louver efficiency, and survival through the salvage process to release) of these fish may be reduced. If reservoir releases are not reduced simultaneously, the net flow patterns in Delta channels are changed to the benefit of emigrating salmonids and other fish. The relative magnitude and significance of these factors on direct and indirect mortality of juvenile salmon, however, has not been quantified.

Table 6-8 Total Chinook salmon salvage (all sizes combined) by year at the SWP and CVP salvage facilities (Source: DFG fish salvage database).

Year	SWP	CVP	Total
1981	101,605	74,864	176,469
1982	278,419	220,161	498,580
1983	68,942	212,375	281,317
1984	145,041	202,331	347,372
1985	140,713	137,086	277,799
1986	435,233	752,039	1,187,272
1987	177,880	92,721	270,601
1988	151,908	54,385	206,293
1989	106,259	42,937	149,196
1990	35,296	6,107	41,403
1991	39,170	31,226	70,396
1992	22,193	41,685	63,878

Year	SWP	CVP	Total
1993	8,647	20,502	29,149
1994	3,478	12,211	15,689
1995	19,164	64,398	83,562
1996	14,728	39,918	54,646
1997	11,853	53,833	65,686
1998	3,956	167,770	171,726
1999	50,811	132,886	183,697
2000	45,613	78,214	123,827
2001	28,327	29,479	57,806
2002	6,348	15,573	21,921
2003	17,339	15,977	33,336
2004	12,393	24,110	36,503
2005	13,050	25,625	38,675
2006	8,611	34,923	43,534
2007	833	3,709	4,542

Table 6-9 Average Chinook salmon salvage (all sizes and marks combined) by facility 1981 - 1992.

Month	SWP	CVP
Jan	2,889	1,564
Feb	5,989	47,227
Mar	7,679	8,241
Apr	40,552	33,983
May	56,327	55,146
Jun	21,863	15,929
Jul	496	2,105
Aug	232	233
Sep	33	0
Oct	1,474	4,814
Nov	2,181	4,133
Dec	9,682	3,365

Table 6-10 Average Chinook salmon salvage (all sizes and marks combined) by facility, 1993 - 2007.

Month	SWP	CVP
Jan	1,439	4,389
Feb	1,000	7,726
Mar	1,597	5,194
Apr	6,008	12,126
May	4,910	12,749
Jun	1,921	6,197
Jul	65	246
Aug	30	18
Sep	145	108
Oct	40	56
Nov	29	116
Dec	300	403

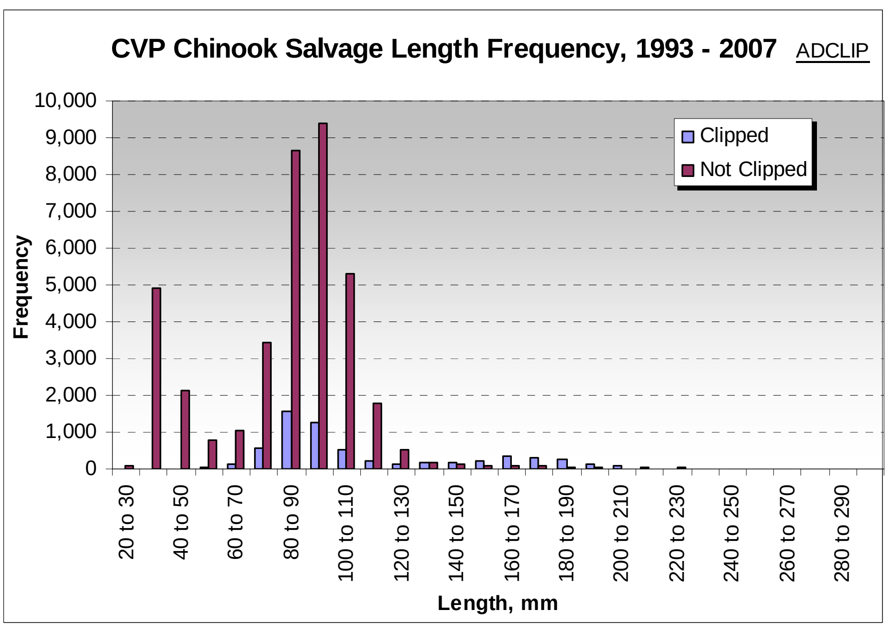

Figure 6-26 Length frequency distribution of Chinook salvaged at the CVP.

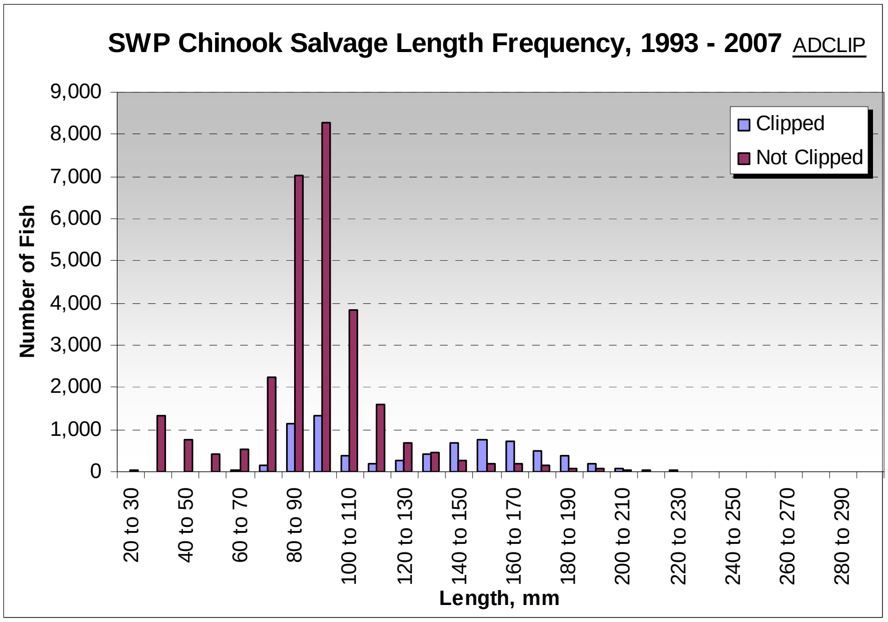

Figure 6-27 Length frequency distribution for Chinook salvaged at SWP.

Past Chinook salmon expanded loss density (fish lost per cfs of water pumped) for winter-run and spring-run are shown in Figure 6-28 through Figure 6-31 for the Tracy Fish Salvage Facilities (CVP) and the Skinner Fish Salvage Facilities (SWP).

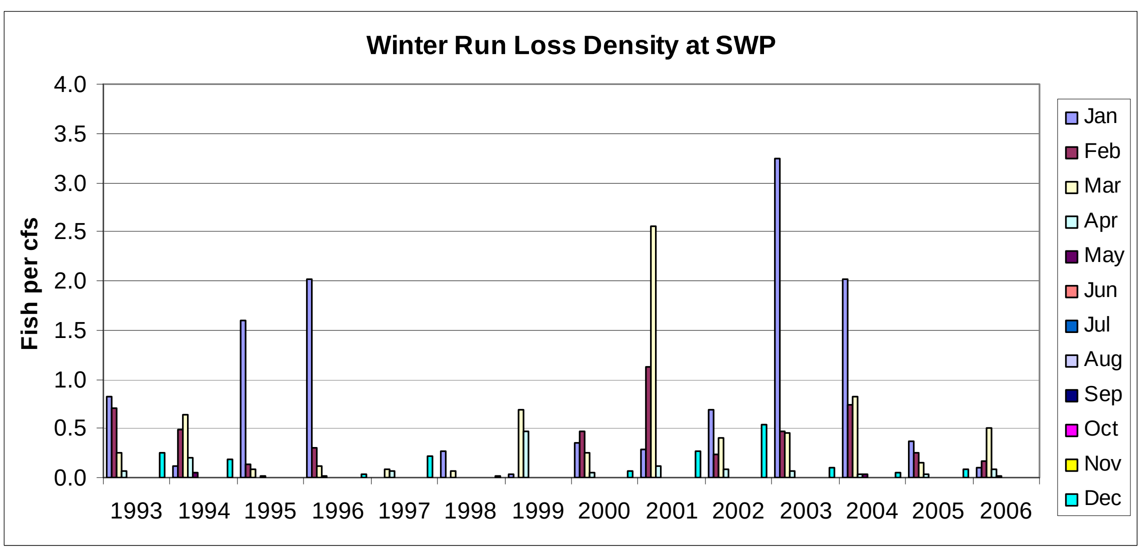

Figure 6-28 Winter run loss per cfs at the SWP, 1993 – 2006.

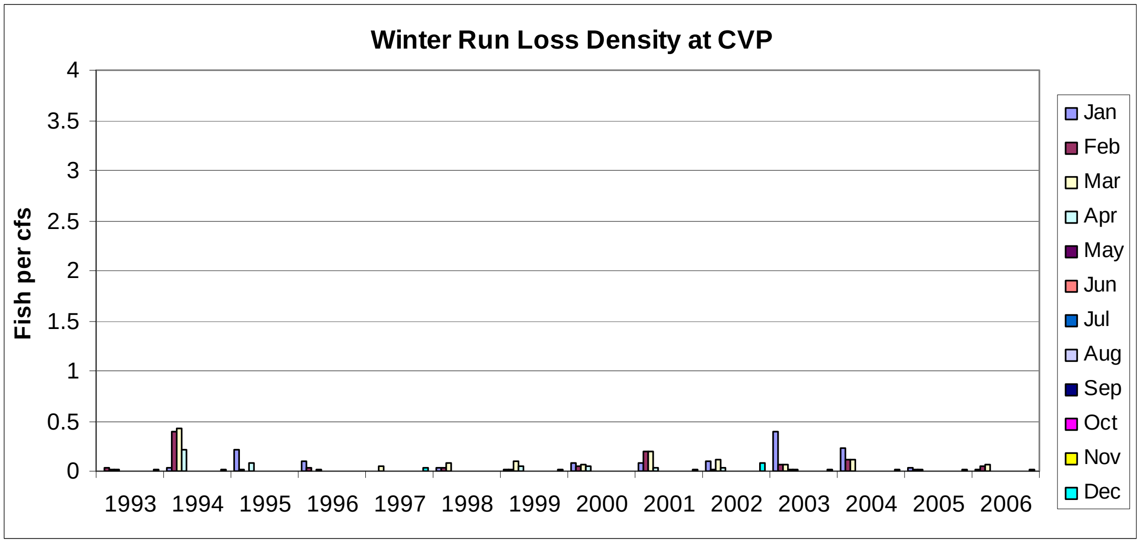

Figure 6-29 Winer run loss per cfs at the CVP, 1993 – 2006.

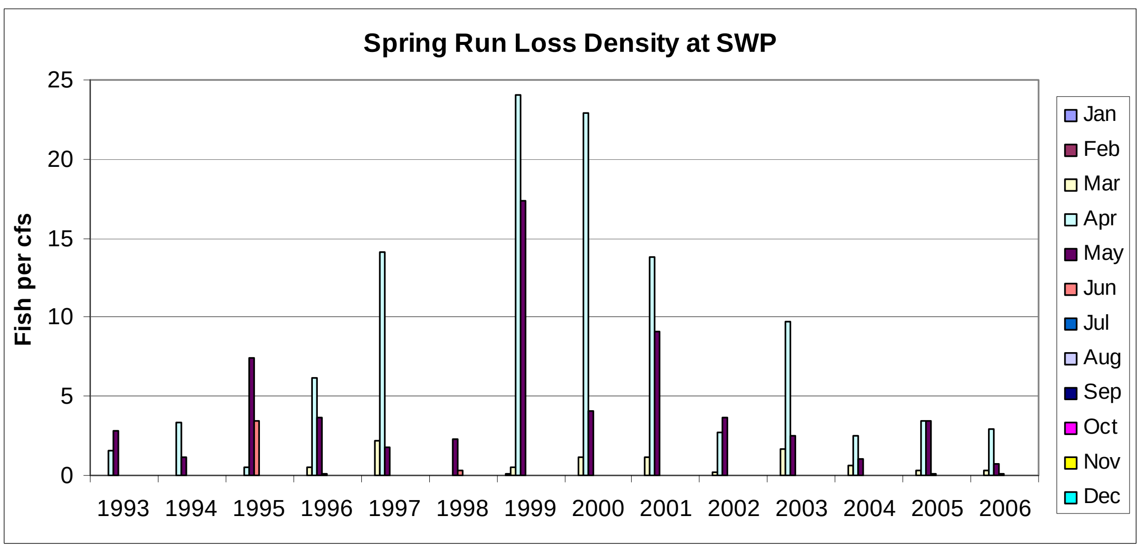

Figure 6-30 Spring run loss density (fish per cfs) at the SWP.

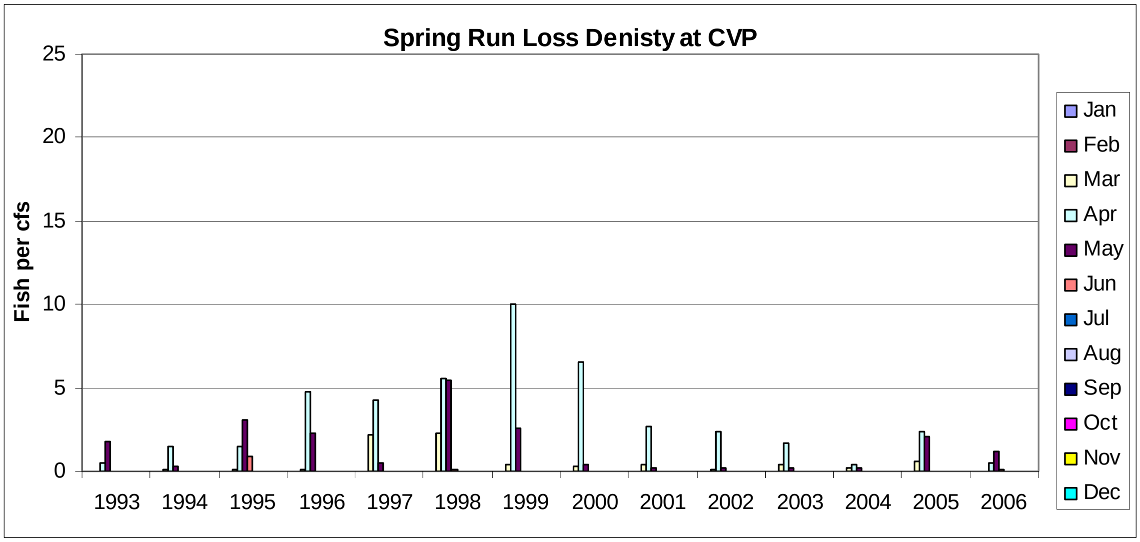

Figure 6-31 Spring run loss density (fish per cfs) at the CVP.

Although the number of fish entrained by the SWP and CVP appear large or of concern, the number is generally relatively small compared to number of outmigrating smolts or the overall population. In most years, the entrainment of fish by the SWP and CVP is limited to very small percent (i.e. less than 2 percent for winter-run) of the outmigrating smolts.Indirect In-Delta Effects on Salmon.

Indirect In-Delta Effects on Chinook Salmon SWP/CVP

Delta water project effects on rearing and migrating juvenile Chinook salmon are both direct (based on observations of salvaged fish at the fish salvage facilities) and indirect (mortality in the Delta that is related to export operations). The entrainment rate (direct loss) of juvenile salmon at the facilities is an incomplete measure of water project impact to juvenile salmon, because it does not include indirect mortality in the Delta.

There are indirect effects on salmon caused by natural and human alterations that increase the route through the central Delta to the western Delta, higher water temperatures, higher predation, and impairments due to agricultural and municipal discharges.

FWS CWT studies have been used to assess survival rates of juvenile Chinook migrating through the Delta relative to those remaining in the Sacramento River (Kjelson et al. 1982, Newman and Rice 1997, Brandes and McLain 2001). Results of these studies suggest survival rates are higher for fish that remain in the Sacramento River, although they do not provide quantitative information regarding what proportion of emigrants remain in the main river, compared to fish that enter the central Delta through the DCC and Georgiana Slough. Many potential influencing factors have been suggested as indirect effects to salmon survival that may occur when salmon move into the central and/or south Delta from the Sacramento River. Most of these have not been explicitly studied, but the available information is discussed below.

Length of Migration Route and Residence Time in the Delta

The length of time Chinook juvenile salmon spend in the lower rivers and the Delta varies depending on the outflow, time of year the salmon emigrate, and the developmental stage of the fish (Kjelson et al. 1982). Residence times tend to be shorter during periods of high flow relative to periods of low flow, and tend to be longer for fry than for smolts. A proportion of the Chinook salmon production enters the Delta as fry or fingerlings rather than as smolts (DFG 1998). Extending Delta residence time for any juvenile salmon likely increases their susceptibility to the cumulative effects of mortality factors within the Delta but also decreases susceptibility to mortality once they enter the ocean because they are larger.

Much attention has been given to the lower river migration route of salmon produced in the Sacramento watershed (Kjelson et al. 1982; Stevens and Miller 1983; Brandes and McLain 2001). At issue is the migration route via Georgiana Slough (about 37 miles to Chipps Island) compared to that in the Sacramento River from Ryde (27 miles to Chipps Island). Tests completed by FWS found survival is higher for late-fall-run Chinook smolts released in the Sacramento River at Ryde versus Georgiana Slough even though the Georgiana Slough route is only 1.4 times longer. Fish emigrating through Georgiana Slough probably have increased residence time in the Delta due to both the longer travel distance and the generally lower flows in the slough. These factors potentially increase the duration of a migrating salmon’s exposure to migration hazards. DCC closures are one of the actions being taken to reduce the likelihood that juvenile Chinook salmon will use an internal Delta route.

The following is an analysis of the relationships between the through-Delta survival of Coleman Hatchery late-fall-run Chinook smolts, Delta export losses of these fish in the fall and winter, and Delta hydrologic variables.

FWS has conducted these experiments using late-fall-run smolts since 1993. The purpose of the experiments is to determine what factors in the Delta affect yearling Chinook survival. One factor hypothesized to affect survival is emigration route. Based on previous results for fall-run salmon (Brandes and McLain 2001) FWS hypothesized yearlings emigrating through the interior Delta survive at a lower level than juveniles emigrating through the main stem Sacramento River (Brandes and McLain 2001). The juveniles can enter the interior Delta through Georgiana Slough or the DCC when it is open. Since FWS does not have measurements of gear efficiency for its Chipps Island trawl, and gear efficiency is assumed to vary from experiment to experiment, the survival estimates are considered indices of relative survival, not absolute numbers of survivors. To overcome this limitation, FWS uses the ratio of the survival indices of paired releases in the interior Delta and the main stem Sacramento River at Ryde. Evaluating the relative interior Delta survival cancels out differences in gear efficiency.

Models generated using the data from CWT’ed juvenile salmon support the conclusion that closure of the DCC gates will improve survival for smolts originating from the Sacramento Basin and emigrating through the Delta. The greatest mortality for smolts between Sacramento and Chipps Island was in the central Delta, and survival could be improved if the gates were closed (Kjelson et al. 1989). However, survival for salmon smolts released in the Sacramento River upstream of the DCC and Georgiana Slough are generally higher than those for releases made at downstream, mainstem locations (e.g. Ryde) or into the interior delta (Delta Action 8 Workshop, Brown and Kimmerer 2006). This trend suggests that experimental smolt releases intended to evaluate through delta survival may not be representative for naturally salmon outmigrating either because relatively few fish actually enter the interior delta or because smolt releases into Georgiana Slough are subject to uncontrolled experimental artifacts (e.g. shock effect, disorientation) which negatively bias observed survival rates.

In a generalized linear model that estimates the effects of various parameters on salmon smolt survival through the Delta, Newman and Rice (1997) found that mortality was higher for smolts released in the interior Delta relative to those released on the main stem Sacramento River. They also found lower survival for releases on the Sacramento River associated with the DCC gate being open. Using paired release data, Newman (2000) found that the DCC gate being open had a negative effect on the survival of smolts migrating through the Delta and was confirmed using Baysian and general linear modeling (Newman and Remington 2000).

The analyses to date appear to support the conclusion that closing the DCC gates will improve the survival of smolts originating from the Sacramento basin and migrating through the Delta. However, a recent particle tracking study (Kimmerer and Nobriga 2008) shows that DCC closure results in substantial compensatory increases in the proportion of Sacramento River water flowing into Georgiana Slough, Threemile Slough, and at the confluence of the Sacramento and San Joaquin Rivers. This result suggests that DCC closure may have less influence on the potential for central Delta fish mortality than previously supposed.

Radio-tracking studies of large juvenile salmon in the Delta (Vogel 2003) showed that localized currents created by the DCC operations and flood and ebb tide cycles greatly affected how radio-tagged Chinook moved into or past the DCC and Georgianna Slough. Chinook migration rates were generally slower than the ambient water velocities. Chinook were documented moving downstream past the DCC during outgoing tides and then moving back upstream and into the DCC with the incoming tide. When the DCC gates were closed, Chinook movement into Georgianna Slough was unexpectedly high, probably due to fish positions in the water column in combination with physical and hydrodynamic conditions at the flow split. Radio-tagged smolts moved large distances (miles) back and forth with the incoming and outgoing tides. Flow conditions at channel splits were a principal factor affecting the routes used by migrating salmon. Hydroacoustic tracking and trawling (Horn 2003, Herbold and Pierce 2003) showed that juvenile Chinook in the vicinity of the DCC were most actively moving at night and that they tend to go with the highest velocity flows. Water flow down through the DCC is much greater during the incoming tidal cycles than on the outgoing tides. These results suggest that during periods of high juvenile salmonid abundance in the vicinity of the DCC, closing the gates during the incoming tidal flows at night could reduce juvenile salmon movement into the central Delta through the DCC but may also increase movement into Georgianna Slough.

The survival indices and estimated losses of juvenile Chinook at the Delta fish facilities for all Georgiana Slough and Ryde releases since 1993 are illustrated in Figure 6-32. A unique symbol is used to highlight each paired experiment. In every paired experiment, the survival index of the Ryde release was higher than the Georgiana Slough release. Evaluating the Georgiana Slough and Ryde data separately, the Georgiana Slough releases all have low survival over a wide range of losses, and the Ryde releases all have low losses over a wide range of survival indices. Survival indices and losses for each of the Georgiana Slough and Ryde releases were not strongly correlated.

Delta hydrology is another factor hypothesized to affect juvenile Chinook survival, although hydrology should not be viewed independently from effects of migration route. The relative interior Delta survival of Coleman late-fall juveniles was plotted against Delta exports, Sacramento River flow, QWEST, and export to inflow ratio. The explanatory (hydrologic) variables are average conditions for 17 days from the day of release. This value was selected by FWS based on previously collected data on the average travel time from the release sites to Chipps Island. The combined CVP and SWP expanded losses from salvage for each of the Georgiana Slough and Ryde releases are also plotted against the same four hydrologic variables. A linear regression was calculated.

Regression and correlation analyses of these data (1993-98) indicate that the survival of smolts released into Georgiana Slough is increased as exports are reduced, relative to the survival of salmon released simultaneously at Ryde (Figure 6-33). These findings are the basis for reducing exports to further protect juvenile salmon migrating through the Delta. There was also a trend of increased loss of Georgiana Slough releases with increased exports, but it was not statistically significant (Figure 6-34).

Relationships between relative survival (Figure 6-35) or late-fall-run Chinook salvage at the Delta export facilities (Figure 6-36) and Sacramento River flow were not statistically significant. QWEST was also a poor predictor of both relative survival (Figure 6-37) and losses to the export facilities (Figure 6-38).

This data demonstrate that there may be relationships between certain factors and take of salmon. The data do not demonstrate, however, that the take affects the abundance of salmon.

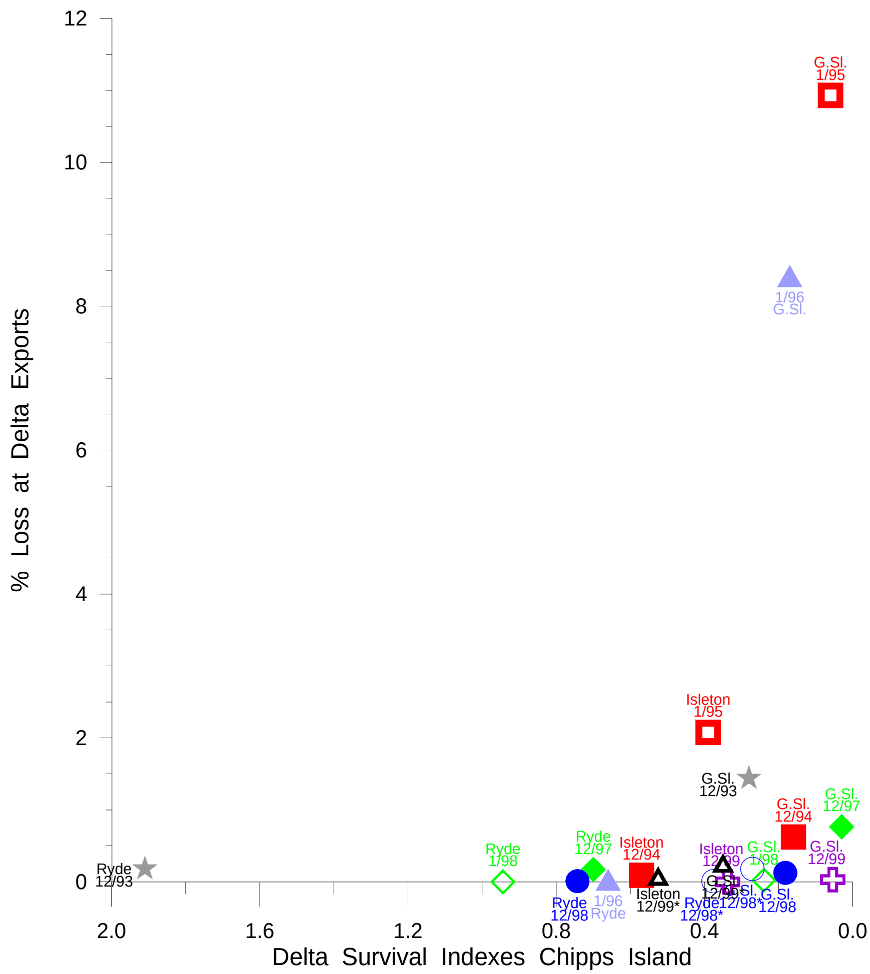

Figure 6-32 Scatterplot of Delta survival indices for Coleman Hatchery late-fall-run Chinook salmon from paired release experiments in the Sacramento River and Georgiana Slough v. percentage of the release group salvaged at the CVP and SWP Delta facilities.

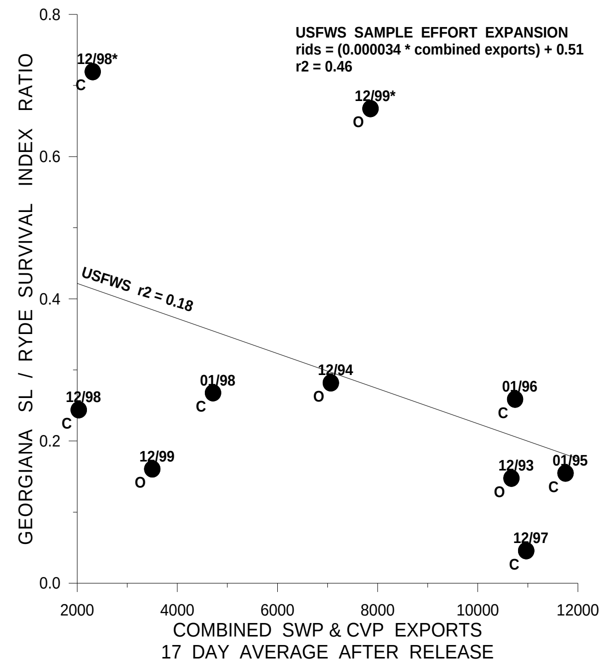

Figure 6-33 Relationship between Delta exports and the Georgiana Slough to Ryde survival index ratio. The export variable is combined average CVP and SWP exports for 17 days after release.

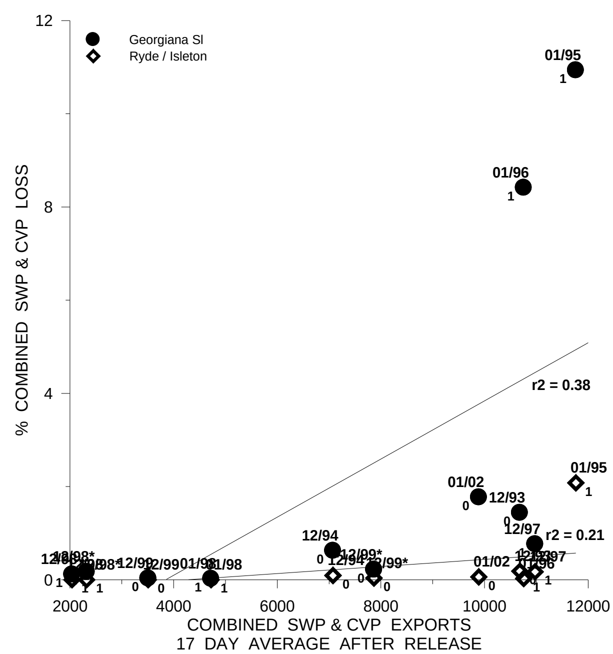

Figure 6-34 Relationship between Delta exports and percentage of late-fall-run CWT Chinook salmon Delta release groups salvaged at the CVP and SWP Delta facilities. The export variable is combined average CVP and SWP exports for 17 days after release.

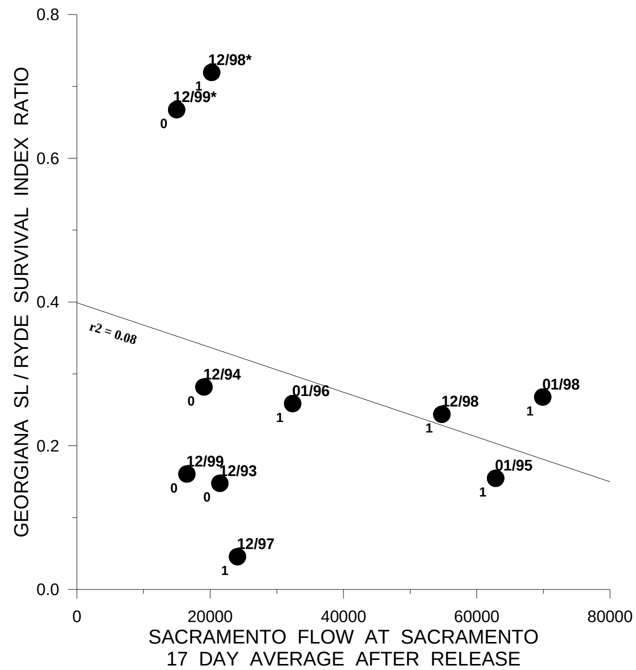

Figure 6-35 Relationship between Sacramento River flow and the Georgiana Slough to Ryde survival index ratio. The flow variable is average Sacramento River flow at Sacramento for 17 days after release.

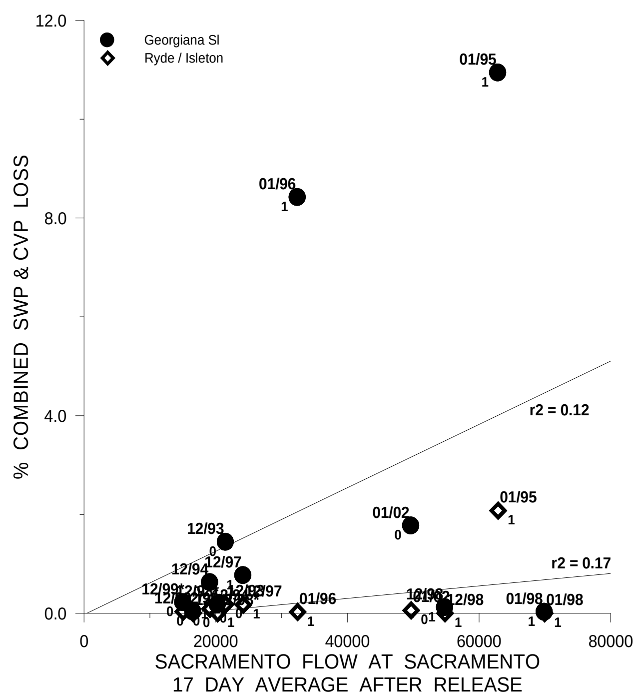

Figure 6-36 Relationship between Sacramento River flow and the percentage of late-fall-run CWT Chinook salmon Delta release groups salvaged at the CVP and SWP Delta facilities. The flow variable is average Sacramento River flow at Sacramento for 17 days after release. Georgiana Slough and Ryde releases are plotted separately.

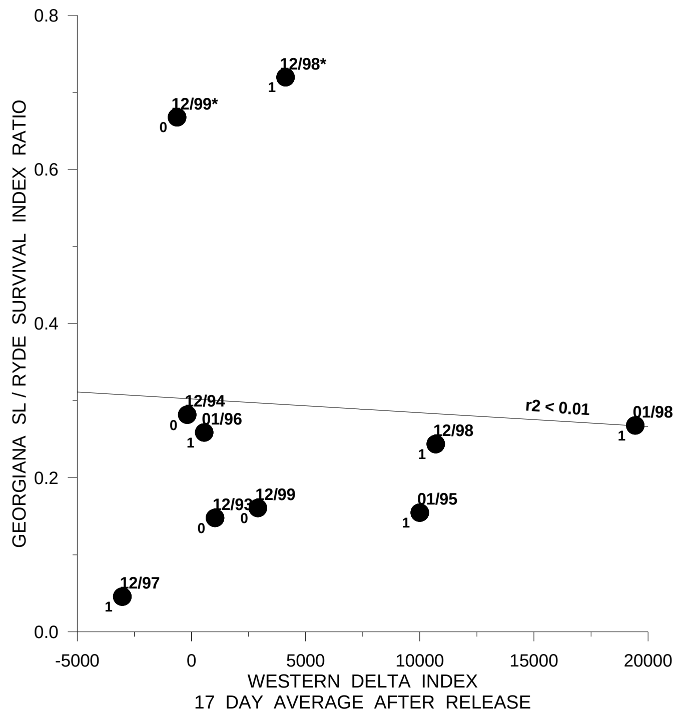

Figure 6-37 Relationship between QWEST flow and the Georgiana Slough to Ryde survival index ratio. The flow variable is average QWEST flow for 17 days after release.

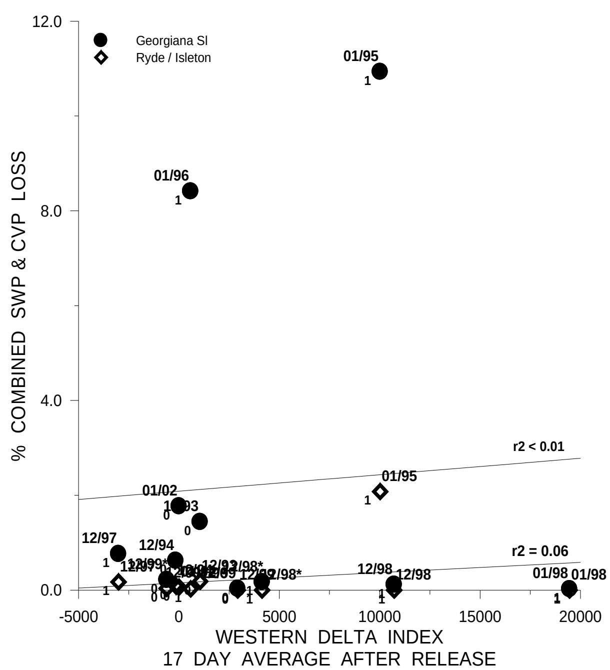

Figure 6-38 Relationship between QWEST flow and the percentage of late-fall-run CWT Chinook salmon Delta release groups salvaged at the CVP and SWP Delta facilities. The flow variable is average QWESTflow for 17 days after release.

There was no evidence of decreased relative survival with increased export to inflow ratio (Figure 6-39). The relationship between the export to inflow ratio and the percentage of late-fall-run yearlings salvaged was highly insignificant (Figure 6-40), providing no evidence that entrainment is the primary mechanism for reduced relative survival. Newman and Rice (1997), and more recent work by Newman (2000), suggests that reducing export pumping will increase the survival for smolts migrating through the lower Sacramento River in the Delta. Newman and Rice's updated 1997 extended quasi-likelihood model (Ken Newman, personal communication) provides some evidence that increasing the percent of Delta inflow diverted (export to inflow (E/I) ratio) reduces the survival of groups of salmon migrating down the Sacramento River, but the effect was slight and not statistically significant. In Newman's extended quasi-likelihood model using paired data, there was a significant export effect on survival (approximate *P* value of 0.02 for a one-sided test) (Newman 2000).

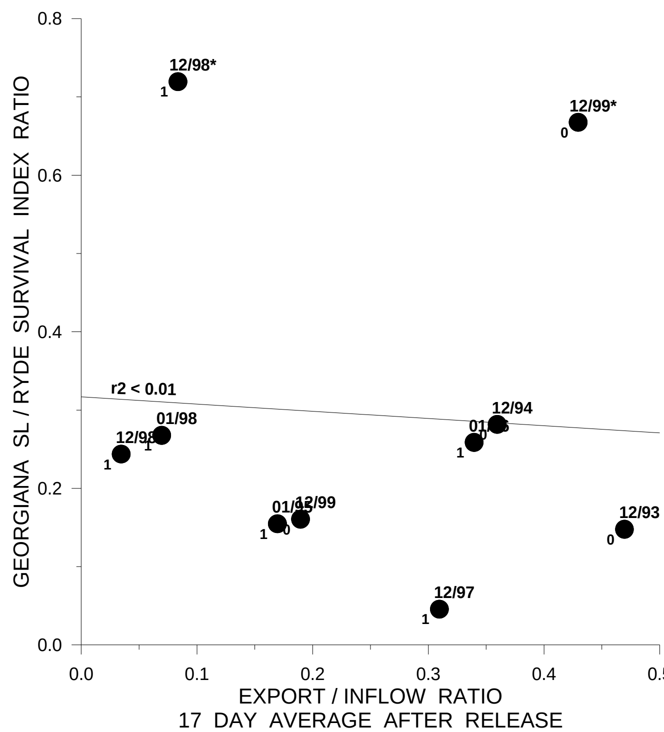

Figure 6-39 Relationship between Export/Inflow ratio and the Georgiana Slough to Ryde survival index ratio. The flow variable is average Export/Inflow ratio for 17 days after release.

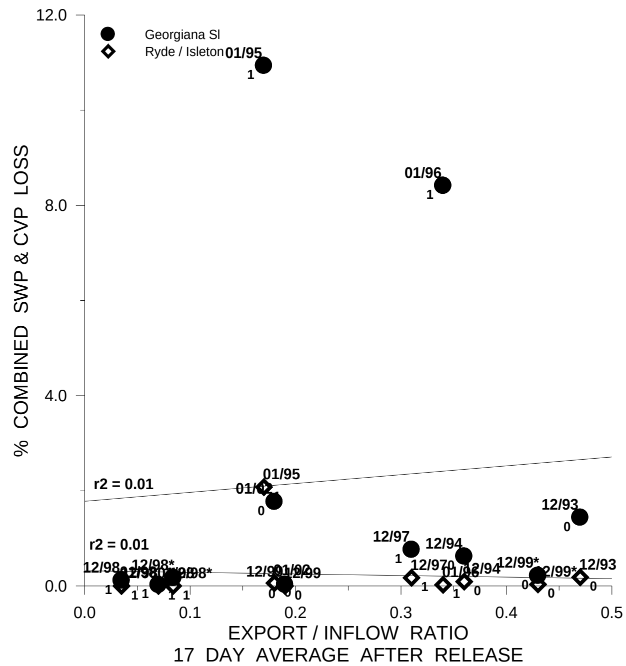

Figure 6-40 Relationship between Export/Inflow ratio and the percentage of late-fall-run CWT Chinook salmon Delta release groups salvaged at the CVP and SWP Delta facilities. The flow variable is average Export/Inflow ratio for 17 days after release.

In summary, no significant linear relationships were found between the Georgiana Slough-Ryde survival ratios for the Coleman late-fall-run releases, or the losses of these fish at the Delta export facilities, and commonly used Delta hydrologic variables. Although not statistically significant, relative interior Delta survival was high and losses of both Georgiana Slough and Ryde release groups were low during one of the two low-export experiments. At high exports, relative interior Delta survival was generally lower, with relatively high losses of Georgiana Slough release groups on two occasions. The data are not sufficient to provide the information necessary to quantify the benefit of export reductions to the Chinook population, due to the lack of information on the proportion of yearling emigrants using the DCC or Georgiana Slough routes. The relatively high degree of statistical uncertainty in most of the current modeled salmon mortality-Delta export relationships precludes highly confident conclusions whether or not exports are consistently and significantly impacting overall juvenile salmon mortality that ultimately affect population dynamics of fishery and spawner recruitment. The data are difficult to use for quantitative guidance in computing a take level or for suggesting a best mitigation measure. The middle poartion of the data sets are the most uncertain, while the extreme ends of the data relationships suggest with a higher degree of certainty that in years with higher fish abundance there is higher take at the pumps and very high export:inflow ratios result in higher take.

FWS Delta experiments were not designed to test the effects of Delta operations on fish released by hatchery personnel upstream of the Delta. However, releases of Coleman Hatchery late-fall-run yearlings in the upper Sacramento River have occurred coincident with the Delta experiments. These were not paired releases, but they were made within a week of the Delta experiments. A comparison of the direct losses of fish released in the upper Sacramento River, and in the Delta is illustrated in Figure 6-41. The losses of the upper Sacramento releases are all very small (less than 2 percent) even though the releases encompass a wide range of hydrologic conditions. In addition, the loss estimates for fish released upstream of the Delta are very similar to those calculated for the Ryde releases and most of the Georgiana Slough releases.

The survival indices of the upper Sacramento River releases may be helpful in the evaluation of effects on the population. This evaluation should be repeated when FWS completes the calculations of the upper Sacramento River releases' survival indices.

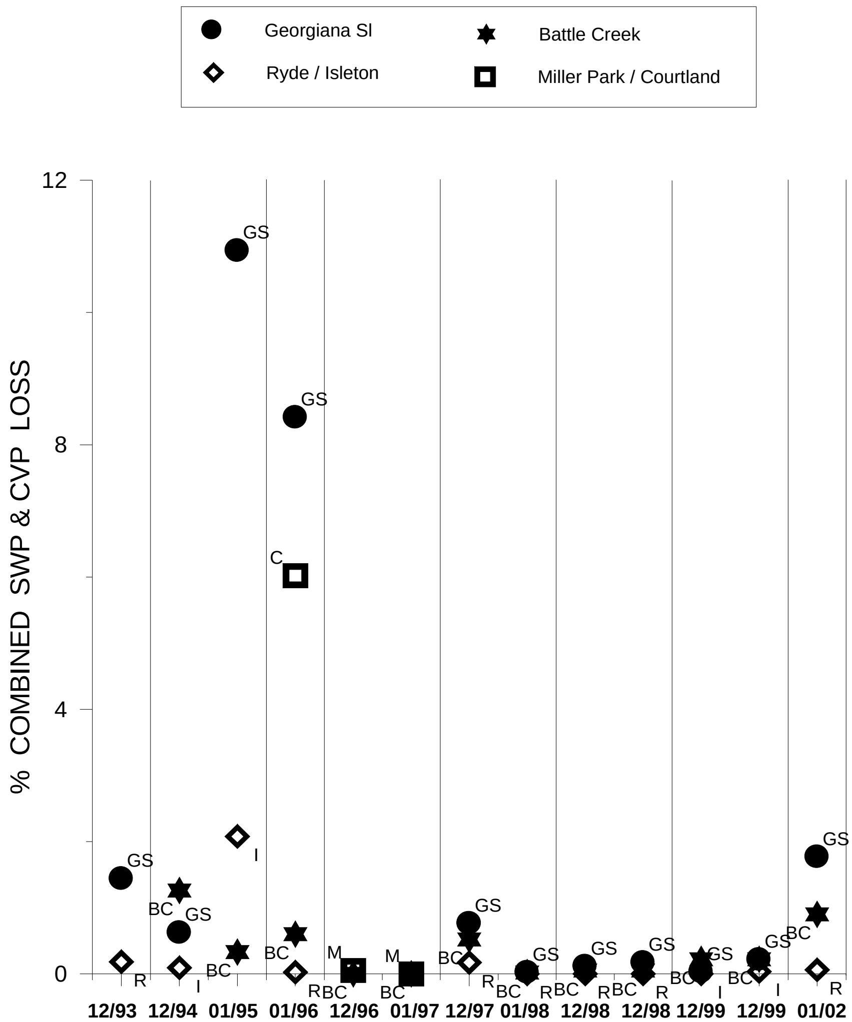

Figure 6-41 The percentage of late-fall-run CWT Chinook salmon Sacramento River and Delta release groups salvaged at the CVP and SWP Delta facilities grouped by release date.

Altered Flow Patterns in Delta Channels

Flow in the Delta results from a combination of river-derived flow and tidal movement. The relative magnitudes of river and tidal flow depend on location and river flow, with greater tidal dominance toward the west and at lower river inflows. The presence of channel barriers at specific locations has a major influence in flow dynamics. Tidal flows, because of the complex geometry of the Delta, can produce net flows independent of river flow and cause extensive mixing. During high-flow periods, water flows into the Delta from Valley streams. During low-flow periods, flow in the San Joaquin River is lower than export flows in the southern Delta, so water is released from reservoirs to provide for export and to meet salinity and flow standards in the Delta.

Particle tracking models, using data from direct measurement of river or channel velocities and volume transport at various Delta locations, have given us our most recent view of net flow in Delta channels. The general trend of model results seems to be that particles released in the Delta will move generally in the direction of river flow but the distribution of particles spreads extensively due to tidal dispersion. SWP, CVP and Delta island agricultural diversions impose a risk that the particle will be lost, as a result of entrainment at the diversions, from the system. This risk increases with greater diversion flow, initial proximity of the particle to the diversion, and duration of the model run.

Tidal flow measurements allow calculation of tidally averaged net flows. Results indicate that tidal effects are important in net transport, and that net flow to the pumping plants is not greatly affected by the direction of net flow in the western (lower) San Joaquin River.

With respect to fish movement, relatively passive life stages as Delta smelt larvae should move largely under the influence of river flow with an increasing behavioral component of motion as the fish develop. Larger, strong-swimming salmon smolts are more capable of moving independently but may still be affected to some degree by river flow. Particle tracking model results are not being used for the salmonid effects analysis.

Altered Salinity in the Delta

Increasing salinity westward through the estuary may provide one of many guidance cues to emigrating juvenile salmon (DFG 1998). Salinity levels in the central and south Delta are sometimes increased above ambient conditions by agricultural return waters from the south Delta and San Joaquin River. Salmon emigrating from the Sacramento River may move into the interior and south Delta in response to the elevated salinity levels. Agricultural return water increases salinity but has a different chemical composition than ocean water so does not likely attract salmon (Oltmann 1998).

Contaminants

The role of potential contaminant-related effects on salmon survival in the Delta is unknown (DFG 1998). Elevated selenium levels in the estuary may affect salmon growth and survival. The EPA is pursuing reductions in selenium loadings from Bay Area oil refineries, and the San Francisco Regional Water Quality Control Board has recommended an additional 30 percent reduction in selenium levels to adequately protect the Bay's beneficial uses. Nonpoint sources (including urban and agricultural runoff) contribute to elevated levels of polychlorinated biphenyls (PCBs) and chlorinated pesticides, which have been found in the stomach contents of juvenile salmon from the Bay, the Delta, and from hatcheries (NMFS 1997, as cited in DFG 1998). Collier (2002) found that juvenile Chinook salmon in Puget Sound estuaries were contaminated with sediment-associated contaminants such as PCBs. He found a reduced immune response affecting fitness in these fish. These contaminants may also affect lower-level food-web organisms eaten by juvenile salmon, or bioaccumulate in higher trophic level organisms like the salmon themselves.

During periods of low flow and high residence time of water through the Stockton deep-water ship channel, high oxygen demand from algae concentrations can deplete dissolved oxygen to lethal levels. This can result in a barrier to upstream and downstream migrating salmon and steelhead and could kill fish present in the area of low-dissolved oxygen.

Food Supply Limitations

Food limitation and changes in the Delta's invertebrate species composition have been suggested as factors contributing to abundance declines and/or lack of recovery of estuarine-dependent species such as Delta smelt and striped bass (Bennett and Moyle 1996; Kimmerer et al. 2000). There is no direct evidence of food limitation for salmon in the Delta or lower estuary (DFG 1998). However, there is evidence that some habitats (like nonnatal tributaries and Yolo Bypass) may provide relatively better feeding and rearing opportunities for juvenile Chinook than the channelized Sacramento River (Moore 1997; Sommer et al. 2001b). Improved feeding conditions contribute to faster growth rates for fish using these habitats. Faster growth may yield at least a slight survival advantage, but the current evidence is insufficient to demonstrate this effect with statistical significance (Sommer et al. 2001b).

Predation and Competition

Predation is an important ecosystem process that helps to structure and maintain fish communities. Predation effects are very difficult to discern in nature because they are typically nonlinear and density-dependent (Bax 1999). Even without human intervention, natural predation rates are affected by spatio-temporal overlap of predators and prey, activity and metabolic needs of predators and prey at different temperatures, efficiency of different types of predators at capturing different prey, and the relative availability of appropriate prey types. Every Central Valley and Pacific Ocean predator's diet includes prey items other than salmon. Anthropogenic changes to ecosystems can alter these predator-prey dynamics, resulting in artificially elevated predation rates (Pickard et al. 1982a; Gingras 1997). Perhaps the most significant example of altered predation rates on Chinook salmon is human predation through harvest, which is discussed in the next section. Excepting direct human harvest, there are three factors that could affect predation dynamics on juvenile salmon in the project area. These are changes in the species composition and diversity of potential salmon predators through exotic species introductions, changes in the abundance of potential salmon predators (both of these may or may not be coupled to habitat alteration), and the placement of large structures in the migratory pathways of the salmon.

Striped bass and largemouth bass were introduced into the system and although they have coexisted with Chinook salmon, the Delta ecosystem has changed and altered this relationship. Chinook may be more sensitive to predation by these species now than in the past.

Changes in the species composition of predators can cause fish declines. Many potential salmon predators have been introduced to Central Valley waterways, particularly during the latter part of the 1800s and the early part of the 1900s (Dill and Cordone 1997). These included piscivorous fishes like striped bass, largemouth bass, crappies, and white catfish. Channel catfish is another common Delta-resident piscivore that seems to have become established considerably later, during the 1940s. All of these fish were establishing Central Valley populations during a time spring-run Chinook were declining for a variety of reasons. This makes it difficult to determine whether one or more of these predatory fishes significantly affected juvenile salmon survival rates.

There have been substantial changes in the abundance of several potential Chinook salmon predators over the past 20 to 30 years. These changes could have altered the predation pressure on salmon, but the data needed to determine this have not been collected. A few examples of changes in potential predator abundance are discussed below.

The striped bass is the largest piscivorous fish in the Bay-Delta. Its abundance has declined considerably since at least the early 1970s (Kimmerer et al. 2000). Both striped bass and spring-run and winter-run Chinook were much more abundant during the 1960s (DFG 1998) when comprehensive diet studies of striped bass in the Delta were last reported on. During fall and winter 1963-1964, when spring-run yearlings and juvenile winter-run would have been migrating through the Delta, Chinook salmon only accounted for 0 percent, 1 percent, and 0 percent of the stomach content volume of juvenile, subadult, and adult striped bass respectively (Stevens 1961). During spring and summer 1964, Chinook salmon accounted for up to 25 percent of the stomach content volume of subadult striped bass in the lower San Joaquin River, although most values were less than 10 percent. Presumably most of these spring and summer prey were fall-run since they dominate the juvenile salmon catch during that time of year. These results do not suggest striped bass had a major predation impact on spring-run Chinook during the year studied, though a year is not adequate to draw firm conclusions. Despite lower population levels, striped bass are suspected of having significant predation effects on Chinook salmon near diversion structures (see below).

Although striped bass abundance has decreased considerably, the abundance of other potential Chinook salmon predators may have increased. Nobriga and Chotkowski (2000) reported that the abundance of virtually all centrarchid fishes in the Delta, including juvenile salmon predators like largemouth bass and crappies, had increased since the latter 1970s, probably as a result of the proliferation of Brazilian water weed, *Egeria densa*. The increase in largemouth bass abundance is further corroborated by DFG fishing tournament data (Lee 2000). Predation by centrarchids such as largemouth bass and bluegill on salmon is probably minor because centrarchids are active at higher temperatures than those preferred by salmon so the two species are not likely present in the same areas at the same time.

Surveys at the Farallon Islands also indicate populations of pinnipeds (seals and sea lions) have increased substantially since the early 1970s (Sydeman and Allen 1999). High concentrations of seals and sea lions at the relatively narrow Golden Gate could impact the abundance of returning adult salmon. However, the extent to which marine mammals target the salmon populations over other prey types has not been studied thoroughly.

Predatory fish are known to aggregate around structures placed in the water, where they maximize their foraging efficiency by using shadows, turbulence, and boundary edges. Examples include dams, bridges, diversions, piers, and wharves (Stevens 1961, Vogel et al. 1988, Garcia 1989, Decoto 1978, all as cited in DFG 1998).

In the past, salmon predation losses to Sacramento pikeminnow predation at RBDD were sometimes high, particularly after large releases of juvenile Chinook from Coleman Hatchery. Currently, predation mortality on juvenile salmonids at RBDD is probably not elevated above the background in-river predation rate (DFG 1998). All spring-run juvenile emigrants should pass RBDD during the gates-out period based on average run timing at RBDD (FWS 1998, as cited in DFG 1998). Winter-run juveniles also should pass primarily during gates out periods. During the gates-out operation (September 15 through May 14) fish passage conditions are run-of-the-river and most of the adverse effects associated with the diversion dam have been eliminated. The structure in the river may congregate predators somewhat but salmonids will not be flushed through gates and likely disoriented as happens when the gates are closed. Gates-out operations are also important in preventing the large aggregations of Sacramento pikeminnow and striped bass that once occurred at RBDD.

The GCID diversion near Hamilton City is another one of the largest irrigation diversions on the Sacramento River (DFG 1998). Predation at this diversion is likely most intense in the spring when Sacramento pikeminnow and striped bass are migrating upstream, juvenile Chinook are migrating downstream, and irrigation demands are high. Predation may be significant in the oxbow and bypass system (DFG 1998), but this was not substantiated during 2 years of study in the GCID oxbow (Cramer et al. 1992). The GCID facility is an atypical oxbow with cooler temperatures and higher flows than most.

Predation in Clifton Court Forebay (CCF) has also been identified as a substantial problem for juvenile Chinook. Between October 1976 and November 1993, DFG conducted 10 mark and recapture experiments in CCF to estimate prescreen loss (which includes predation) of fishes entrained to the forebay (Gingras 1997). Eight of these experiments involved hatchery-reared juvenile Chinook salmon. Prescreen loss (PSL) rates for juvenile fall-run Chinook ranged from 63 percent to 99 percent, and for late-fall-run smolts they ranged from 78 percent to 99 percent. These studies were used to establish the standard prescreen loss figures used today. PSL of juvenile Chinook was inversely proportional to export rate, and striped bass predation was implicated as the primary cause of the losses. Although a variety of potential sampling biases confound the PSL estimates, the results suggest salmon losses are indeed high at the times of year when the studies were conducted. Studies being completed by DWR seek to determine prescreen loss rates for steelhead.

Predation studies have also been conducted at the release sites for fish salvaged from the SWP and CVP Delta pumping facilities (Orsi 1967, Pickard et al. 1982, as cited in DFG 1998). Orsi (1967) studied predation at the old surface release sites, which are no longer in use. Pickard et al. (1982a) studied predation at the currently used subsurface release pipes. Striped bass and Sacramento pikeminnow were the primary predators at these sites. They were more abundant and had more fish remains in their guts at release sites than at nearby control sites. However, Pickard et al. (1982a) did not report the prey species composition found in the predator stomachs. The current release sites release fish in deeper water where tidal currents distribute fish over 7 miles.

DFG conducted predator sampling at the Suisun Marsh Salinity Control Gates (SMSCG) from 1987 through 1993 and concluded the striped bass population increased substantially in the vicinity of this structure (DWR 1997). However, the sampling during 1987 through 1992 did not include a control site to measure background predation potential. During the 1993 study, a control site was added 2 miles upstream. Results from the 1993 study showed no significant differences in catch of predatory fishes between the control site and sampling sites at the SMSCG.

An analysis of the Suisun Marsh Monitoring database indicated few juvenile Chinook salmon (of any race) occur in Suisun Marsh (only 257 were captured by beach seine and otter trawl between 1979 and 1997). This suggests that even if striped bass have increased in abundance at SMSCG, they may not pose a predation problem for the winter-run or spring-run population as a whole. This hypothesis is supported by diet data from striped bass and Sacramento pikeminnow collected near the SMSCG. Only three Chinook salmon were found during 7 years of diet studies (Heidi Rooks, personal communication, 1999). Dominant striped bass prey were fishes associated with substrate, such as three-spine stickleback, prickly sculpin, and gobies (DWR 1997). Dominant pikeminnow prey types were gobies and smaller pikeminnows. Adult Chinook are too large to be consumed by any predatory fishes that inhabit the Delta. Pinnipeds seasonally occur in areas of the Delta to prey on immigrating salmonids.

Ocean Conditions and Harvest

The loss of inland salmonid habitat in the Central Valley to human development has resulted in substantial ecological effects to salmonids (Fisher 1994; Yoshiyama et al. 1998). Ocean sport and commercial fisheries harvest large numbers of adult salmon. Central Valley salmon populations are managed to maintain a fairly consistent level of spawner escapement of 122,000 to 180,000 fall-run Chinook salmon in the Sacramento River watershed (Figure 6-43). The ocean fishery is largely supported by hatchery-reared fall-run Chinook salmon. A large hatchery system is operated to allow these levels of harvest. Harvest may be the single most important source of salmon mortality, but all the hatchery fish probably would not be reared and released if there were no ocean harvest. During 1994 an estimated 109 coded-wire tagged winter-run were harvested in the ocean troll fishery off the California coast while escapement in the Sacramento River was estimated at only 144 fish (Table 5-11). Major changes in ocean harvest regulations were made in 1995, due to ESA concerns for winter-run Chinook. Harvest levels on Central Valley stocks have been lower since 1995. Strong year-classes like 1988 and 1995 were so heavily fished that their reproductive potential was never realized. The 2000 Central Valley fall-run Chinook spawning escapement of 478,000 was the highest recorded since 1953 when an escapement of 478,000 also occurred. The high escapement in 2000 was probably due to above-average precipitation during freshwater residency and good ocean conditions combined. The high escapement in 2000 was exceeded in 2001 when an estimated escapement of 599,158 occurred and again in 2002 with an escapement of 850,000. The reason for the high escapement in 2001 was probably because most of the Chinook were concentrated north of the open commercial fishing area and thus were missed by the commercial fisheries. The commercial harvest in 2001 of 179,600 Chinook was the second lowest harvest since 1966. The Central Valley Index of abundance (commercial landings + escapement) in 2001 was 806,000 Chinook, which was actually lower than the forecasted production based on prior year 2-year-old returns. The Central Valley harvest index in 2001 of 27 percent (percent of production harvested) was the lowest ever recorded. The next lowest harvest index was 51 percent in 1985 (PFMC 2002). This illustrates the substantial effect of ocean harvest on Chinook escapement. Restrictions on ocean harvest to protect southern Oregon and northern California coho salmon, Klamath Chinook, and

Central Valley winter-run and spring-run played a role in the recent high escapements and contributed to the recent increases in winter-run and spring-run escapement to the Central Valley.

Returns of several West Coast Chinook and coho salmon stocks were lower than expected in 2007. In addition, low jack returns in 2007 for some stocks suggest that 2008 returns will be at least as low. Central Valley fall run Chinook escapement was estimated to have been less than 25 percent of predicted returns and below the escapement goal of 122,000 – 180,000 for the first time since the early 1990's and continuing a declining trend since the recent peak abundance in 2002. For the spring and summer of 2005 (the ocean-entry year for 2004 brood fall Chinook and 2003 brood coho), two approaches to estimating ocean suitability for juvenile salmon both indicated very poor conditions for salmon entering the ocean, indicating poor returns for coho in 2006 and age 3 fall Chinook in 2007. Coast-wide observations showed that 2005 was an unusual year for the northern California Current, with delayed onset of upwelling, high surface temperatures, and very low zooplankton biomass. These poor ocean conditions provide a plausible explanation for the low returns of Central Valley fall Chinook in 2007 and coho in 2006 and 2007. Consistent with Central Valley fall Chinook record low jack return in 2007, the ocean indicators would predict very low fall Chinook adult returns in 2008 (Varanasi and Bartoo, 2008).

MacFarlane et al (2008) report on the Wells Ocean Productivity Index (WOPI), a composite index of 13 oceanographic variables and indices, weighted heavily by sea level height, sea surface temperature, upwelling index, and surface wind stress, has been used to accurately predict zooplankton, juvenile shortbelly rockfish, and common murre production along the California coast, and is thus a valid indicator of ocean productivity. Index values for the spring-summer of 2005 and 2006 were low, indicating poor conditions for growth and survival (Figure 6-42). In fact, only the El Niño years (1982-83, 1992-93, 1999) had lower WOPI values. The WOPI assesses conditions on a local scale for California, but has tracked another index, the Northern Oscillation Index (NOI), which is based on the strength of the North Pacific high pressure cell and describes a broader region of the North Pacific Ocean. In 2005 and 2006, the WOPI decoupled from the NOI, suggesting local conditions on the California coast were worse than for the larger North Pacific region. The WOPI also predicts low Chinook returns for 2008.

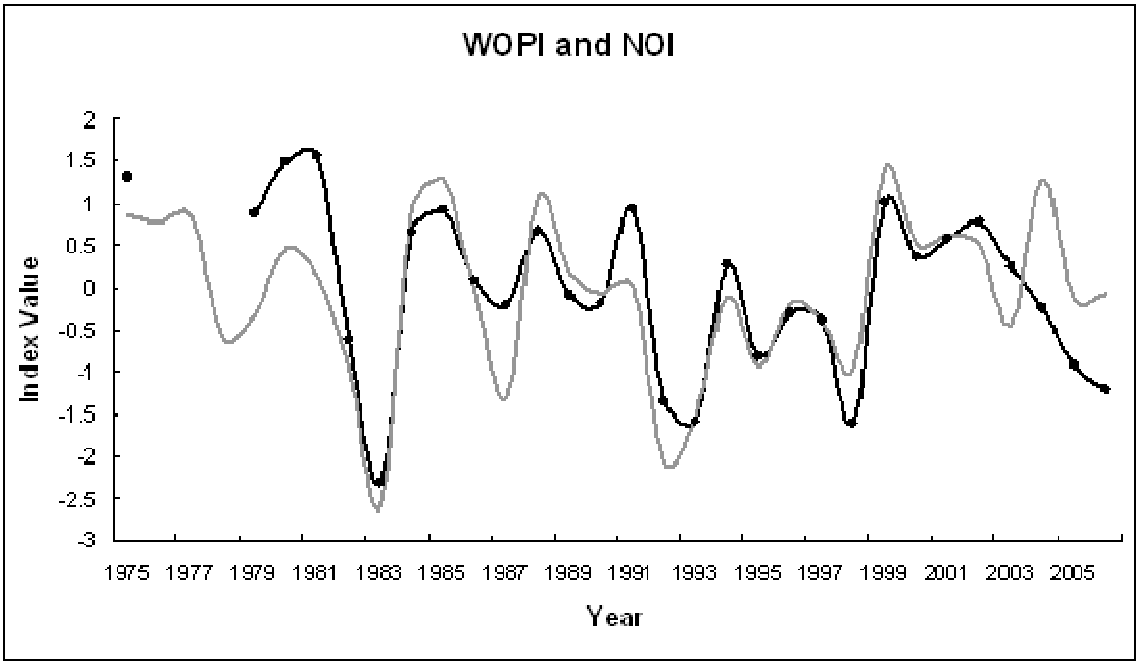

Figure 6-42 The Wells Ocean Productivity Index (WOPI, black line) and the Northern Oscillation Index (NOI, grey line) between 1975 and 2006. Values derived for March-August. Note the close fit between the larger-scale NOI, which represents the strength of the North Pacific high pressure cell, and local-scale WOPI, except for recent years (2004-2006), suggesting a change in local conditions. Low values indicate conditions for lower biological productivity. Source: MacFafrlane et al (2008)

The percentage of Central Valley salmon harvested in ocean fisheries has averaged 60 percent since 1970 (Figure 6-43), and has exceeded 70 percent several times. The average number of Central Valley Chinook landed in ocean fisheries between 1970 and 2006 was 430,000 fish per year (all races combined). Survival rates of young salmon are very low, meaning a large number must enter the ocean to support an average annual fishery of 430,000 fish. Beamish and Neville (1999) reported that smolt to adult survival rates for Fraser River (British Columbia) Chinook ranged from about 0.2 percent to about 6.8 percent, with an average during good ocean conditions of 4.8 percent. If the average Chinook smolt to adult survival is 4.2 percent and the pumps take 2 percent of winter-run, this take would equate to 67 adults out of a winter-run escapement of 7,000, a 0.96 percent reduction in number of adults.

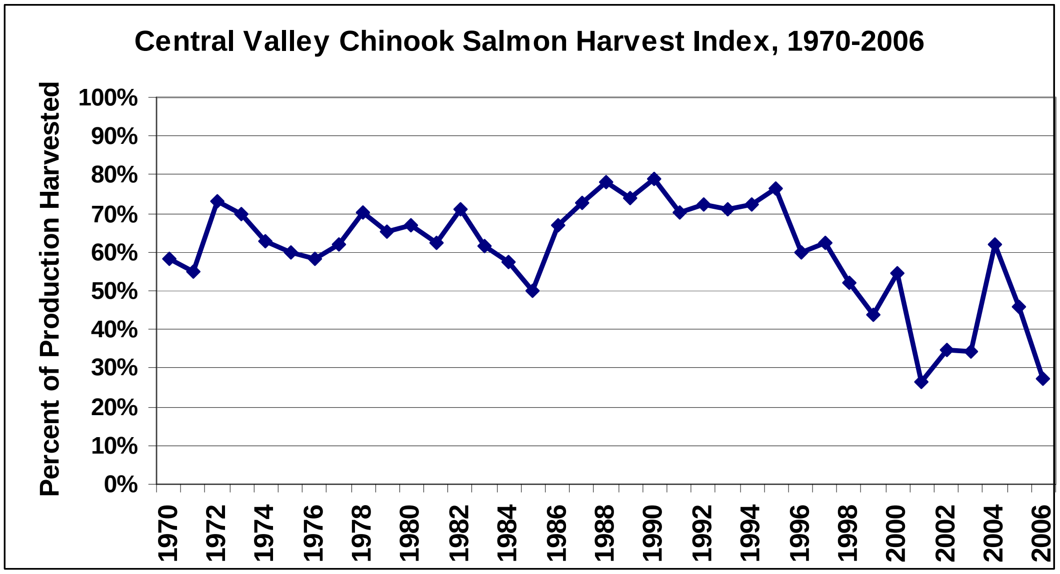

Figure 6-43 Central Valley fall-run Chinook salmon Ocean Harvest Index, 1970–2006.

Assuming Central Valley smolt to adult survival rates also average 4.8 percent, 9.2 million Central Valley smolts would have to enter the ocean every year to support the average ocean fishery. Production of fall-run Chinook at Central Valley hatcheries exceeds 9.2 million smolts, and may more than support the entire ocean fishery. This number is actually higher than the total number of young salmon salvaged at both the SWP and CVP facilities (about 7 million or 230,000 per year) during the 30-year period 1970 through 1999. Salvage does not account for indirect losses attributable to SWP/CVP project operations, which may be substantial and are estimated to be five times the direct losses. Nonetheless, this suggests that on average, indirect losses from Delta operations would have to be more than 30 times higher than the number salvaged to equal the adult-equivalent mortality contributed by the ocean fisheries, assuming 4.8 percent smolt to adult survival. Considering the SWP/CVP projects are exporting a high portion of the total freshwater outflow, this suggests that salmon are finding their way out of the system and not being diverted at the facilities in direct proportion to the diversion rate. Both the ocean harvest and Delta salvage are managed to protect the ESA-listed races.

Recent advances in the scientific understanding of interdecadal changes in oceanographic conditions on marine fisheries were outlined in Chapter 4. The abundance of pink, chum, and sockeye salmon appears to fluctuate out of phase with Chinook stocks to the south (Beamish and Bouillon 1993, as cited in Bakun 1999; Beamish and Neville 1999). Beamish and Neville (1999) found Chinook smolt survival rates to adulthood in the Strait of Georgia (Fraser River stocks) declined from 4.8 percent prior to abrupt changes in local oceanographic conditions during the latter 1970s, to 0.7 percent after the oceanographic changes. As a consequence, adult Chinook returns to the Fraser River system decreased to about 25 percent of 1970s levels even though approximately twice as many smolts were entering the Strait during the 1980s. The specific reasons for decreased smolt survival rates were unclear, but the authors suggested that decreased coastal precipitation and resultant decreased river discharge, increased temperatures in the strait and an increased tendency for spring plankton blooms to precede the peak smolt immigration into the strait were likely contributing factors. In addition, aggregations of opportunistic predators like spiny dogfish, may have contributed to lower hatchery smolt survival rates due to the increasing density of young fish added into the Strait of Georgia by hatcheries.

No dramatic change in Central Valley salmon abundance occurred during the latter 1970s (Figure 6-44), like the one observed in Fraser River stocks. In fact, Central Valley salmon abundance was remarkably consistent during the 1970s. However, the variation in abundance of Central Valley Chinook increased dramatically beginning in 1983. Since 1983, Central Valley salmon abundance has varied by a factor of three during two periods of 5 years or less.

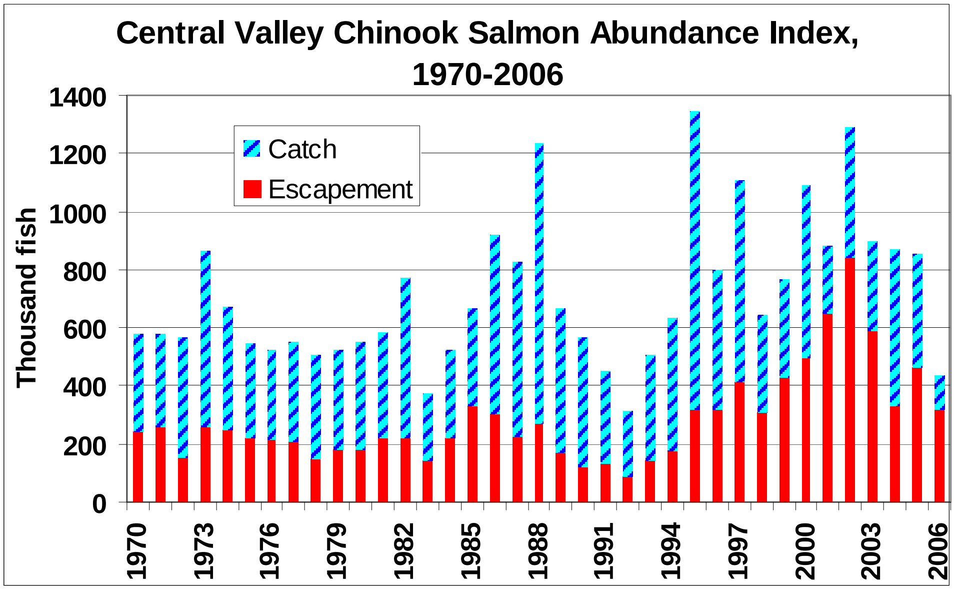

Figure 6-44 Central Valley Chinook salmon (all races) abundance index, 1970–2006 (PSFMC data).

All Central Valley Chinook salmon stocks have overlapping ocean distributions (DFG 1998). This may provide the opportunity for occasional overharvest of a rare stock like winter or spring-run, relative to the abundant target stock, fall-run Chinook salmon. This situation has occurred occasionally in the past. The brood year 1976 Feather River Hatchery spring-run was fished at levels about five to 13 times higher than the background rate on coded wire tagged fall-run Chinook by both the recreational and commercial fisheries for several years (Figure 6-45) This may also have happened to a lesser degree with the brood year 1983 spring-run from FRH. For whatever reason, these year classes remained particularly susceptible to the ocean fisheries for the duration of their ocean residency. Current ocean and freshwater fishing regulations are designed to avoid open fishing in areas where winter-run and spring-run are concentrated. Estimated harvest of winter-run Chinook salmon coded-wire tagged release groups are shown in Table 6-11.

Table 6-11 Winter-run Chinook estimated harvest of code-wire tagged release groups (expanded from tag recoveries) by harvest location (data from RMIS database).

Winter run recoveries (estimated) from RMIS database, 4/15/2003

Sum of estimated_number	run_year											
recovery_location_name	1980	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Grand Total
AMER.R. TO COLUSA									8	17		25
BATTLE CREEK												
BIG LAG.-CENTERV.BEA									4			4
BROOKINGS SPORT 6									3			3
C.VIZCAINO-NAVARR.HD	6									8		14
CARQUINEZ TO AMER. R									14			14
COLEMAN NFH												
COLUSA TO RBDD										67		67
COOS BAY SPORT 5											2	2
COOS BAY TROLL 5									4		4	8
FORT ROSS-PIGEON PT	24	5	55	8	4	18		8	25			147
GSPTS YEO PT								3				3
NEWPORT SPORT 4										2		2
NEWPORT TROLL 4										3		3
NTR 02W-118							6					6
NWTR 026-000											7	7
PIGEON PT.-POINT SUR	7	7	34	5	5	19			86	22	34	218
PIGEON PT-CA/MEX.BOR									8			8
POINT SUR-CA/MEX.BOR			20	9	5	10			3	14	8	68
PT.ARENA-PT.REYES										7	15	22
PT.REYES-PIGEON PT.										18	27	45
PT.SN.PEDRO-PIGN.PT.										4	8	12
SACRA.R, ABO FEATHER												
Grand Total	37	13	109	22	13	47	6	11	154	162	105	679
Escapement	1,142	349	144	1,159	1,001	836	2,930	3,288	1,352	7,572	7,337	27,110
# CWT fish released 2 years prior	9,988	10,866	27,383	17,034	41,412	48,154	4,553	20,846	147,393	30,433	162,198	530,653
Estimated % of cwt released fish recovered	0.37%	0.12%	0.40%	0.13%	0.03%	0.10%	0.13%	0.05%	0.10%	0.53%	0.06%	0.13%

In addition to occasional effects to particular year-classes, ocean fishing may affect the age structure of Central Valley spring-run Chinook. A DFG (1998) analysis using CWT spring-run from the Feather River Hatchery estimated harvest rates were 18 percent to 22 percent for age-3 fish, 57 percent to 85 percent for age-4 fish, and 97 percent to 100 percent for age-5 fish. Since length tends to be correlated with age, and fecundity is correlated with length (DFG 1998), the effect of ocean fishing on the age structure of the population has effects on population fecundity.

Recent papers have reemphasized the ecological importance of salmon carcasses to stream productivity (Bilby et al. 1996, 1998; Gresh et al. 2000). As mentioned in the preceding chapter on steelhead, the substantial declines in mass transport of marine-derived nutrients to streams due to overall salmonid declines may also affect growth and survival of juvenile salmonids (Bilby et al. 1996, 1998). Levels of ocean harvest that attempt to maximize production from a minimum of adults may exacerbate nutrient deficiencies (Gresh et al. 2000).

In addition to ocean harvest, legal and illegal inland fishing for spring-run salmon undoubtedly occurs at fish ladders and other areas where adult fish are concentrated, such as pools below dams or other obstructions (DFG 1998). Mill, Deer, and Butte Creeks, as well as other tributaries with spring-run populations, are particularly vulnerable to poaching during the summer holding months because of the long period in which adults occupy relatively confined areas. The significance of illegal freshwater fishing to the spring-run salmon adult population, however, is unknown. The increased law enforcement programs have reduced poaching. The Central Valley angler survey was restarted during 2007 and should yield valuable harvest data.

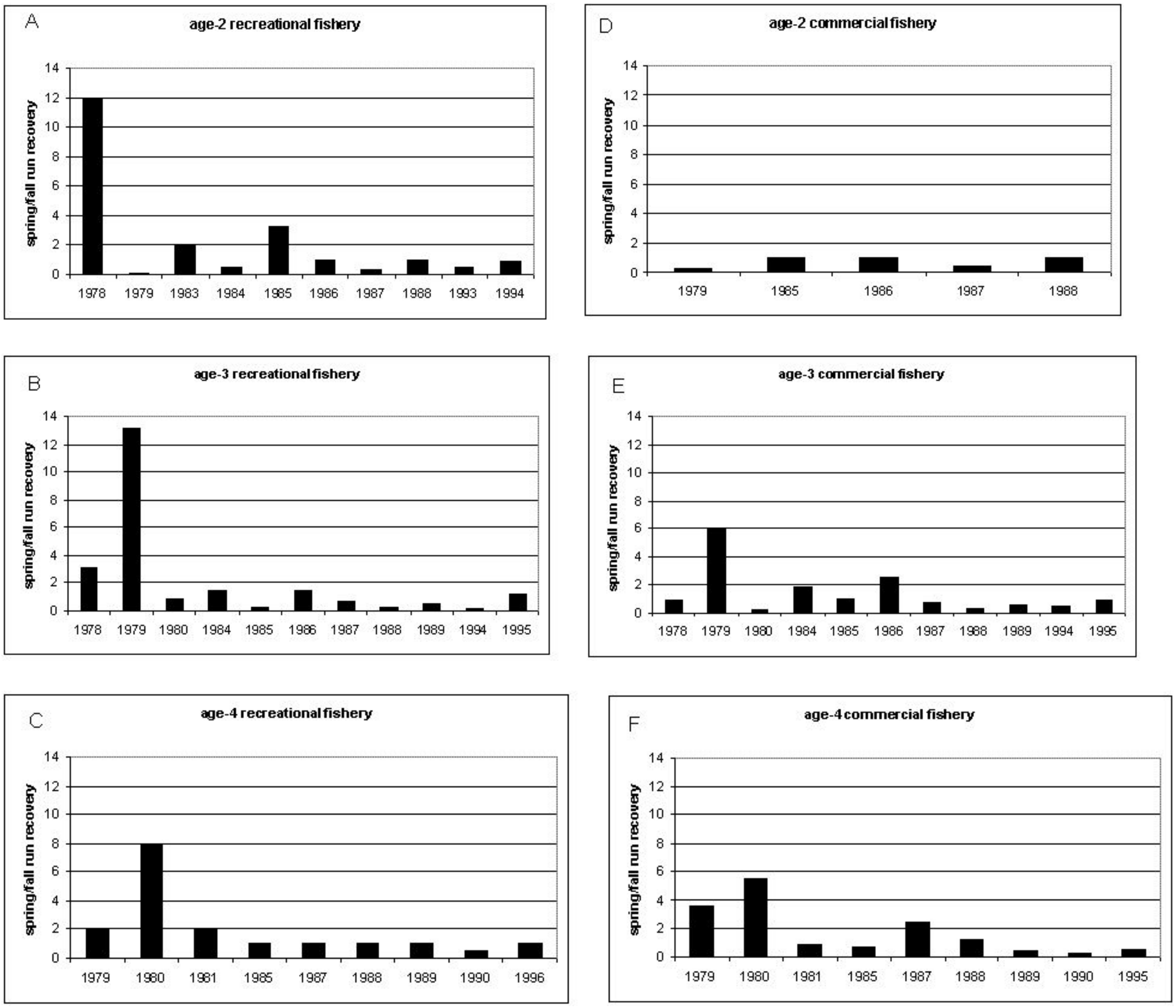

Figure 6-45 Coded-wire tag recovery rate of Feather River Hatchery spring-run Chinook salmon relative to the coded-wire tag recovery rate of Central Valley fall-run Chinook salmon. Data were taken from DFG (1998), and are presented individually for recreational and commercial fisheries for age-2, age-3, and age-4 fish. Values greater than one indicates fishing pressure above the level sustained by the fall-run.

Hatchery Influence

Central Valley Chinook salmon runs are heavily supplemented by hatcheries to mitigate for the loss of habitat when dams were built. Table 6-12 lists salmon hatcheries operating in the Central Valley and their yearly production goals. When all hatcheries reach their production goals, over 34 million Chinook smolts are released into the system. This large number of smolts in the common ocean environment may result in competition with wild fish in times of limited food resources. Chinook and coho salmon are also produced in the Trinity River hatchery and released in the Trinity River. NMFS now requires HGMP plans to address effects of hatchery operations on listed species. HGMPs are being developed at Nimbus, Feather River, Coleman, and Trinity River Hatcheries under separate ESA constultation processes.

Table 6-12 Production data for Central Valley hatchery produced Chinook salmon.

Hatchery	River	Chinook Runs	Yearly Production Goal
Coleman NFH	Battle Creek	Fall, late-fall, winter	13,200,000 smolts
Livingston Stone	Sacramento	winter	
Feather River	Feather	Fall, spring	~14,000,000 smolts
Nimbus	American	Fall	4,000,000 smolts
Mokelumne River	Mokelumne	Fall	2,500,000 post smolt
Merced River	Merced	Fall	960,000 smolts
Total			34,660,000
Source: DFG and NMFS 2001.			

The percentage of the Central Valley fall-run Chinook adult escapement taken at hatcheries has shown a gradual increase since 1952 (Figure 6-46). Hatcheries have likely helped to maintain Chinook populations at a level allowing a harvestable surplus (not in 2008 though). However, hatcheries may have reduced genetic fitness in some populations, especially the more depressed runs, by increasing hybridization between different runs. Fish have been transferred between watersheds resulting in various genetic effects. Livingston Stone Hatchery produces winter-run Chinook and has assisted in the recent population increases for winter-run.

A majority of hatchery releases are trucked to downstream release locations and in all except Coleman and Livingston Stone hatcheries are trucked to San Pablo Bay. The downstream releases increase survival of the hatchery stocks but also increase the proportion of hatchery relative to wild survival and increase straying. Recent CWT data shows that a good portion of the Chinook in spring-run streams like Clear Creek and Mill Creek are of hatchery origin (NOAA Fisheries 2003). A recent review of hatchery practices (DFG and NOAA fisheries 2001) recommended reducing the practice of using downstream releases and instead releasing fish in the river of origin. This practice would reduce the survival of hatchery fish, but could also reduce the in-river survival of wild fish when the carrying capacity of the habitat is surpassed resulting in intraspecific competition. Currently the proportion of hatchery versus wild fish contributing to fisheries and to the escapement is unknown. Barnett-Johnson et al (2007) examined otoliths of hatchery and wild fish from the California coastal fishery and estimated that the contribution of wild fish was only 10 percent plus or minus 6 percent, indicating hatchery supplementation may be playing a larger role in supporting the central California coastal fishery than previously assumed. A program to mark 25 percent of fall-run Chinook salmon released was begun in the 2007 release year. This program should substantially improve hatchery effects evaluation capabilities.

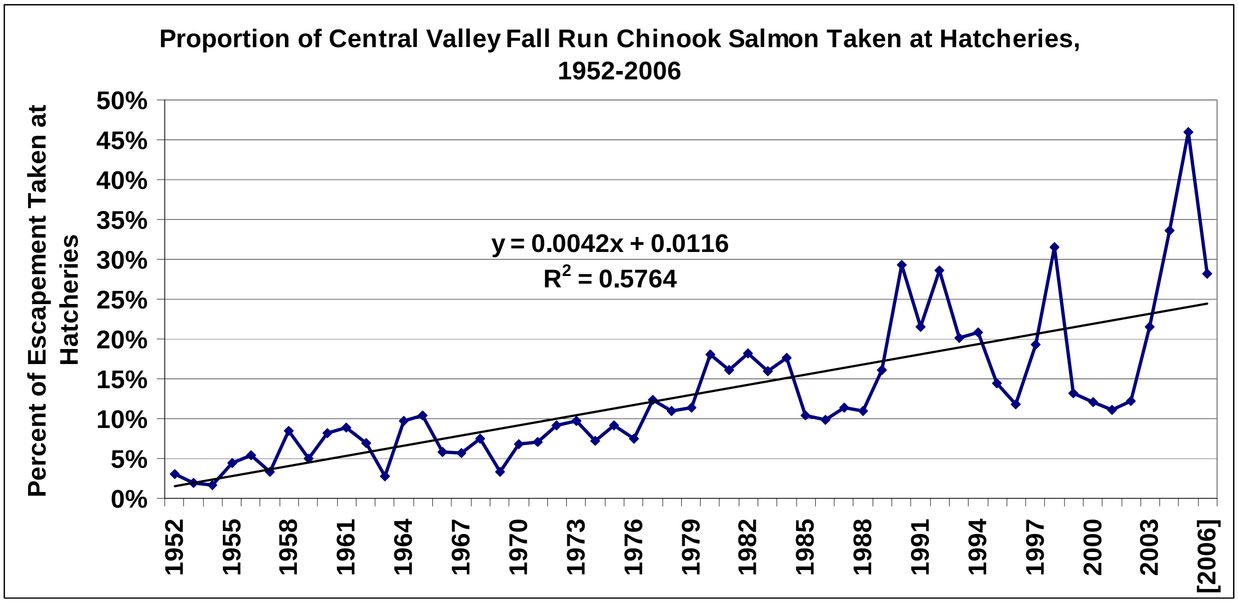

Figure 6-46 Percent of Central Valley fall-run Chinook escapement taken at hatcheries 1952–2006.

Feather River Hatchery-Genetics, Competition for Spawning, and Rearing Habitat

Historically, the adult spring-run salmon immigration into the upper rivers and tributaries extended from mid-March through the end of July with the peak in late May and early June (DFG 1998). Spawning started in mid-August, peaked in early September, and ceased in late September. The peaks of spawning between spring- and fall-run salmon were almost 2 months apart, and more than 30 days separated the end of spring-run spawning and the onset of fall-run spawning at Baird Hatchery at the end of the 1800s.

Although hydraulic mining and dams initially fostered intermixing of Chinook races in the Sacramento River system, hatchery practices have contributed as well (DFG 1998; NOAA fisheries 1998). The Feather River Hatchery (FRH) was built by DWR at the request of DFG to mitigate for the loss of habitat upstream of Oroville Dam. The hatchery was dedicated on October 1, 1967, and is operated by DFG. During the 5-year period prior to the opening of the hatchery (1962 through 1966) all adult salmon were trapped and transported above the site of Oroville Dam. During 1968 and 1969 spring-run salmon were allowed to enter the hatchery as soon as they arrived. The result was greater than 50 percent mortality, because warm water temperatures resulted in an inability to hold adults during the summer months until they were ready for spawning. As a result, since 1970 hatchery policy has been to exclude spring-run salmon entry until the onset of spawning, (August through October, generally early September to October 1). This practice has resulted in the inability of the hatchery operators to clearly identify spring-run based on their adult upstream migration timing, thereby increasing the likelihood of genetic introgression of spring-run and fall-run Chinook stocks.

Coded-wire-tag analysis provided verification of the intermixing of fall and spring runs. Twenty-two percent of juveniles tagged as fall-run subsequently spawned as spring-run, and 295 juveniles tagged as spring-run subsequently spawned as fall-run (Brown and Greene 1994). Preliminary genetic characterization results from the IEP Central Valley Salmonid Genetics Project provided additional evidence of intermixing. University of California geneticists presented preliminary work on Feather River spring-run genetic characterization at the 1999 Salmon Symposium in Bodega Bay. They had access to samples from FRH spring-run, late-summer-season in-river carcass surveys and a limited number of samples from spring-season in-river angler surveys. They found no genetic difference between the Feather River fall and spring runs. The two groups were genetically similar and homogenous. They were most similar to Central Valley fall-runs, and were not genetically similar to spring-run from Mill, Deer, or Butte Creeks.

In 1994, the FRH fish ladder was kept open between May 16 and June 6 to assess the current numbers of Chinook that exhibited spring-run adult migration timing. Prior to June 6, only one fish had entered the hatchery. On June 6, 31 fish entered the hatchery and the ladder was closed (DFG 1998). The implication is that few fish exhibiting the “typical” spring-run salmon adult migration timing ascended the Feather River during 1994. Alternatively, many spring-run adults may have been holding, or not moving, during the period the gates were open. When the ladder was reopened on September 6, 1994, 3,641 spring-run Chinook entered the hatchery.

FRH spring-run have been documented as straying throughout the Central Valley for many years and have intermixed with wild-spawned spring-run and fall-run Chinook in the upper Sacramento River, although the extent of hybridization has not been determined (DFG 1998). In 1982, early returning CWT Chinook were observed at RBDD and subsequently identified as FRH fall-run from the 1980 brood year. Now it is commonplace at RBDD to intercept fish tagged as fall-run during the spring-run migration period (mid-March through the end of July) (Figure 5–6). This intermixed life history pattern was evident when FRH fish were used in an attempt to reestablish spring-run in Clear Creek. More than 523,000 FRH spring-run fry were planted at the base of Whiskeytown Dam during the 3-year period 1991–1993 (DFG 1998). Some of the fish were CWT’ed. Since 1993, snorkeling surveys have been performed during the adult spring-run holding period to determine if the plants were successful. Three unmarked salmon were observed during the spring-run adult holding period in 1993 and two in 1995. However, 23 CWT adults returned between 1993 and 1995 during the adult fall-run spawning migration.

DFG (1998) questioned the viability and genetic integrity of the Butte Creek spring-run because of the potential for intermixing with Feather River salmon. Butte Creek has several different sources of introduced water, including West Branch Feather River water, main stem Feather River water, and Sacramento River water. As a consequence, it is possible that some spring-run salmon in Butte Creek could be strays from the Feather River. Despite the mixing of Feather River water into Butte Creek, DFG (1998) suggested the relative numbers of adult spring-run entering Butte Creek and FRH, for the period 1964 to 1991 did not show a strong relationship, suggesting they are generally independent. In support of this information, Banks et al. (2000) published genetic characterization research results and determined spring-run from Deer and Mill Creeks are more closely related to Central Valley fall-run populations than Butte Creek spring-run. This result would not be expected if Butte Creek spring-run were hybridized with

FRH spring-run because FRH spring-run are known to be hybridized with FRH fall-run. More recently, Hedgecock et al. (2002) reexamined Feather River fall hatchery, spring hatchery and spring wild. Field biologists have found a spring-run phenotype in the Feather River. Hedgecock et al. (2002) found that spring hatchery and spring wild form a genetically distinct population that is different from the fall-run, although the Feather River spring-run population is still more closely related to fall-run than to either Mill or Deer Creeks spring-run populations. In conclusion, Hedgecock et al. (2002) found two distinct populations in the Feather River, one of which exhibits a spring-run phenotype. The Feather River spring-run population is not closely related to Mill and Deer Creeks spring-run and may be, therefore a spring-run in the Sacramento Valley may be poly-phyletic.

The Banks et al. (2000) genetic results are surprising, however, because the escapement estimates for Butte Creek and Feather River spring-run are strongly correlated over more recent years (1987 through 1998), (Spearman R = 0.83-0.86, $p < 0.001$). (The variability in the R-value is due to separate tests of FRH spring-run escapement versus the smallest and largest available Butte Creek escapement estimates.) In contrast, the spring-run escapement estimates for Deer and Mill Creeks, which Banks et al. (2000) found were not genetically different from each other, are not significantly correlated for the 1987 through 1998 period (Spearman $r = 0.27$, $p = 0.40$).

FRH spring-run fry and juveniles were released into Butte Creek in 1983, 1984, and 1985, Brood Years 1982, 1983, and 1984 respectively. Only BY 1983 releases affected resultant year-classes, showing large increases in BY 1986 and BY 1989. There was a significant reduction in adult returns for BY 1992, but BY 1995 was the largest observed (7,500 adults) since 1960, and BY 1998 was higher still (20,259 adults). Since 1995 there have been over 500,000 Butte Creek spring-run tagged and released. While the inland recoveries have been limited, all of the tags recovered within the spring-run population have been from spring-run tagged and released in Butte Creek. One tagged fish was recovered in the Feather River, but no Feather River or other origin fish have been found among the Butte Creek spring-run (DFG 2003).

During the 1977 drought, adult spring-run were trucked from RBDD to Mill, Deer, and Butte Creeks (DFG 1998). No appreciable effect was seen in the subsequent year class (1980) on Butte or Mill Creeks. However there was an apparent single year (1980) increase in the Deer Creek population.

The Yuba River was planted with surplus FRH spring-run in 1980 (15,925), 1983 (106,600), and 1985 (96,800) (DFG 1998). Influence of these three introductions on subsequent adult spring-run returns cannot be determined since escapement surveys were not conducted. In 1984, Antelope Creek was planted with 302,733 FRH spring-run juveniles. In 1985, the creek was planted with another 205,000 juveniles. There is no persistent spring-run population in Antelope Creek, so the effect of hatchery supplementation in this drainage is irrelevant.

The effects of introgression and planting are poorly understood. In the case of the Feather River, Sommer et al. (2001a) found evidence that hatchery operations have had major population effects. Sommers et al. (2001a) examined factors responsible for a long- term shift in the spawning distribution of Chinook salmon toward the low-flow channel of the Feather River. While they found statistical evidence that flow and escapement may affect the distribution of spawning salmon, they concluded that hatchery operations probably account for much of the change. One hypothesis was introgression with spring-run causes the fall-run population to spawn as far upstream as possible, similar to the historical spring-run life history pattern. Another possibility was that a shift in the stocking location of young salmon to the estuary resulted in higher survival rates and an increased proportion of hatchery fish in the population. Hatchery fish would tend to spawn closer to the hatchery in the low-flow channel. In support of the latter hypothesis, there has been a significant increase in the number of fish entering FRH since 1968 (Ted Sommer, DWR unpublished data). A shift in spawning distribution to the heavily-used low-flow channel is expected to result in exceptional spawning superimposition and egg mortality for any spring-run that may be present.

Disease and Parasites

Chinook salmon are susceptible to numerous diseases during different phases of their life cycle. Disease problems are often amplified under crowded hatchery conditions and by warm water. See DFG (1998) for a detailed discussion of Central Valley salmonid diseases.

In-stream Habitat

Dam operations generally store water runoff during winter and spring to be released for instream flows, water delivery, and water quality during late spring, summer and fall. Historical high flows in regulated rivers have been dampened for flood control and water storage. Moderate flows have been extended throughout much of the year to provide appropriate instream flows for fish, water quality in the Delta, and water for pumping in the Delta. The long-term effect of the lack of high flows is the simplification of instream habitat. High channel-forming flows maintain high-quality spawning habitat and riparian floodplain conditions. High flows mobilize spawning-sized gravels from streambanks and incorporate them into the active channel. Low flows that typically occurred in late summer and fall do not occur because of the dampening effect of dam operations. High flows are not as high as occurred under natural conditions but the duration of high flows is longer because flood control operations spread them out over time. The longer duration of moderately high flows may be sufficient enough to wash quality spawning gravel out of riffles and deposit it in deeper water where it is unavailable for spawning but not high enough to mobilize new gravel supplies from the gravel bars, banks, and floodplain. It is anticipated that riffles downstream of dams will continue to degrade as floodflows move gravel downstream without replenishment from upstream areas. The presence of dams has eliminated upstream sources of bedload and woody debris, increasing the importance of streamside sources. Programs are in place to replace gravel recruitment lost due to the presence of dams.

Levees and bank protection projects have been constructed along the lower reaches of many Central Valley rivers, limiting the potential for rivers to meander and reducing seasonal floodplain inundation. Many streambanks near developed areas have been riprapped to cut down on natural channel adjustments and streambank erosion. Natural streambanks generally provide higher quality habitat to salmonids than riprapped banks. In addition, when banks are riprapped riparian vegetation is eliminated in the riprapped portion, eliminating overhanging vegetation and future woody debris sources.

Large woody debris provides valuable habitat to salmonids. Woody debris has been removed from some rivers because it is perceived as a hazard to swimmers and boaters and impedes navigation. The habitat loss cumulatively from lack of woody debris recruitment, woody debris removal, and riprapping could be a significant factor in the the decline of some Central Valley salmon populations. The likelihood that this would reduce the survival of the current Chinook or steelhead populations is unknown.

Factors that May Influence Abundance and Distribution of Coho Salmon

A number of interrelated factors affect coho abundance and distribution in the Trinity River. These include water temperature, water flow, habitat suitability, habitat availability, hatcheries, predation, competition, disease, ocean conditions, and harvest. Current CVP operations affect primarily water temperature, water flow, and habitat suitability in the Trinity River. Water temperature suitability criteria for coho salmon are shown in Table 6-13.

Table 6-13 Water temperature suitability criteria for Coho salmon life stages from DFG 2002a.

Life Stage	Suitable Range, degrees F	Reference or Citation
Migrating adult	44.6 – 59	Reiser and Bjornn 1979
Spawning adult	39.2 – 48.2	Bjornn and Reiser 1991
Rearing juvenile	35 = lower lethal 78.8 - 83.8 = upper lethal 53.6 – 57.2 = optimum 48 – 59.9 = optimum 63.7 – 64.9 = maximum weekly average temperature 62.1=maximum weekly average and 64.4=maximum weekly maximum temperature	Bjornn and Reiser 1991; Flosi et al 1998; Ambrose et al 1996; Ambrose and Hines 1997, 1998; Hines and Ambrose ND; Welsh et al. 2001
Eggs and fry	39.2 – 51.8 39.2 – 55.4 = optimum 32 – 62.6	Davidson and Hutchinson 1938; Bjornn and Reiser 1991; PFMC 1999

Juvenile coho salmon in the Trinity River spend up to a full year in freshwater before migrating to the ocean. Their habitat preferences change throughout the year and are highly influenced by water temperature. During the warmer summer months when coho are most actively feeding and growing, they spend more time closer to main channel habitats. Coho tend to use slower water than steelhead or Chinook salmon. Coho juveniles are more oriented to submerged objects such as woody debris while Chinook and steelhead tend to select habitats in the summer based largely on water movement and velocities, although the species are often intermixed in the same habitat. Juvenile coho tend to use the same habitats as pikeminnows, a possible reason that coho are not present in Central Valley watersheds. Juvenile coho would be highly vulnerable to predation from larger pikeminnows during warm-water periods. Pikeminnow do not occur in SONCC coho streams. When the water cools in the fall, juvenile coho move further into backwater areas or into off-channel areas and beaver ponds if available. There is often no water velocity in the areas inhabited by coho during the winter. These same off-channel habitats are often dry or unsuitable during summer because temperatures get too high.

Lewiston Dam blocks access to 109 miles of upstream habitat (U.S. Department of the Interior 2000). Trinity River Hatchery produces coho salmon with a production goal of 500,000 yearlings to mitigate for the upstream habitat loss. Habitat in the Trinity River has changed since flow regulation with the encroachment of riparian vegetation restricting channel movement and limiting fry rearing habitat (Trush et al 2000). According to the Trinity River Restoration Plan, higher peak flows are needed to restore attributes of a more alluvial river such as alternate bar features and more off-channel habitats. These are projected in the restoration plan to provide better rearing habitat for coho salmon than the dense riparian vegetation currently present. A number of restoration actions have been completed. A new flow schecule has provided higher spring releases to geomorphically maintain habitat. Physical habitat manipulations have been implemented providing better juvenile rearing in selected sites along the river.

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