Comprehensive Analyses of Water Export, Flow, Tide Height, and the Salvage and Abundance of Juvenile Salmonids in the Sacramento-San Joaquin Delta

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Executive Summary

We provide in this report a comprehensive analysis for flow, water export, tide height, and juvenile salvage and abundance in the Delta in order to better understand how these variables affect juvenile salvage at the water export facilities in the south Delta. We hypothesize that juvenile salmonid salvage during their migration season:

(1) increases with increasing water export. If there were no water export, there would be no fish salvage;
(2) increases with increasing fish abundance. If there were no fish entering the Delta, there would be no fish salvage;
(3) increases with increasing flow from the Sacramento River. High Sacramento River flows (e.g., pulse flows) can carry a large quantity of juveniles into the Delta, which are subject to entrainment;
(4) decreases with increasing flow from the San Joaquin River. High San Joaquin River flows can help push Sacramento juveniles out to the western Delta;
(5) decreases with increasing Delta outflow. Higher outflows help juveniles migrate more quickly through the Delta; and
(6) increases with increasing tide height. Higher tides are expected to slow down outflow and push water inward and may lead to more juveniles going to the pumping facilities.

Inflows

From water year 1956 to 2011, flows from the Sacramento (including Yolo Bypass) and San Joaquin Rivers, on average, contributed to 96% (ranging from 93% to 99% of the total annual inflows to the Delta. On an annual basis, Sacramento River flow accounted for 85% (ranging from 70% to 96%) of the total annual inflows to the Delta. The average monthly inflow to the Delta was highest in February and lowest in October.

Water Exports

The combined average rate of water exported through the JPP and BPP facilities showed a linear increase from about 1,000 cfs in the late1950s (when only the JPP existed) to 6,000 cfs in early 1980s, when both facilities were in operation. This increasing trend has slowed down since then. The combined average rate of water exports reached the highest level (9,000 cfs) in 2011. On an annual basis, the combined rate of water exports was highest in the months of July, August, and September, whereas the lowest monthly rates occur in April and May. Since 1980s, the combined water export rates have decreased for the months of April and May, while it remained relatively stable for the months of January, February, March, and June. In contrast, the average monthly combined water export rates have steadily increased for the months of July to December. The percent water export over the total delta inflow (Export:Inflow or E:I) was > 40% for the months of July through November since 1990.

OMR Flows

Three OMR flows showed a similar pattern to water exports in seasonal variability—highest (positive or less negative) in April and May and lowest (more negative) in July, August, and September. OMR flows with the spring HORB installed were lower (more negative) than those with no spring HORB installed. The daily OMR flow (OMR2) can be reliably estimated with the following equations:

Equations for estimating the OMR flow (Q_{OMR}) based on the combined water export (Q_{EXP}) and SJR flow (Q_{SJR})

Spring HORB	Regression Equation	N	R^2
Not Installed	$Q_{OMR} = -555 - 0.897\ Q_{EXP} + 0.552\ Q_{SJR}$	5815	0.971
Installed	$Q_{OMR} = -1109 - 0.669\ Q_{EXP} + 0.0923\ Q_{SJR}$	230	0.766

Juvenile Fish Salvage

The median sampling duration at the SFPF was between 20 and 30 minutes except for 1998 when the median duration was 10 minutes. The median sampling duration at the TFCF was 10 minutes from 1993 to 2009 and increased to 30 minutes since 2010.

The median primary channel velocity at the SFPF was about 2.6 ft/s since 2000. There were 2,292 records (3% of the total records) that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the SFPF. The median velocity at the TFCF was 3 ft/s for most years except for 1994, 2008, 2009, and 2012, in which the median velocity had a value of about 1.5 ft/s. There were 14,013 records (15% of the total records) that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the TFCF.

The median size of salvaged salmonid juveniles at the SFPF and TFCF is in the following decreasing order: Steelhead >> Late fall-run Chinook salmon (late fall-run) > Winter-run Chinook salmon (winter-run) > Spring-run Chinook salmon (spring-run) ≈ Fall-run Chinook salmon (fall-run). Hatchery fish appeared to have a larger median size when compared to wild fish for winter-run, fall-run, and late fall-run; were smaller in size than wild steelhead; and were similar in size to wild spring-run. The median size of salvaged striped bass was smaller than the median sizes for juvenile Chinook salmon or steelhead. The size distribution of salvaged fall-run juveniles showed two peaks – one around 37 mm and the other around 90 mm. The size distribution of salvaged striped bass also showed two peaks – one around 30 mm and the other around 90 mm.

The diel juvenile salvage patterns for Chinook salmon, steelhead, and striped bass at the SFPF are similar to those at the TFCF. The salvage rates for Chinook salmon were 2-4 times higher at night than during the day. The salvage rates for steelhead were somewhat lower at night than during the day, although the difference is much smaller compared to Chinook salmon. The salvage rate for striped bass was the highest at 2 AM.

The combined mean annual salvage of salmonid juveniles across years was about 57,000 fish. The magnitude of juvenile fish salvage at the SFPF and TFCF varies with species and month. Listed below are the three months with the highest juvenile fish salvage by species and run:

Months with the highest salvage of juvenile fish

Species	Highest Month	2nd Month	3rd Month
Wild winter-run Chinook salmon	March	February	January
Wild spring-run Chinook salmon	April	May	March
Wild fall-run Chinook salmon	May	June	April
Wild late fall-run Chinook salmon	December	January	November
Wild steelhead	March	February	April
Striped bass	July	June	August

Juvenile Fish Loss

After systematically examining the process of using juvenile salvage data to calculate juvenile losses, we found a number of flaws in the current calculation method that underestimates the juvenile loss. We developed new formulas for quantifying juvenile losses at the water export facilities. The loss (Ψ_T) of juvenile Chinook salmon and steelhead should be quantified using the following equation:

$$\Psi_T = N_4 K$$

where N_4 is the juvenile fish salvage and K is a coefficient varying with facility and species, which is provided in the following table. The estimated mean annual juvenile fish loss was about 11,000 fish for wild winter-run, 79,000 fish for wild spring-run, and 13,000 fish for wild steelhead.

K values for quantifying the fish losses of juvenile Chinook salmon and steelhead at the SFPF and TFCF

Facility	Fish Density or Primary Channel Velocity	K Value	
		Chinook	Steelhead
SFPF	Low	No Data	9.48
	High	12.53	4.54
TFCF	Low	19.27	1.97
	Median	2.98	No Data
	High	1.50	0.25

Juvenile Fish Flux and Abundance

We described two methods to compute juvenile flux or abundance in the Delta. The first method is based on trawl efficiency and the second method is based on the depth distribution and migration speed of juvenile salmonids. We provide the results from the first method. The mean monthly flux of wild juvenile fish varies with month and species. The highest monthly flux is in March for wild winter-run Chinook salmon and wild steelhead, and in April for wild spring-run Chinook salmon (see the following table), which correspond to the highest juvenile salvages at the SFPF and TFCF.

Months with the highest juvenile flux

Species	Location	Highest Month	2nd Month	3rd Month
Wild winter-run Chinook salmon	Sherwood Harbor	March	February	December
	Chipps Island	March	April	February
Wild spring-run Chinook salmon	Sherwood Harbor	April	March	May
	Chipps Island	April	May	March
Wild steelhead	Sherwood Harbor	March	February	April
	Chipps Island	March	February	April

The median annual juvenile flux from the 1992 to 2011 brood years is summarized in the following table. Using the juvenile influx from the Sacramento River at Sherwood Harbor and the San Joaquin River (Mossdale) and outflux at Chipps Island, we calculated the overall Delta survival rates. The median Delta survival rate was 0.28 for wild winter-run juveniles, 0.43 for wild spring-run juveniles, and 0.53 for wild steelhead juveniles.

Median annual juvenile flux at three monitoring stations

Species	Sherwood Harbor (fish)	Mossdale (fish)	Chipps Island fish)
Wild winter-run Chinook salmon	614,513	Not Applicable	201,067
Wild spring-run Chinook salmon	6,093,530	Not Applicable	1,288,216
Wild steelhead	70,931	7,051	38,872

In order to understand how fish abundance influences salvage, we need to estimate the number of juveniles available for entrainment, i.e., the daily juvenile abundance. We developed a method to estimate the daily juvenile abundance in the Delta based on the influx, outflux, daily survival rate, and residence time of juveniles in the Delta.

Factors Controlling Juvenile Fish Salvage

We tested the six hypotheses set forth in the beginning using Pearson's correlation and multiple linear regression methods. The salvage of wild juvenile winter-run and spring-run Chinook salmon and wild juvenile steelhead is positively correlated to water export (SWP, CVP, or combined), juvenile fish abundance by race/run, Sacramento River flow at Freeport, or tide height at Golden Gate Bridge; but negatively correlated to the SJR flow at Vernalis, the OMR flow, the SJR inflow to export (I:E) ratio, or Delta outflow. The multiple linear regression results indicate that water export and juvenile fish abundance are the most important variables impacting the number of juveniles salvaged at the SFPF and TFCF. To a lesser degree, inflow, tide height, the I:E ratio, or the OMR flow played a role in controlling fish salvage.

1 Introduction

The Federal Jones Pumping Plant (JPP) and State Banks Pumping Plant (BPP) export water from the Sacramento-San Joaquin Delta to the San Joaquin Valley, Bay Area, and Southern California, serving some two-thirds of the state's population (approximately 27 million people) and 3.75 million acres of irrigated farmland. In the meantime, these two pumping plants results in fish entrainment at the magnitude of millions of fish each year. Among the entrained fish are those species listed as endangered or threatened pursuant to the Federal Endangered Species Act, including winter-run and spring-run Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and green sturgeon (*Acipenser medirostris*). The total loss of the listed salmonid juveniles to the pumping plants can be as high as hundreds of thousands of fish per year. In order to better mitigate the substantial loss of listed juvenile salmonids, it is necessary to better understand the factors affecting the loss of juveniles at the pumping plants. In this report, we present results from a comprehensive analysis for factors that potentially impact the juvenile salvage or loss at the pumping facilities. We first provide a data analysis on water export and flow in the Delta, followed by analyzing juvenile salvage and juvenile monitoring data. We finally perform an analysis on how water export, juvenile fish abundance, river inflow, and tide height affect the juvenile fish salvage or loss to the pumping plants.

2 Water Flow, Water Export, and Tide Height

2.1 Data Sources

Daily flow and water export data were obtained from the U.S. Geological Survey (USGS) California Water Data (http://ca.water.usgs.gov/data) (Figure 1), California Data Exchange Center (CDEC) (http://cdec.water.ca.gov) (Table 1), or Department of Water Resources' (DWR) Dayflow Program (http://www.water.ca.gov/dayflow). It is important to note that DWR provides water export data from Banks Pumping Plant (i.e., HRO in CDEC) and water inflow data from the Old River to Clifton Court Forebay (i.e., CLC in CDEC and SWP in Dayflow). We used water export data from Banks Pumping Plant in analyzing correlations to fish salvage data and used the inflow data to Clifton Court Forebay in analyzing hydrodynamics (i.e., Old and Middle Rivers (OMR) flow). For consistency, if the same data are available from two sources, data with the longest coverage are used and data gaps are filled in from the other data source if necessary. For example, the inflow data to Clifton Court Forebay from Dayflow, which covers February 1968 through September 2011, were supplemented with the inflow data from CDEC, which provides data up to the current date. The JPP water export data from Dayflow were supplemented with the CDEC TRP data from October 2011 to the current date. The BPP water export data from CDEC (1992 to present) were supplemented with the 1979-1992 data provided by DWR's Project Records and Reports Section.

The data compiled from the sources described above were checked to assure data quality. Time series data were plotted for visual inspection. Any records of data, which showed apparent recording errors (*e.g.*, spikes in flow) or were marked as "missing", were excluded from use in the report. Any water export data exceeding the design capacity of the BPP (10,670 cfs) or JPP (4,600 cfs) were excluded from use.

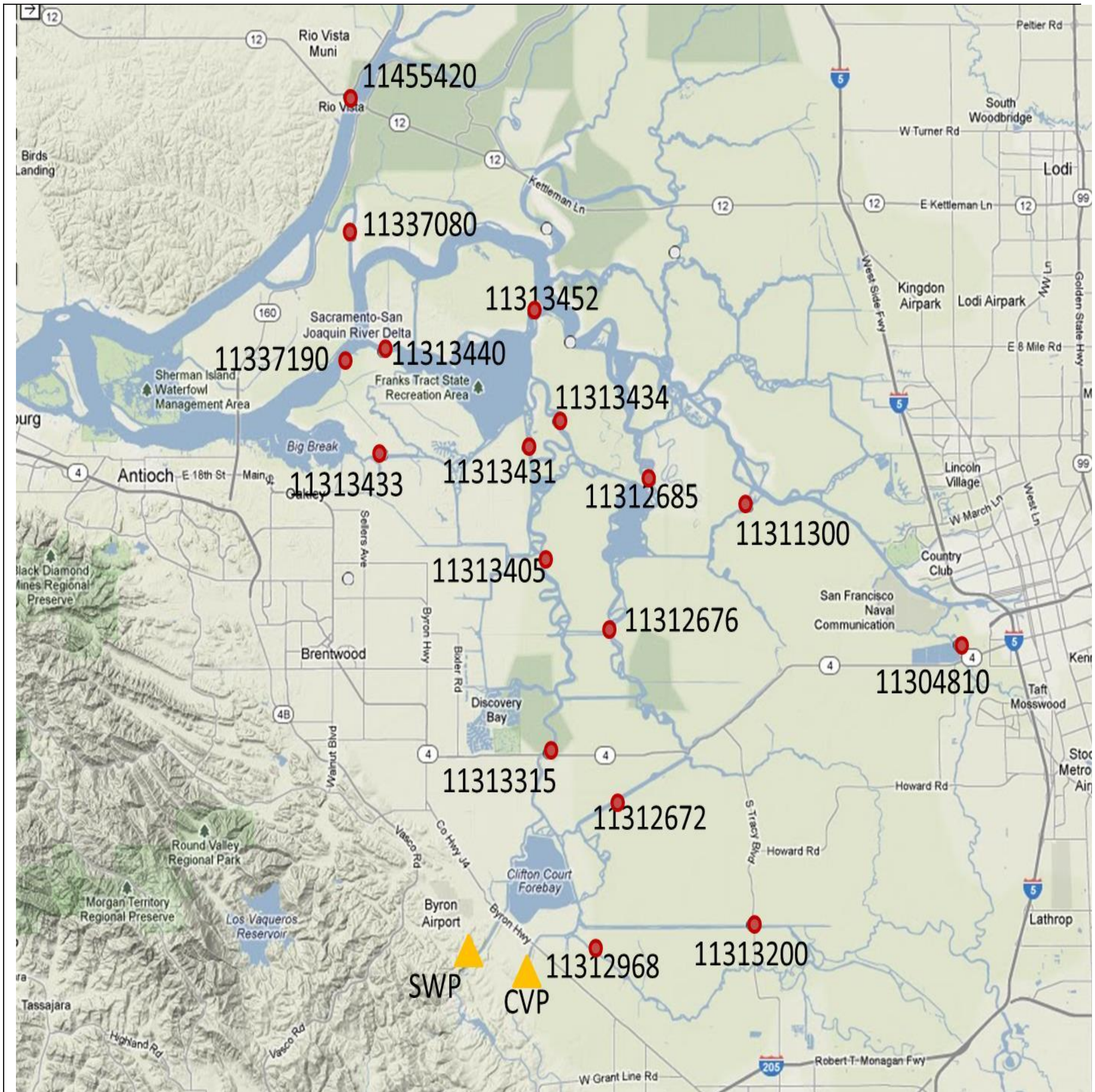


Figure 1. USGS flow gages in the Delta where flow data were obtained

Table 1. Flow and water export stations

Station ID	Location	Start Date	End Date	Source
11303500	San Joaquin River near Vernalis	10/1/1923	8/3/2012	USGS
11304810	San Joaquin River below Garwood Bridge at Stockton	8/20/1995	8/3/2012	USGS
11311300	Turner Cut near Holt Canal	2/25/2005	8/4/2012	USGS
11312672	Victoria Canal near Byron	2/23/2005	8/3/2012	USGS
11312676	Middle River at Middle River	1/9/1987	8/3/2012	USGS
11312685	Middle River near Holt Canal	5/26/2006	8/4/2012	USGS
11312968	Old River at Delta Mendota Canal	12/2/2005	8/3/2012	USGS
11313200	Grant Line Canal at Tracy Rd Bridge	5/8/1999	8/3/2012	USGS
11313315	Old River Near Byron	6/25/1999	8/3/2012	USGS
11313405	Old River at Bacon Island	1/8/1987	8/3/2012	USGS
11313431	Holland Cut near Bethel Island	6/15/2006	8/4/2012	USGS
11313433	Dutch Slough below Jersey Island Rd at Jersey Island	2/11/1996	8/4/2012	USGS
11313434	Old River at Quimby Island near Bethel Island	6/10/2006	8/4/2012	USGS
11313440	False River near Oakley	7/1/2006	8/4/2012	USGS
11313452	Old River at Franks Tract near Terminous	5/18/2006	8/4/2012	USGS
11337080	Threemile Slough near Rio Vista	2/18/1994	8/4/2012	USGS
11337190	San Joaquin River at Jersey Point	5/14/1994	8/3/2012	USGS
11447650	Sacramento River at Freeport	10/1/1948	8/3/2012	USGS
11455420	Sacramento River at Rio Vista	4/22/1995	8/3/2012	USGS
11336600	Delta Cross Channel near Walnut Grove	9/1/2001	12/28/2012	USGS
11447903	Georgiana Slough near Sacramento River	9/19/2001	12/28/2012	USGS
11336685	N Mokelumne near Walnut Grove Canal	12/16/2010	12/28/2012	USGS
11336680	S Mokelumne River at New Hope Br near Walnut Grove Canal	2/6/2011	6/23/2012	USGS
11336930	Mokelumne River at Andrus Island near Terminous Canal	6/25/2006	12/25/2012	USGS
11336790	Little Potato Slough at Terminous Canal	5/18/2006	12/28/2012	USGS
DTO	Calculated Delta Outflow	1/1/1994	8/6/2012	CDEC
HRO	SWP export at Banks Pumping Plant	12/1/1979	8/6/2012	DWR and CDEC
CLC	Inflow from the Old River to Clifton Court Forebay	9/29/2007	11/8/2012	CDEC
TRP	CVP export at Tracy Pumping Plant	1/1/1994	8/6/2012	CDEC
SWP	Inflow from the Old River to Clifton Court Forebay	2/20/1968	9/30/2011	Dayflow
CVP	CVP export at Tracy Pumping Plant	10/1/1955	9/30/2011	Dayflow

2.2 Inflows to the Delta

The median monthly San Joaquin River flow at Vernalis was highest in February and lowest from July to September when highest exports occurred (Figure 2).

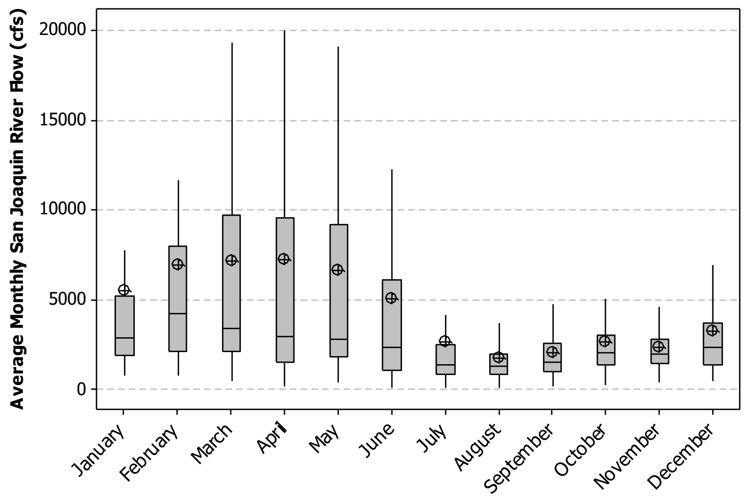


Figure 2. Monthly San Joaquin River flow at Vernalis (WY1956-2011). Key to boxplots: horizontal line, median; ⊕ , mean; box, 25th (Q1) and 75th (Q3) percentiles; whiskers, lower and upper limits. The lower limit = Q1 – 1.5 (Q3 – Q1). The upper limit = Q3 + 1.5 (Q3 – Q1).

San Joaquin River flows varied greatly with year. However, there was no increasing or decreasing trend observed for the past 55 years (Figure 3), as indicated by the lowess smoother[1].

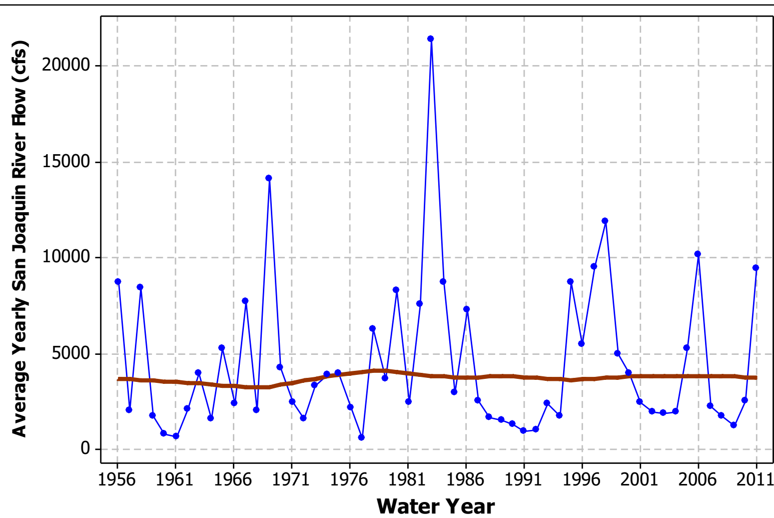


Figure 3. Annual San Joaquin River flow at Vernalis. The curve represents the lowess smoother.

[1] LOWESS (Locally Weighted Scatterplot Smoothing) is a popular tool used in regression analysis that creates a smooth line through a timeseries plot or scatter plot to help see a relationship between variables and foresee trends.

The average monthly Sacramento River flow at Freeport was highest in February and lowest in October (Figure 4).

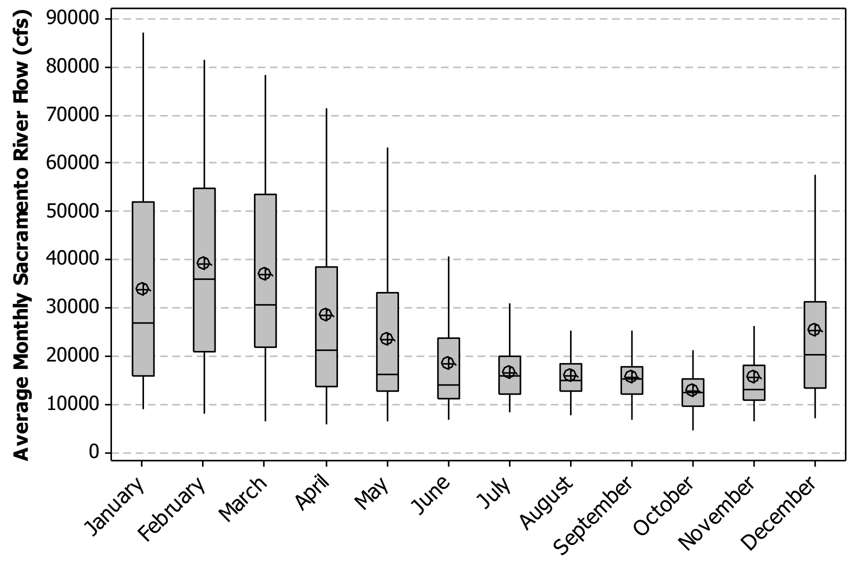


Figure 4. Average monthly Sacramento River flow at Freeport (WY1956-2011). (– median; ⊕ mean)

Sacramento River flow varied greatly with year. There was a slightly decreasing trend starting 1974 (Figure 5). It is unknown whether or not the decline in the Sacramento River flow at Freeport resulted from changes in precipitation, water diversion, or both. The annual Sacramento River flow (including those flows from Yolo Bypass) accounted for 85% (from 70% to 96%), on average, of the total inflow to the Delta.

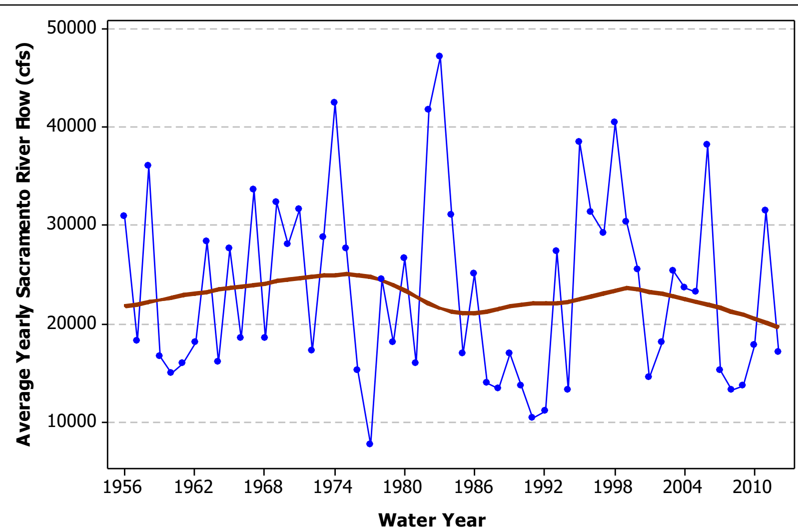


Figure 5. Average yearly Sacramento River flow at Freeport. The curve represents the lowess smoother.

Average yearly inflows to the Delta varied substantially with year. Flows from the Sacramento (including Yolo Bypass) and San Joaquin rivers contributed to 93-99% (with the average of 96%) of the total inflows to the Delta (Figure 6). The flow "Others" include flows from Yolo Bypass, the Cosumnes, Mokelumne, and Calaveras rivers. Note that the flow "Others" were higher than that from the San Joaquin River in some years, mainly attributed to the flow from Yolo Bypass.

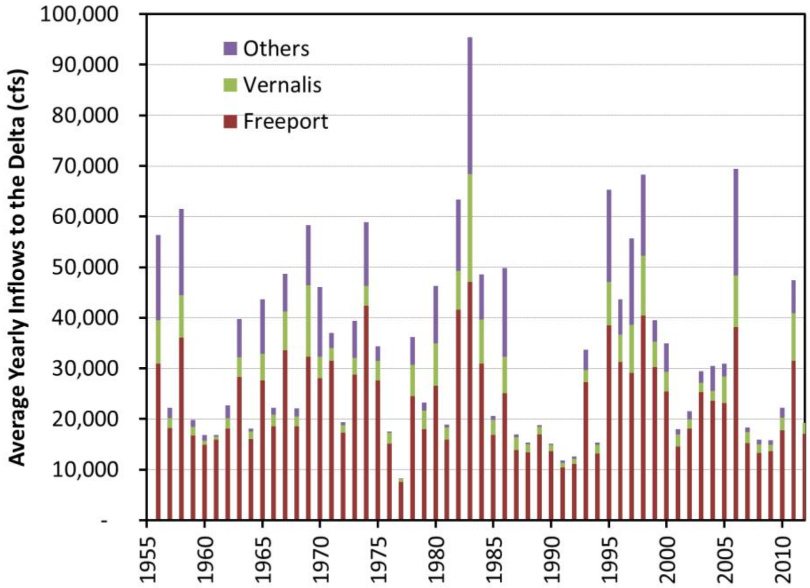


Figure 6. Average yearly inflow to the Delta from the Sacramento River, San Joaquin River, and others including Yolo Bypass, Cosumnes, Mokelumne, and Calaveras rivers

Average monthly inflows to the Delta were highest in February and lowest in October. Flows from the Sacramento (including Yolo Bypass) and San Joaquin rivers contributed to 94-97% of the total monthly inflows to the Delta (Figure 7).

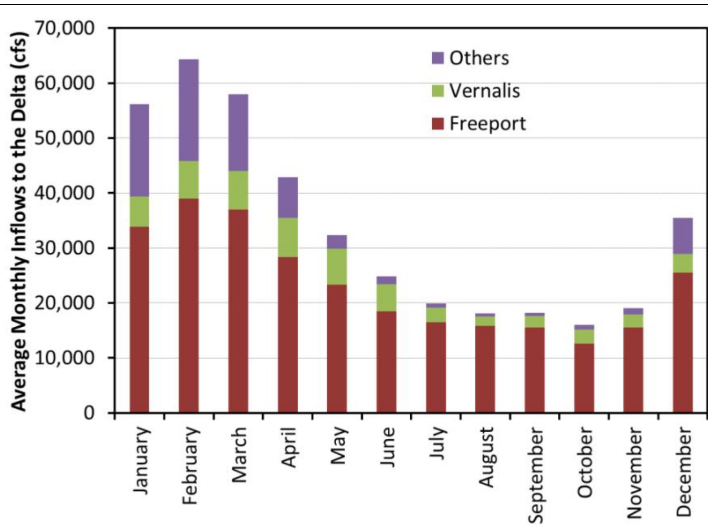


Figure 7. Average monthly inflow to the Delta from the Sacramento River, San Joaquin River, and others including Yolo Bypass, Cosumnes, Mokelumne, and Calaveras rivers

The monthly inflow to the Delta showed substantial variability from January to May, with lower variability from June to December (Figure 8). The total yearly inflow to the Delta showed a slightly decreasing trend starting 1975 (Figure 9), similar to the trend in the Sacramento River (Figure 5)

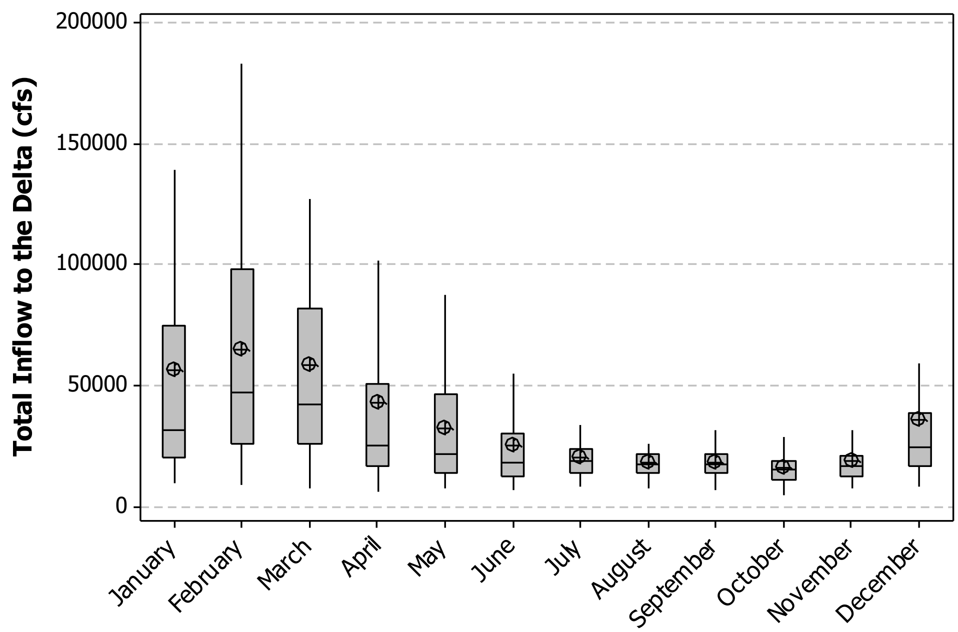


Figure 8. Variability in monthly inflow to the Delta (– median; ⊕ mean)

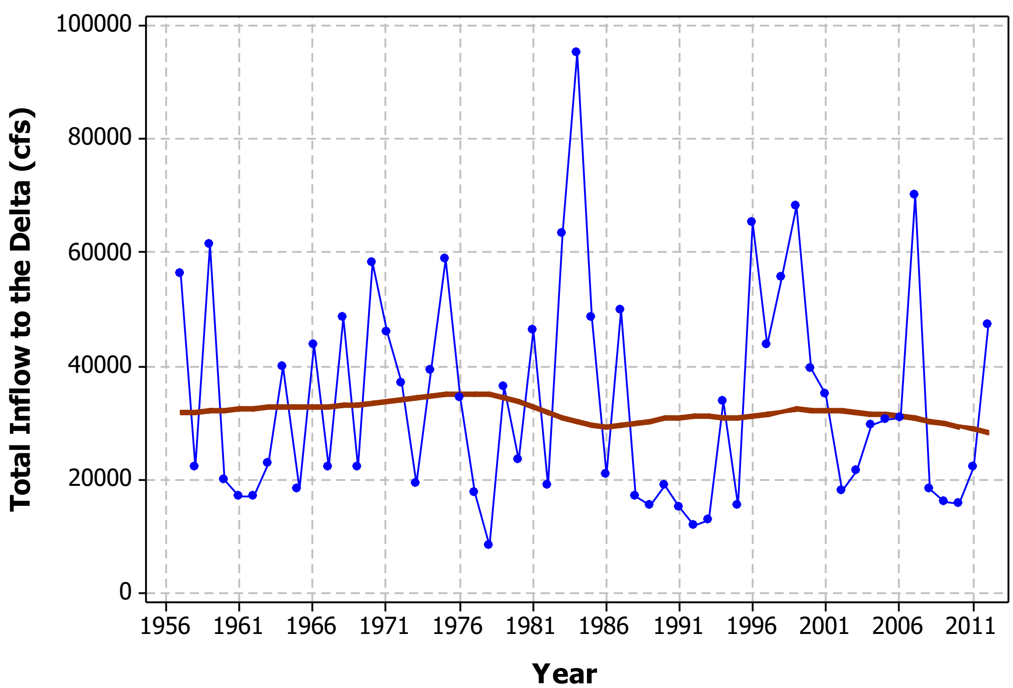


Figure 9. Average yearly total inflow to the Delta. The curve represents the lowess smoother.

2.3 Water Export through Federal and State Pumping Plants in the Delta

2.3.1 Jones Pumping Plant

The Federal Jones Pumping Plant (JPP) was constructed from 1947 to 1951 and is named after C.W. "Bill" Jones, who served as president of the San Luis and Delta-Mendota Water Association/Authority for 20 years and was a pioneer in water service development in the San Joaquin Valley. Water diversions started in 1951 at the JPP.

The pumping plant, located near Tracy, California (Figure 10), is part of the Central Valley Project (CVP). It is operated by the U.S. Bureau of Reclamation (USBR) and the San Luis and Delta-Mendota Water Authority. It lifts water nearly 200 feet from the Delta into the Delta-Mendota Canal through 15-foot diameter pipes with six 22,500-horsepower motors. The Delta-Mendota Canal extends nearly 120 miles to the south, ending at Mendota, California. The CVP water is also conveyed with pumping units to the San Luis Reservoir for deliveries to CVP contractors through the San Luis Canal.

The pumping plant has a permitted diversion capacity of 4,600 cfs with maximum pumping rates typically ranging from 4,300 to 4,500 cfs during the peak of the irrigation season and approximately 4,200 cfs during the winter non-irrigation season. The Project provides water to approximately 2 million Californians and about 3 million acres of irrigated farmland.

Figure 10. A map showing the locations of Jones Pumping Plant, Banks Pumping Plant, Tracy Fish Collection Facility (TFCF), Skinner Fish Protective Facility (SFPF), and Clifton Court Forebay in the South Delta

2.3.2 Banks Pumping Plant

The State Banks Pumping Plant (BPP) in the Delta (Figure 10) was constructed from 1963 to 1968 and is named after Harvey O. Banks, the first DWR director. The plant was initially housed with seven units that provided a pumping capacity of 6,400 cfs. Water diversions started in 1968 and water was initially diverted through Italian Slough. In 1969, Clifton Court Forebay was constructed and water was routed through this regulating structure. In 1991, four more units were added, boosting the total pumping capacity to 10,300 cfs. The Banks Pumping Plant draws water from the Delta through intake gates into Clifton Court Forebay and lifts water 244 feet up into the California Aqueduct, which is a system of canals, tunnels, and pipelines with a total length of about 700 miles. The Project provides supplemental water to approximately 25 million Californians and about 750,000 acres of irrigated farmland.

2.3.3 Water Export Data Analysis

The combined water exports through the JPP and BPP showed a sharp increase from late1950 to early 1980, however, this increasing trend has slowed down since then. The annual average water export rate reached the highest values (9,000 cfs) in 2011 (Figure 11).

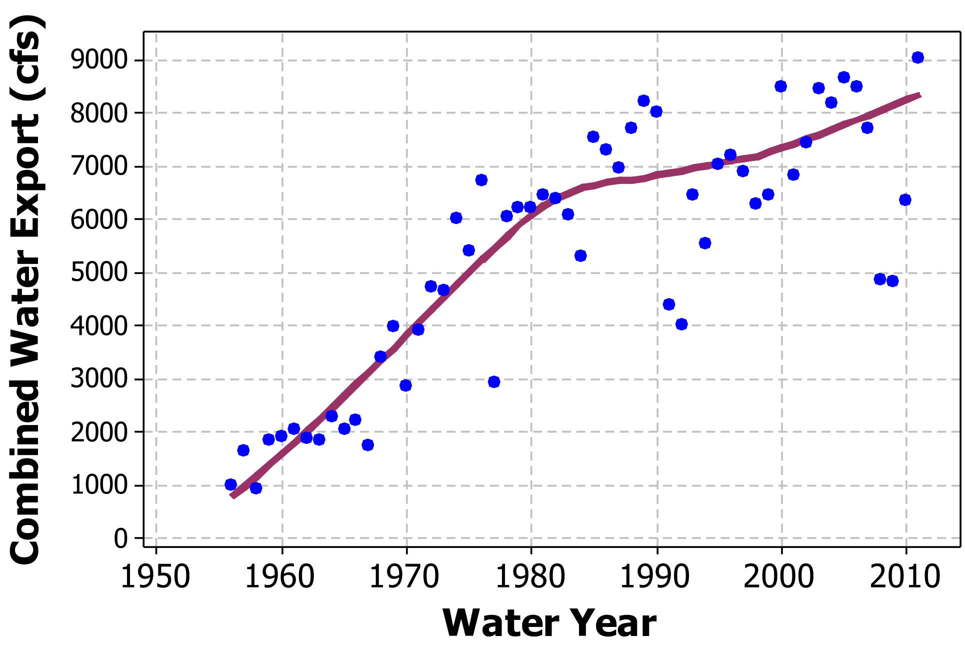


Figure 11. Average annual combined JPP and BPP water export rate. The curve represents the lowess smoother.

The average monthly combined JPP and BPP water export rate was highest in July, August, and September; whereas the lowest average combined exports occurred in April and May (Figure 12).

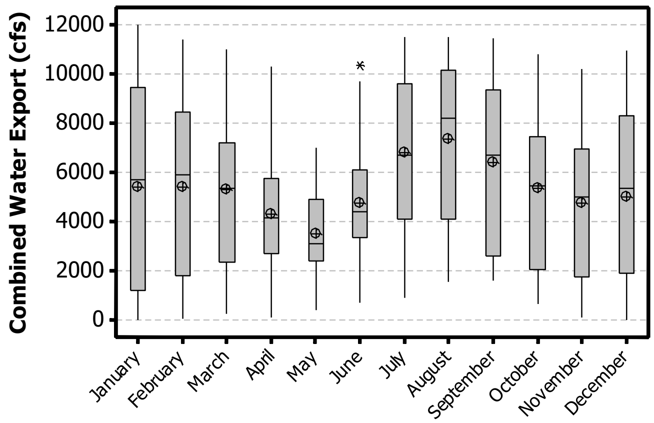


Figure 12. Average combined JPP and BPP water export rate by month (1956-2011).
(– median; ⊕ mean)

Since the 1980s, the average combined water export rate has decreased for the months of April and May, while it has been kept relatively stable for the months of January, February, March, and June. This is in part due to water board decisions limiting exports to protect outmigrating Chinook salmon. However, the average combined water export rate has steadily increased for the months of July to December (Figure 13).

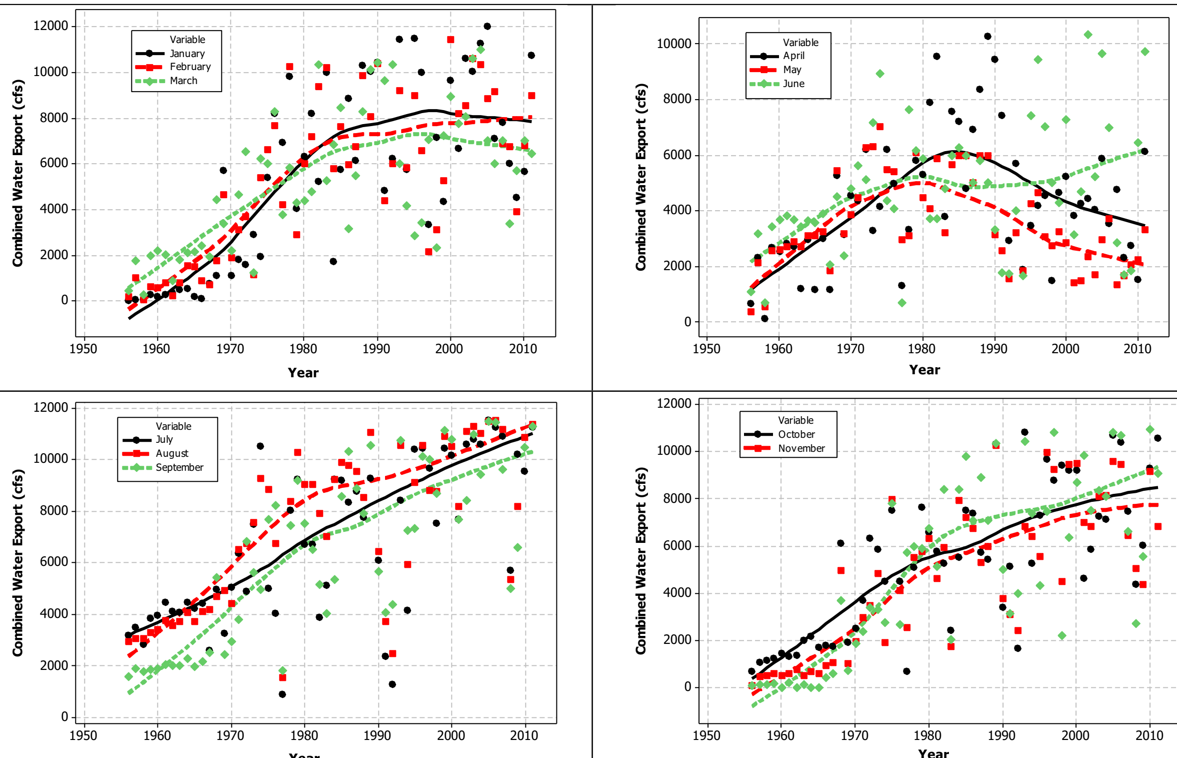


Figure 13. Trend for average monthly water export. The curves represent the lowess smoother.

2.3.4 **Percent Water Export**

Average yearly percent water export over total inflow showed a sharp increase from less than 10% to more than 30% from mid-1950s to late 1980s. The export percentage appeared to level off since the 1990s (Figure 14). The State Water Resource Control Board established Delta outflow criteria and water exports limits beginning in 1978 (e.g., D-1485)

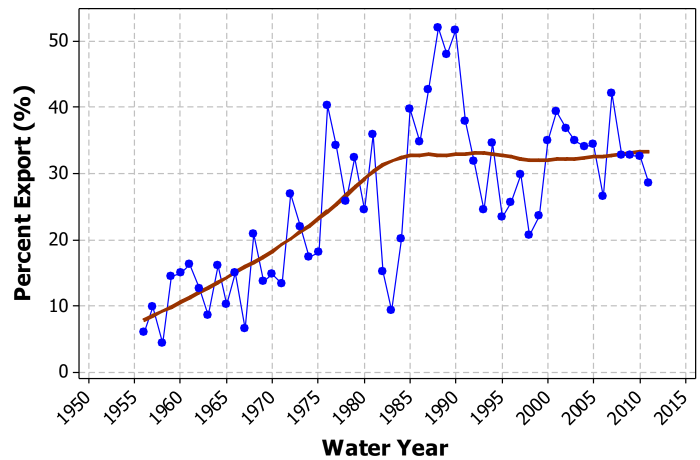


Figure 14. Yearly percent water export over total inflow. The curve represents the lowess smoother.

The median monthly percent water export over total inflow was highest in August (about 40%) and lowest in March (about 10%) (Figure 15), while in some years, the percent water export was greater than 65% in January, September, and October. In addition, although only 35% is allowed during the winter and spring months, precipitation driven storm events may create high flows that are substantially greater than the approximately 12,000 cfs pumping cap currently in place, thus driving the percentage exported to low values, although pumping may be at its maximum capacity. Likewise, water quality restrictions and river flow restrictions (i.e. Rio Vista and net Delta outflows) can restrict pumping during the dry season when exports can be 65% of Delta inflow.

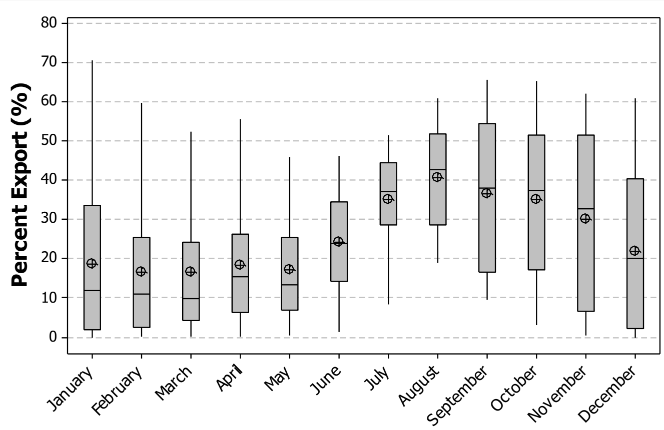


Figure 15. Monthly percent water export over total inflow (1956-2011). (– median; ⊕ mean)

Percent water export increased sharply in October and November from less than 10% in mid-1950s to greater than 50% in 2000s, while decreased to less than 20% in April, May, and June since mid-1980s. The percent export showed an increasing trend for February, March, July, August, and September; whereas it leveled off for January and December since 1990. The percent export was greater than 40% for the months of July through November since 1990 (Figure 16).

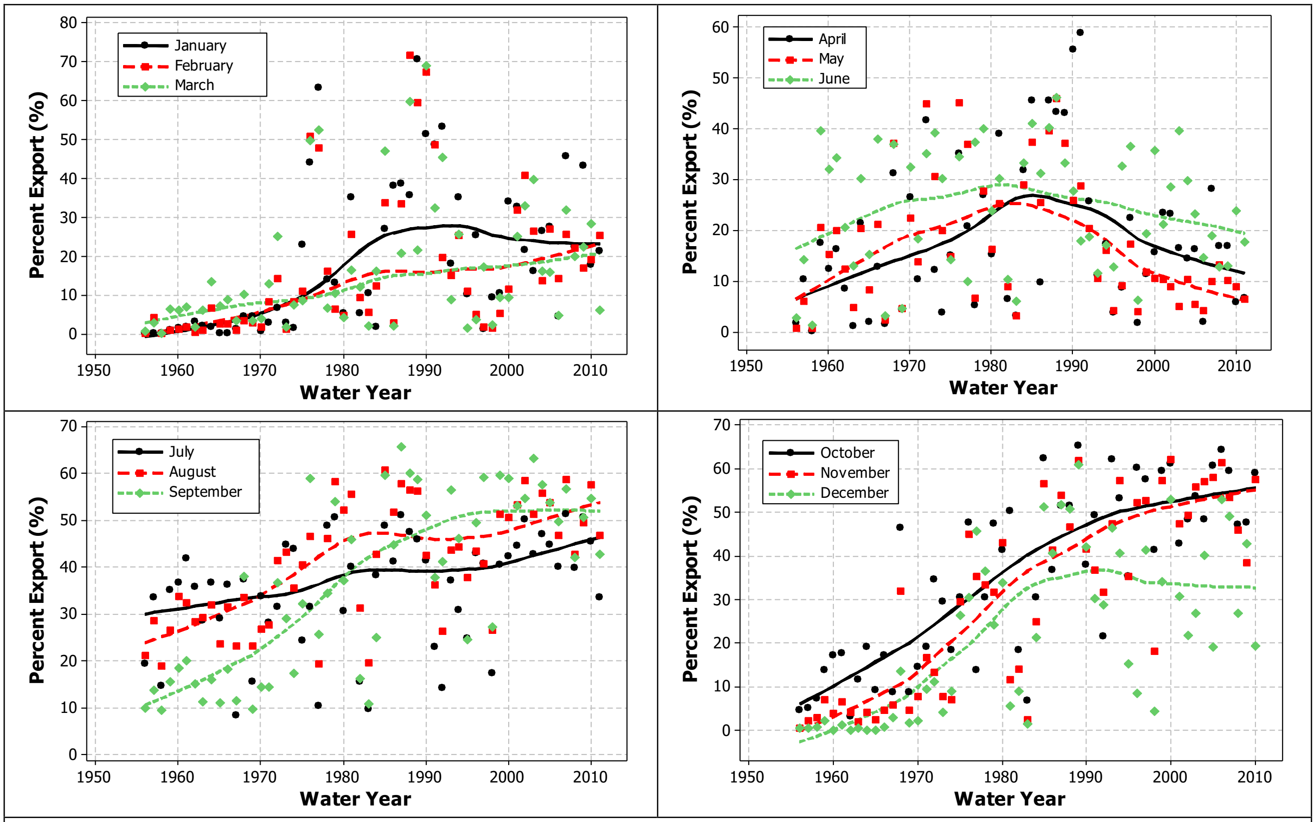


Figure 16. Trend for monthly water export percentage. The curves represent the lowess smoother.

2.4 Flows in the Old and Middle Rivers

The Old and Middle Rivers (OMR) (Figure 10) have served as a pathway to convey water originating from the Sacramento River to the JPP and BPP in the southern Delta. OMR flows are controlled largely by JPP and BPP water exports, inflow from the San Joaquin River (SJR), and the condition of the Head of Old River Barrier (HORB). The installation schedules for the HORB were derived from the table at: http://baydeltaoffice.water.ca.gov/sdb/tbp/web_pg/tempbsch.cfm. The dates for the HORB operation starts on full closure and end on breaching.

OMR flows may be calculated by the following three ways, with the USGS gauge stations represented by their numerical identifiers:

OMR1 = [11312672] + [11313315]

OMR2 = [11312676] + [11313405]
OMR3 = [11312685] + [11311300] + [11313431] + [11313434]

The USGS gauge stations included in the above equations are presented in Figure 17.

Three OMR flows showed a similar pattern in seasonal variability—highest (positive or less negative) in April and May and lowest (more negative) in July, August, and September (Figure 18). OMR flows with the spring HORB installed were lower (more negative) than those with no spring HORB installed. A negative flow indicates a flow direction from north to south while a positive flow indicates a direction from south to north. A natural flow (averaged over the net tidal cycle) would be positive and have flows leading towards the ocean. The presence of the HORB is dependent upon (1) the season, (2) flows in the San Joaquin River, and (3) fishery concerns. The HORB is typically installed in the April – May time frame for fishery protection. It can only be installed when flows in the San Joaquin River are below approximately 7,000 cfs, and if constructed, can only be safely operated in flows up to approximately 10,000 by its design. When flows are over 10,000 cfs in the San Joaquin River, barrier integrity is compromised and flooding concerns are present along adjacent levees. Within recent years, the decision to construct the spring HORB has been influenced by concerns over the entrainment of Delta smelt at the CVP and SWP export facilities. The fall HORB is operated during the September-November time period if dissolved oxygen and water quality concerns in the Port of Stockton reach merit it.

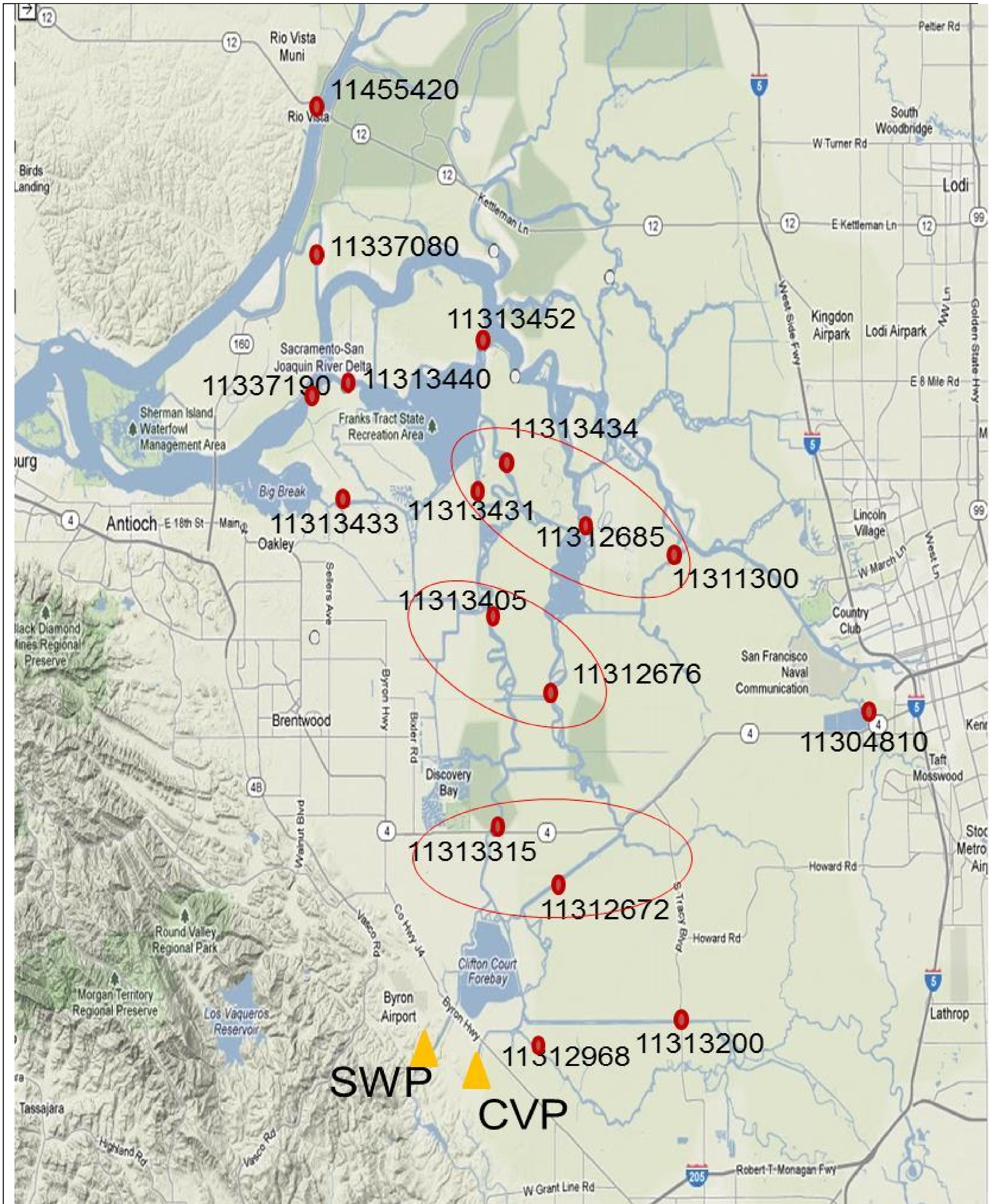


Figure 17. USGS gauge stations used to calculate OMR flows

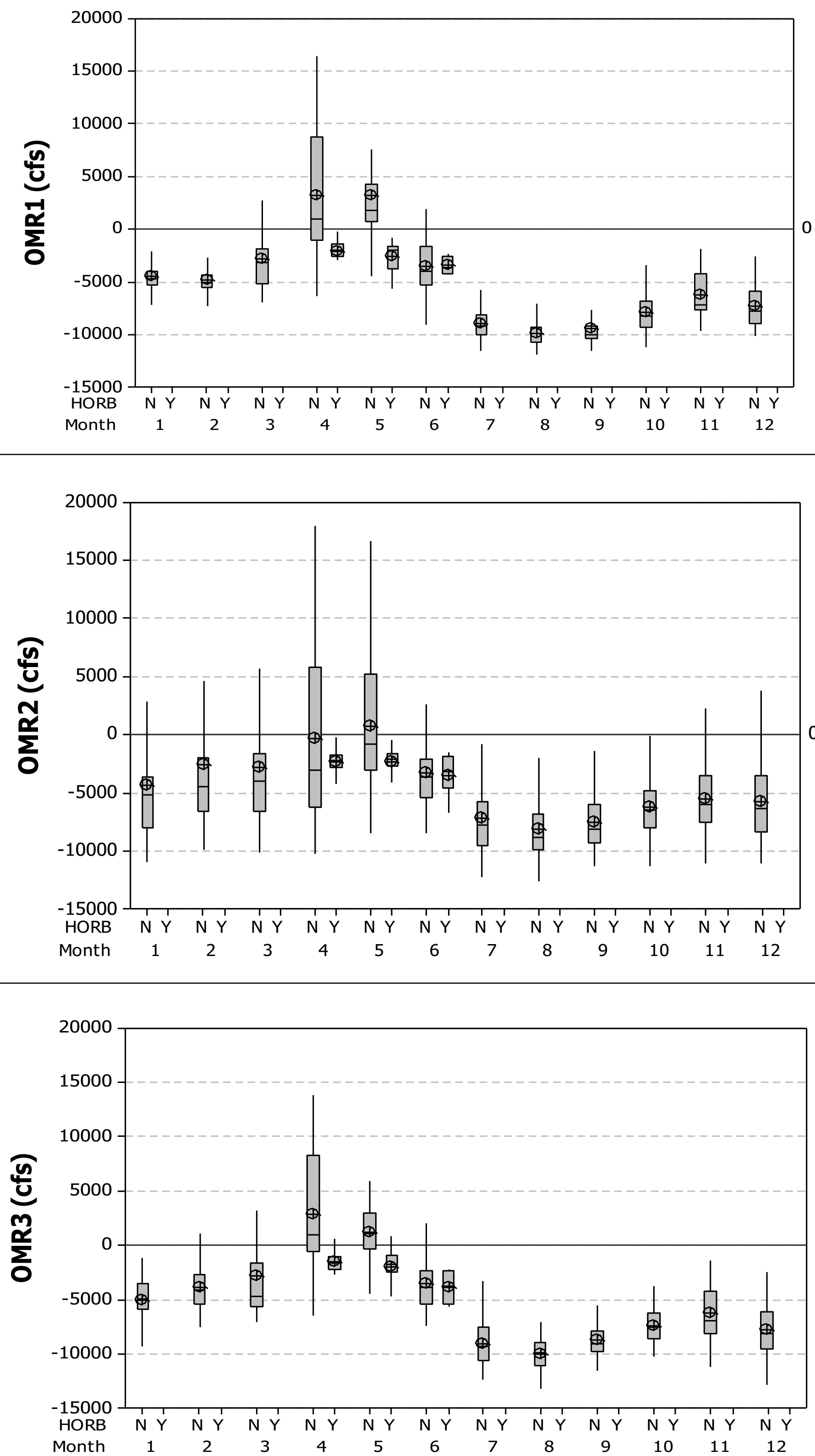


Figure 18. Seasonal variability of OMR flows (1987-2012). (– median; ⊕ mean)

OMR2 has generally been referred to as the OMR flow in the literature and practice. The average yearly OMR2 flow showed an increasing trend (more positive) from 1987 to 1997, followed by a decreasing trend (more negative). It appeared to level off to about -5500 cfs since 2005 (Figure 19). Higher water exports from 1985-1990 may have led to more negative OMR flows, while lower water exports from 1992-1999 may have led to less negative OMR flows.

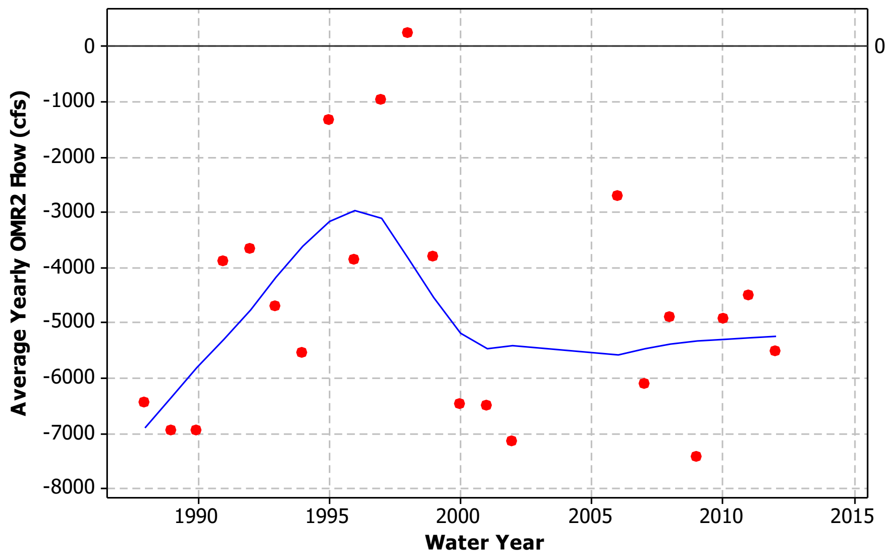


Figure 19. Average yearly OMR2 flow. The curve represents the lowess smoother.

2.5 Relationships of OMR Flows with Water Export and San Joaquin River Flow

The multiple linear regression was used to fit a set of data with the following equation:

$$Q_{OMR} = b_0 + b_1 Q_{Exp} + b_2 Q_{SJR}$$

where Q_{OMR}= OMR flow (cfs); Q_{Exp}= water export (cfs); Q_{SJR}= SJR flow at Vernalis (cfs); and b_0, b_1, b_2 = coefficients.

All three OMR flows showed a close correlation to the combined CVP and SWP water export. Adding the Contra Costa Water District (CCWD) water export did not substantially change regression equations since the CCWD water export accounts for only about 3% of the total water export. The SJR flow at Vernalis is an important factor controlling the OMR flow when the HORB is not installed. However, when the HORB is installed, the SJR flow was either not correlated to the OMR flow or a minor factor controlling the OMR flow. It appeared that OMR1 showed the best correlation to water export and SJR flow, OMR2 the second, and OMR3 the last. The OMR 1 equation uses data from gauges that are located in close proximity to the export facilities, with few alternative pathways for water to flow to the facilities. Thus, there is less "noise" to the OMR flow in relation to the magnitude of exports. Conversely, the OMR3 equation measures flows near the mainstem San Joaquin River, where there is significant tidal influence, and numerous alternative flow pathways to the export facilities (*e.g.*, the braided channels created by instream islands in the Old and Middle river channels and Turner and Columbia Cuts.

HORB	Regression Equation	N	R^2
Out	OMR1 = -199 - 0.999 SWP_CVP + 0.506 Vernalis	1760	0.982
Out	OMR2 = -552 - 0.910 SWP_CVP + 0.581 Vernalis	6052	0.950
Out	OMR3 = -446 - 0.991 SWP_CVP + 0.590 Vernalis	1205	0.923
Out	OMR1 = 4.9 - 0.997 SWP_CVP_CCWD + 0.506 Vernalis	1549	0.984
Out	OMR2 = -386 - 0.910 SWP_CVP_CCWD + 0.579 Vernalis	5838	0.951
Out	OMR3 = -337 - 0.989 SWP_CVP_CCWD + 0.588 Vernalis	1058	0.931
In	OMR1 = -169 - 0.936 SWP_CVP	93	0.871
In	OMR2 = -1000 - 0.725 SWP_CVP + 0.112 Vernalis	263	0.664
In	OMR3 = 337 - 1.000 SWP_CVP	78	0.590
In	OMR1 = -32 - 0.939 SWP_CVP_CCWD	93	0.873
In	OMR2 = -910 - 0.709 SWP_CVP_CCWD + 0.106 Vernalis	263	0.640
In	OMR3 = 488 - 1.005 SWP_CVP_CCWD	78	0.589

HORB = Head of Old River barrier – a temporary rock barrier typically installed in the spring (April and May)
CVP = Water export at Tracy Pumping Plant
SWP = Inflow to the Clifton Court Forebay
CCWD = Water export by Contra Costa Water District
Vernalis = San Joaquin River flow at Vernalis

The regression models for OMR2 were further examined with an attempt to improve these two models. The diagnostic tools applied to identify the points of unusual influence on a model included standardized residual, leverage, and DFFITS (Helsel and Hirsch 2002). This process was used to develop a sub-dataset by eliminating those records with high standardized residual, leverage, or DFFITS. For the dataset without HORB, 237 records out of 6052 were eliminated, while for the dataset with HORB 33 records out of 263 were eliminated. Refined OMR2 regression models developed using the sub-datasets improved the goodness of fit (Table 2) and reduced residuals (Figure 20, Figure 21, Figure 22, and Figure 23).

Table 2. Refined regression models

HORB	Refined Regression Equation	N	R^2
Out	OMR2 = -555 - 0.897 SWP_CVP + 0.552 Vernalis	5815	0.971
In	OMR2 = -1109 - 0.669 SWP_CVP + 0.0923 Vernalis	230	0.766

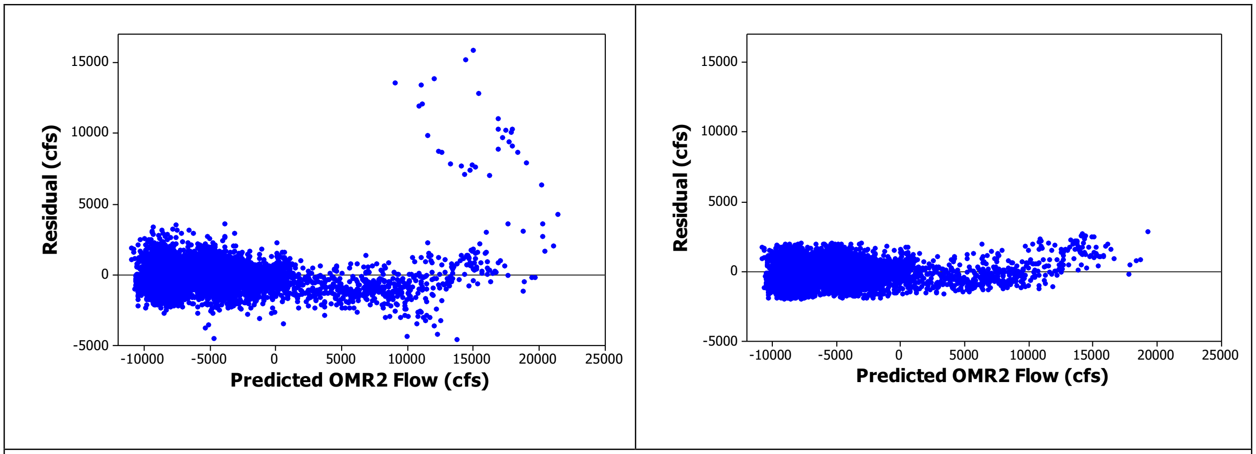


Figure 20. Residual against predicted OMR2 flow from the original (left) and refined (right) models without HORB

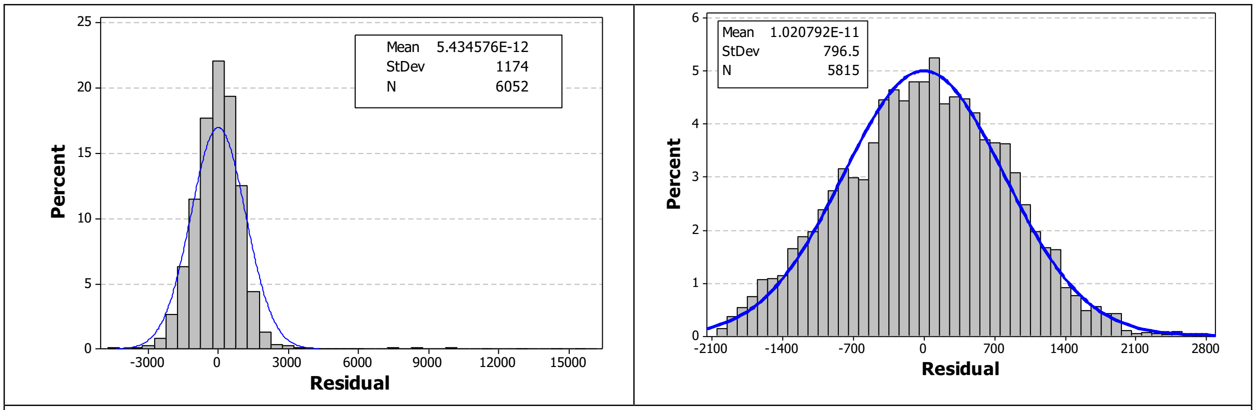


Figure 21. Residual distribution from the original (left) and refined (right) models without HORB

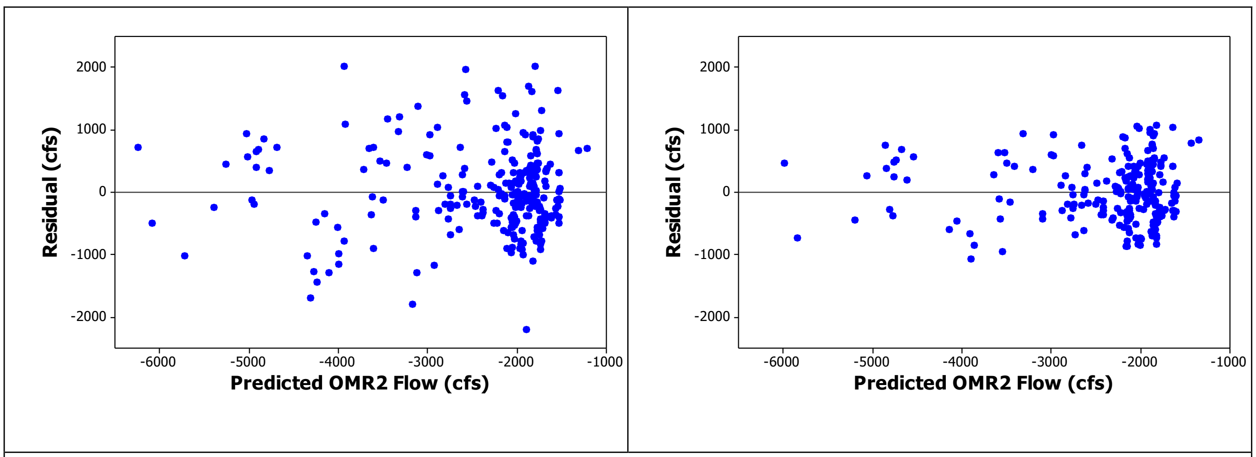
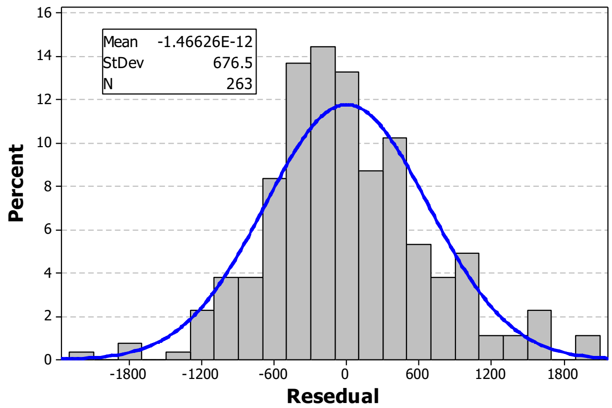


Figure 22. Residual against predicted OMR2 flow from the original (left) and refined (right) models with HORB



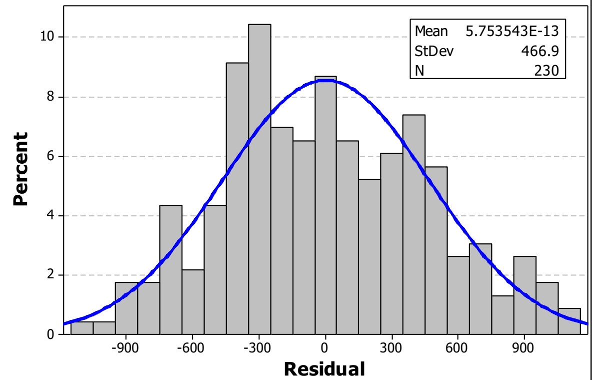


Figure 23. Residual distribution from the original (left) and refined (right) models with HORB

Figure 24 and Figure 25 show the predicted OMR2 flow plotted against the observed OMR2 flow. The prediction interval is the confidence interval for prediction of an estimate of an individual response variable. For example, the 95% prediction interval indicates that 95% of the time the predicted value will be within the interval. Most of the observations are between the upper and lower prediction interval lines.

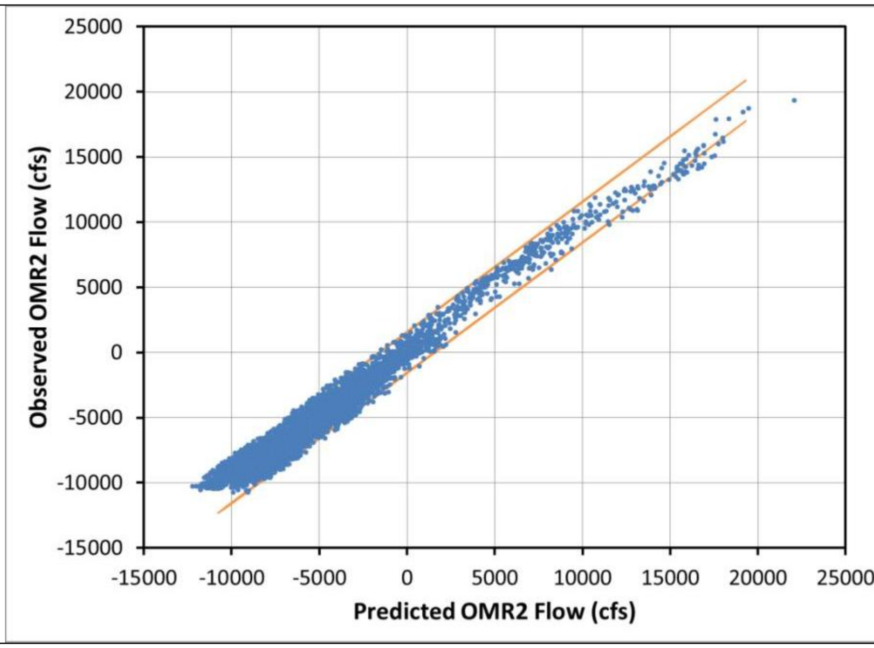


Figure 24. Observed OMR2 flow vs. predicted flow from the refined regression model without HORB. The orange lines represent the 95% prediction interval.

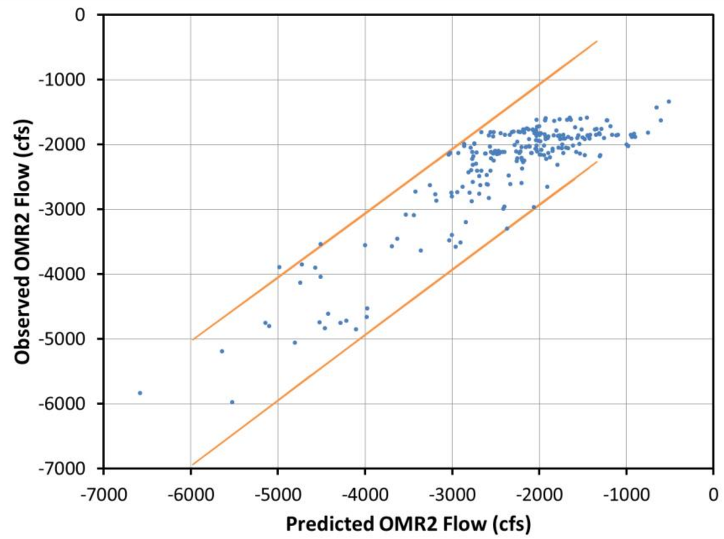


Figure 25. Observed OMR2 flow vs. predicted flow from the refined regression model with HORB. The orange lines represent the 95% prediction interval.

2.6 Tide Height

Tidal data were obtained from NOAA's Center for Operational Oceanographic Products and Services, which provided hourly tidal height data from 1/1/1991 to 9/26/2012 for station 9414290 (latitude: 37° 48.4' N; longitude: 122° 27.9' W) near the Golden Gate Bridge, San Francisco. The data were retrieved with a reference to Station Datum zero, in feet, on LST (local standard time).

Provided in Figure 26 are the daily minimum, mean, and maximum tide heights.

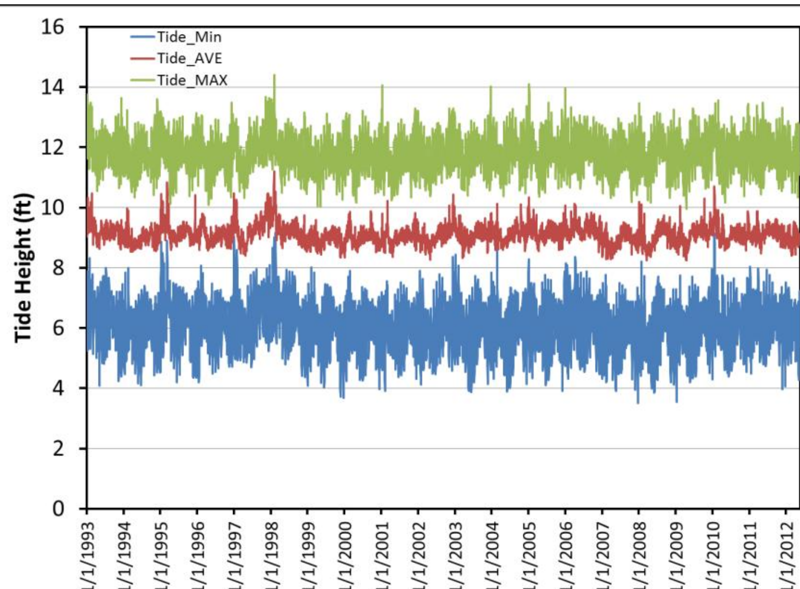


Figure 26. Daily maximum, mean, and minimum tide heights near the Golden Gate Bridge

3 Juvenile Fish Salvage and Loss at the Water Export Facilities in the South Delta

The Federal Jones Pumping Plant and the State Banks Pumping Plant draw massive volumes of water off the Old River channel in the south Delta. These massive pumping plants would also entrain a large quantity of native and migratory fishes if there were no fish screens on the intake channels. Fish salvage facilities were therefore built to reduce the fish loss associated with water exports by the two pumping plants.

The Federal Tracy Fish Collection Facility (TFCF) and the State's Skinner Fish Protective Facility (SFPF) use louver-bypass-collection systems to remove fish from the exported water. The salvaged fish are periodically loaded into tanker trucks, transported to the western Delta, and released at fixed release sites (Figure 27). USBR has operated the TFCF to salvage fish since 1957 (Karp *et al.* 1995), while DWR has operated the SFPF since 1968 (Morinaka 2011).

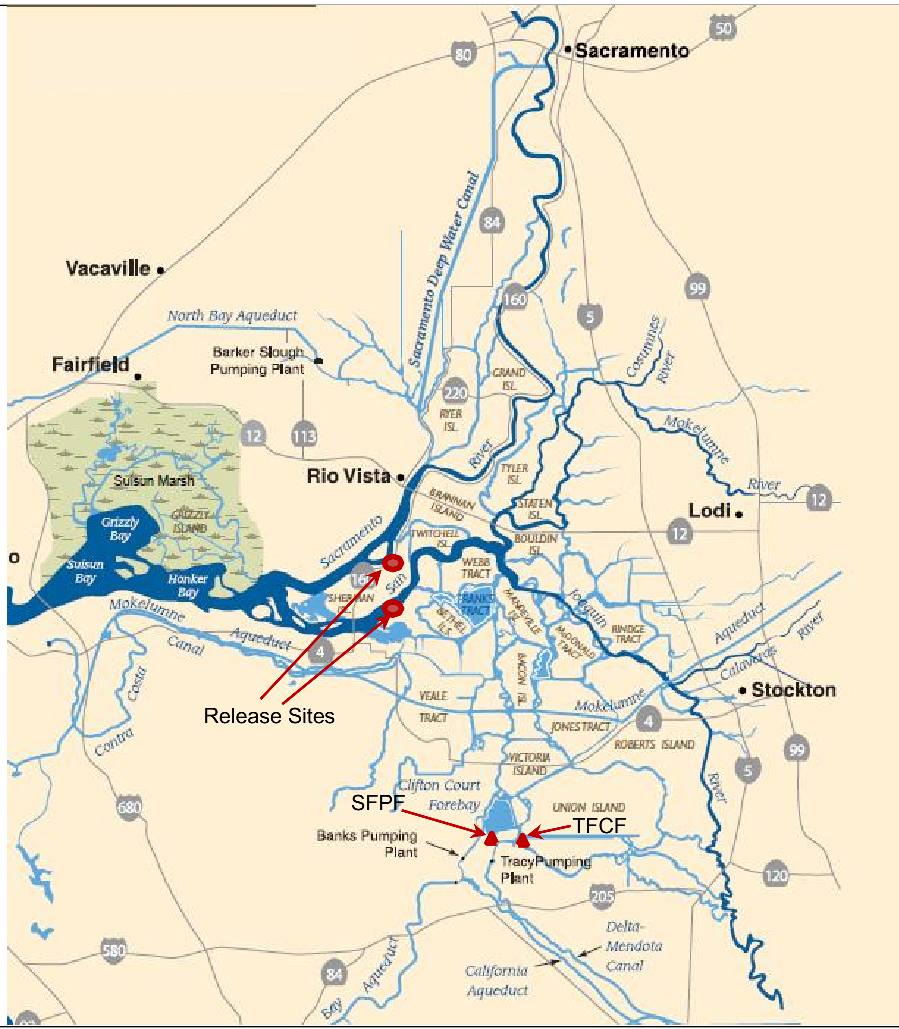


Figure 27. The Delta map showing the Skinner Fish Protective Facility (SFPF), the Tracy Fish Collection Facility (TFCF), and release sites.

3.1 Juvenile Fish Salvage at the Fish Salvage Facilities

3.1.1 Tracy Fish Collection Facility

Fish salvage at the TFCF is accomplished in two louver channels (Figure 28). The primary channel has a maximum depth of 6 meters (m) (20 feet [ft]) and is completely traversed by the primary louver array, which is 97.5 m (320 ft) long and 25.6 m (84 ft) wide. The louver array is angled 15 degrees to the channel and has four bypasses. Each bypass is 15.3 centimeters (cm) (6 inches [in]) wide and leads to a primary bypass pipe 91.4 cm (36 in) in diameter. These four pipes deliver water to the secondary louver channel (Bowen *et al.* 2004).

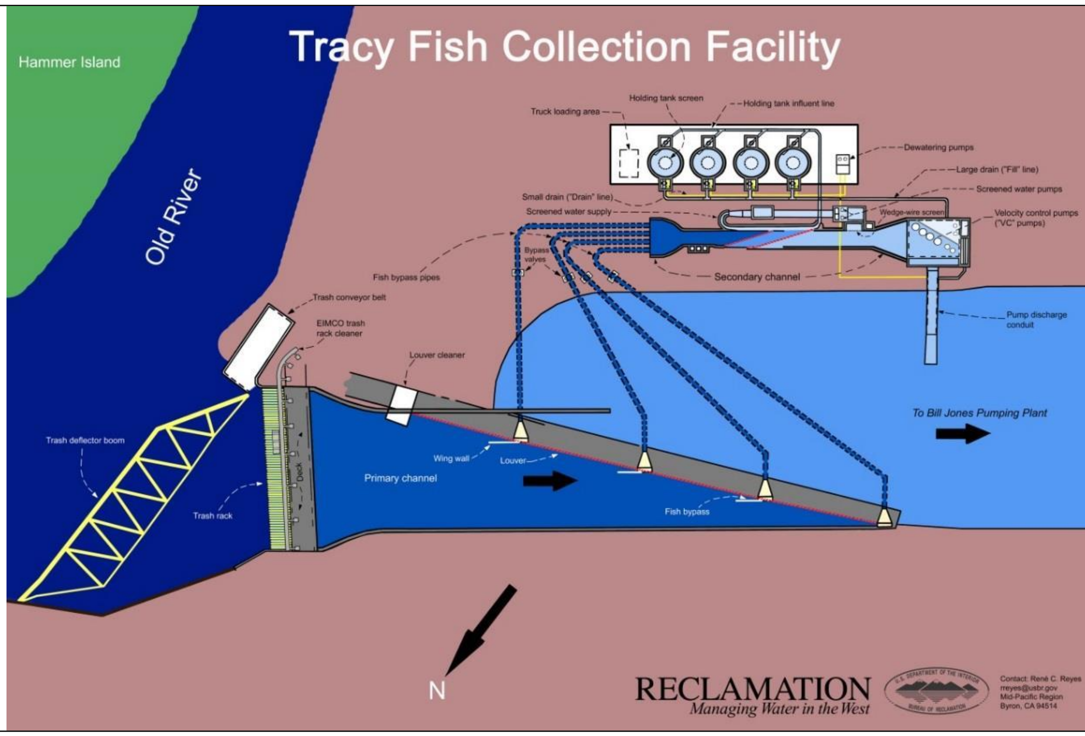


Figure 28. Schematic of the Tracy Collection Fish Facility. Courtesy of Brent Bridges of USBR.

The secondary louver channel (Figure 28) has a maximum depth of 4.9 m (16 ft) and contains two parallel louver arrays that span the channel's entire 2.4 m (8 ft) width. Similar to the primary louvers, both secondary louver arrays are angled 15 degrees to the flow. The anterior louver array in the secondary channel ends in a rectangular opening. This steel "bypass" is 15.3 cm (6 in) wide. However, this is not a bypass to a holding tank; the steel ends 1.7 m (5.6 ft) in front of the posterior louver array's true bypass (width = 15.3 cm [6 in]). Fish could be "louvered" by the anterior secondary louver array and potentially swim through the posterior secondary louver array and be transported into the pumping plant (Bowen *et al.* 2004).

Design of the louver system was based on observations that fish orient into the flow and swim against the current but are eventually transported downstream when the flow velocity is greater than the fish swimming speed. Each louver array consists of a series of vertical slats spaced 2.3 cm (0.9 in) apart. The louver slats allow water to pass to the pumps while creating some turbulence which fish can detect. When fish encounter the louver array it tends to swim laterally away from the turbulence into the more laminar flow. Thus, fish are "guided" toward the bypass.

The probability that a fish will be guided into a bypass opening is most strongly influenced by its swimming ability and size, and the approach velocity. Other factors include the amount of debris clogging the louver spaces, bypass velocities, predator density, day/night, etc. (Karp *et al.* 1995).

Fish that are successfully deterred by the louvers will enter large holding tanks through a bypass pipe (Figure 28). The number of daily fish salvage is estimated by taking a sample of louvered fish every 2 hours. To accomplish this, fish are diverted into a different holding tank for 10 minutes of each 2-hour period and all fish identified and counted. The sampling duration has increased to 30 minutes since 2010.

3.1.2 Skinner Fish Protective Facility

The SFPF (Figure 29) was designed in a similar fashion to the TFCF with primary louvers, secondary louvers, holding tanks, and transport trucks. The line of the louver array (primary or secondary) is angled 15 degrees to the channel water flow. The louvers are spaced 2.54 cm (1 in) apart between louver slats (Skinner 1974). However, there are several differences in system configurations between the TFCF and the SFPF. At the SFPF, a series of louver panels are arranged in a v-shaped configuration to guide fish into bypasses located at the apex of the configuration. Concrete splitter walls divide the channel into 7 bays. A series of wing gates located at the upstream end of each bay in front of the primary louvers are used to regulate the velocity of the water approaching the primary louvers.

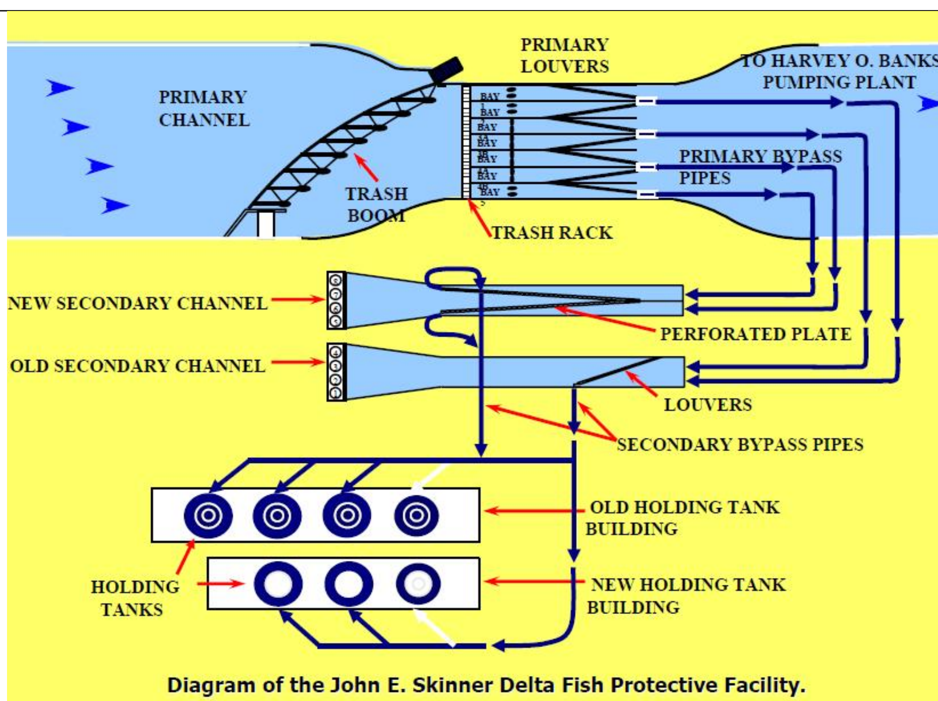


Figure 29. Schematic of the Skinner Fish Protective Facility

There are two secondary channels (Figure 29) that are used to reduce the volume of water, concentrate the fish, and guide the fish into the secondary bypasses and finally to 7 holding tanks. Typically, 1 tank is used for fish counts and other tanks are used for holding salvaged fish. Fish counts are normally conducted every 2 hours whenever DWR is exporting water at the Banks Pumping Plant. From 2001 to 2007, the sampling duration was 20 minutes but has increased to 30 minutes since late-2008 in response to conditions required in the USFWS' biological opinion for the long-term operations of the CVP and SWP. A similar requirement is also contained in the NMFS' 2009 biological opinion for the same operations.

3.2 Juvenile Fish Salvage Data Source

Juvenile fish salvage data were obtained from the California Department of Fish and Wildlife (CDFW) (ftp://ftp.delta.dfg.ca.gov/salvage). CDFW maintains and updates an Access based fish salvage database and posts it on the ftp site. We downloaded the salvage database on December 28, 2012, which included salvage data from January 1, 1993 through December 26, 2012.

The CDFW fish salvage database contains data for 4 study categories (Table 3). However, only the category of "salvage" is used for this data analysis and report. At the SFPF, during predator removal operations, the number of fish resided in the secondary channel was directly counted. The number of fish salvaged during predator removal should be counted toward the yearly or monthly fish salvage or loss. However, it should not be counted toward daily salvage or loss that would be used to correlate with daily water exports, as this quantity of fish salvage or loss is not associated with water exports because primary bypasses are closed during the process. The size and origin (hatchery or wild) of salvaged fish was reported in the database. The database also contains other physical data, including sampling time, sampling time length, and primary channel flow and depth. Some zero values in the database for the primary channel flow and depth prevented the calculation of velocity, prompting the "Overflow" error message in the database.

Table 3. Summary of study categories and records in the fish salvage database from January 1, 1993 through December 26, 2012

Study Category	Study Code	Number of Records for Chinook		Number of Records for Steelhead		Number of Records for Green Sturgeon	
		SFPF	TFCF	SFPF	TFCF	SFPF	TFCF
Salvage	0000	41,314	53,510	10,049	5,408	59	53
Traveling Screen	7777	0	0	0	0	0	0
Special Studies	8888	66	1,703	2	382	0	1
Predator Removal	9999	1,270	97	748	237	1	0

The number of juvenile fish salvaged per day at the SFPF or the TFCF is estimated from the number (counts) of fish sampled. The ratio of the pumping duration to the sampling duration is used to expand the count data to an estimate of the number of fish salvaged in the pumping time period, which is further expanded to the number of fish salvaged per day (24 hours).

3.3 Juvenile Fish Salvage Data Analysis

The CDFW salvage database provided raw salvage and environmental data. We developed a series of queries to retrieve, calculate, and/or present different types of data including sampling time length, expanding factor, primary channel velocity, and the number, size and origin of salvaged fish. We then sum the fish salvage data at the daily, monthly, or yearly (brood year) scale.

3.3.1 Sampling Duration

3.3.1.1 SFPF

While samples are usually taken every 2 hours of pumping, the sampling duration changed over time. In the 1990's, the sampling duration ranged from 1 to 540 minutes, but the sampling duration was less variable since 2000 (Figure 30 A). The median sampling duration was between 20 and 30 minutes except for 1998 when the median duration was 10 minutes (Figure 30 B). The expanding factor, which is defined as the quotient of the pumping duration divided by the sampling duration, ranged from 1 to 180 (Figure 31 A). The median expanding factor was between 3 and 8 from 1993 to 2012. The median expanding factor was 4 since 2007 except for 2008 when it was 3 (Figure 31 B).

3.3.1.2 TFCF

The sampling duration at the TFCF was less variable than that at the SFPF (Figure 32 A). It ranged from 1 to 360 minutes with the majority less than 40 minutes (Figure 32 B). The median sampling duration was 10 minutes from 1993 to 2009 and increased to 30 minutes since 2010. The expanding factor ranged from 1 to 120 (Figure 33 A). The median expanding factor was 12 from 1993 through 2007, decreased to 9 in 2008, 8 in 2009, and remained 4 since 2010 (Figure 33 B).

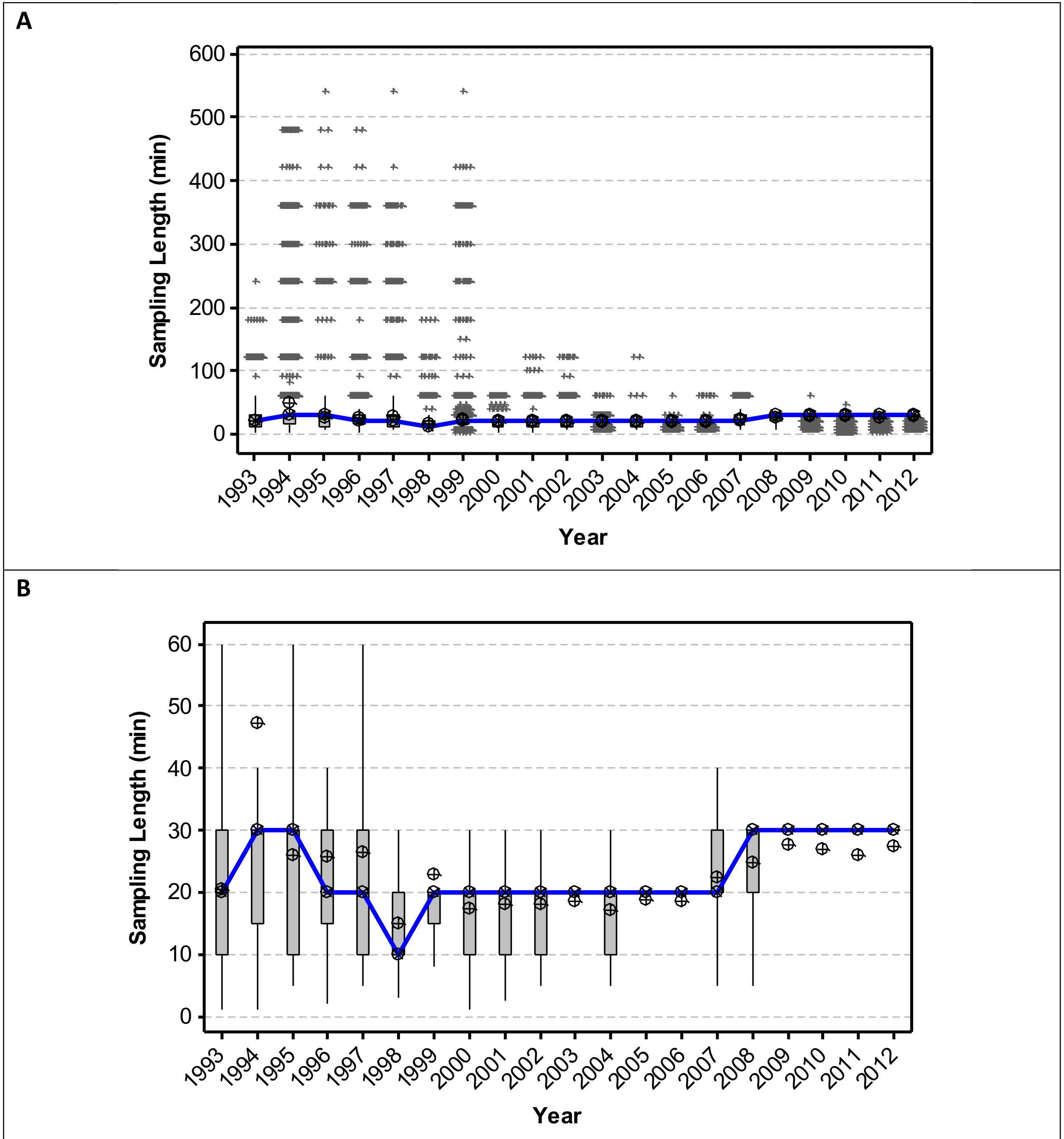
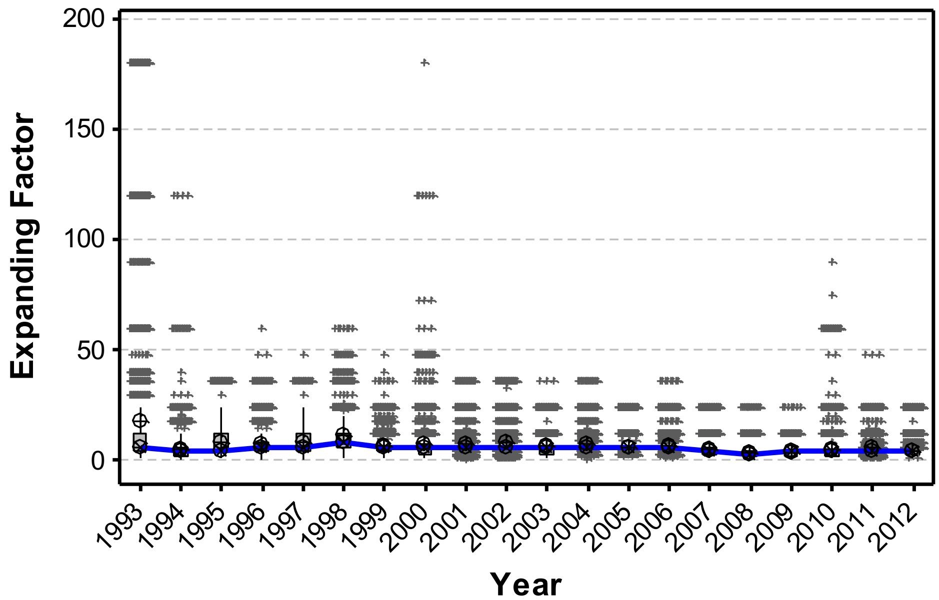


Figure 30. The time length of sampling at the SFPF. The blue line represents the median. A - With outliers; B - Without outliers.

A



B

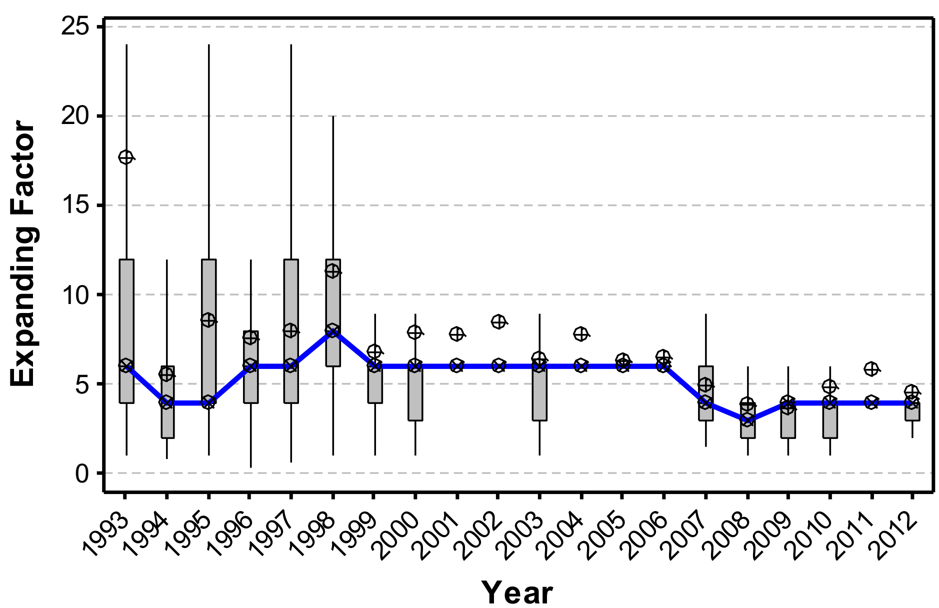
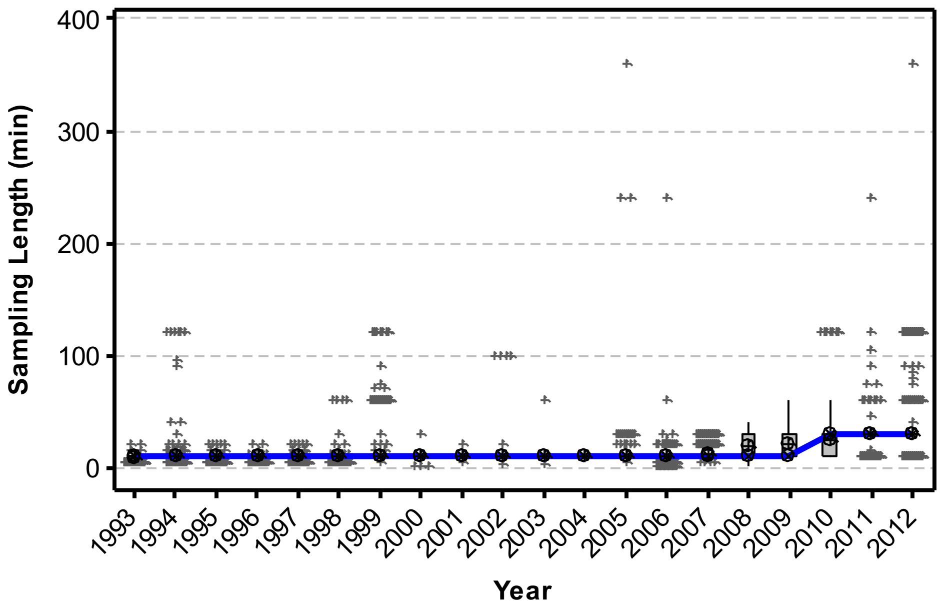


Figure 31. The expanding factor for calculating the number of salvaged fish during the time length of pumping based on the sampling counts at the SFPF. The blue line represents the median. A - With outliers; B - Without outliers.

A



B

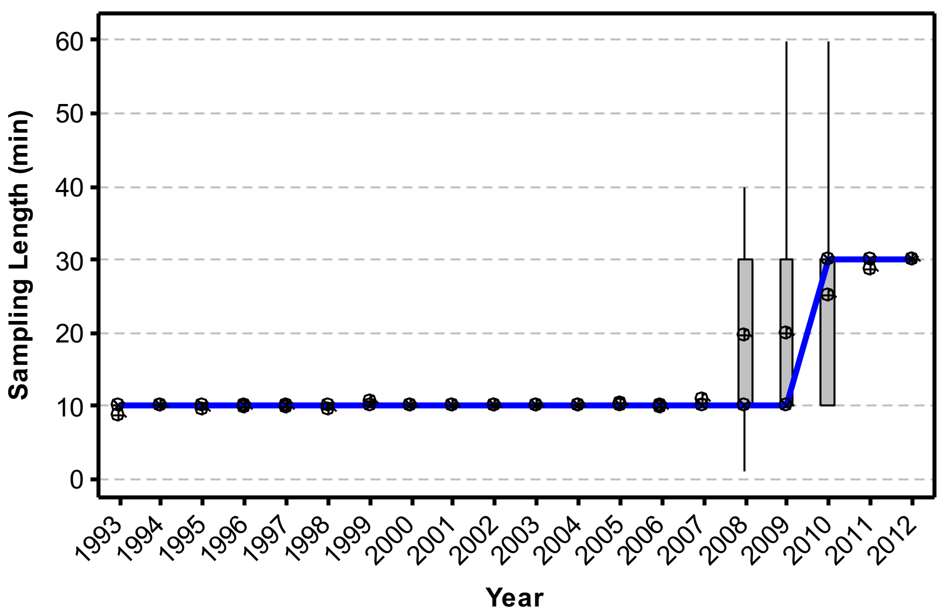
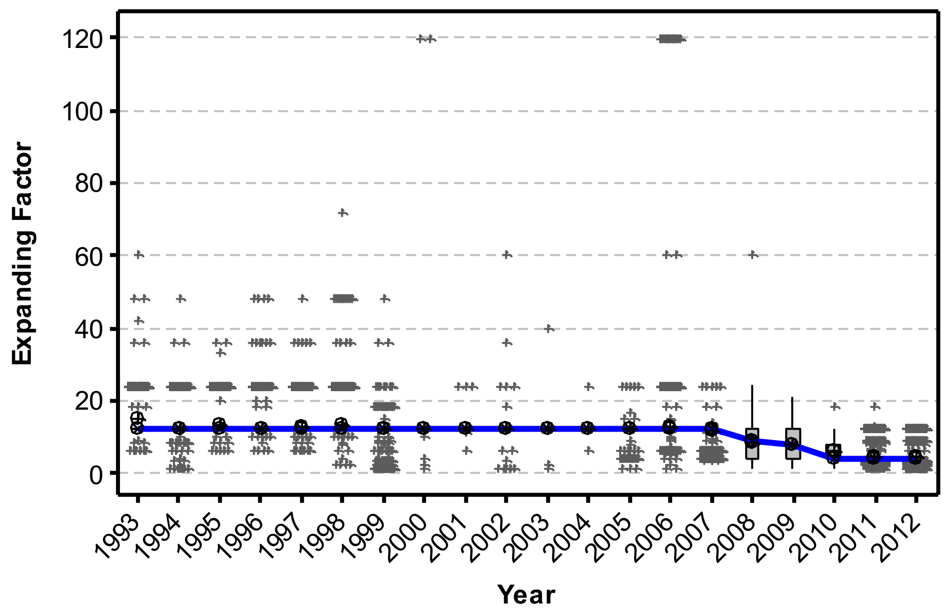


Figure 32. The time length of sampling at the TFCF. The blue line represents the median. A - With outliers; B - Without outliers.

A



B

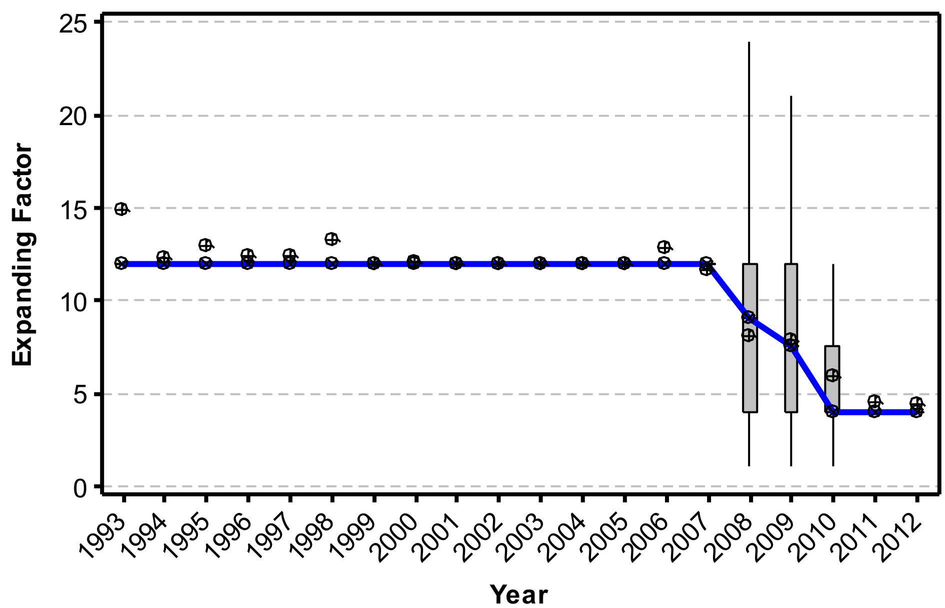


Figure 33. The expanding factor for calculating the number of salvaged fish during the time length of pumping based on the sampling counts at the TFCF. The blue line represents the median. A - With outliers; B - Without outliers.

3.3.2 Flow Velocity in the Primary Channel

3.3.2.1 SFPF

The primary channel velocity (V) at the SFPF was calculated using the following equation:

$$V = Q/(D*W)$$

where Q= channel flow (cfs), D= channel depth (ft), and W= channel width (ft).

The velocity ranged from 0.3 to 14 ft/s (Figure 34). However, the median velocity was about 2.6 ft/s since 2000 (Figure 34).

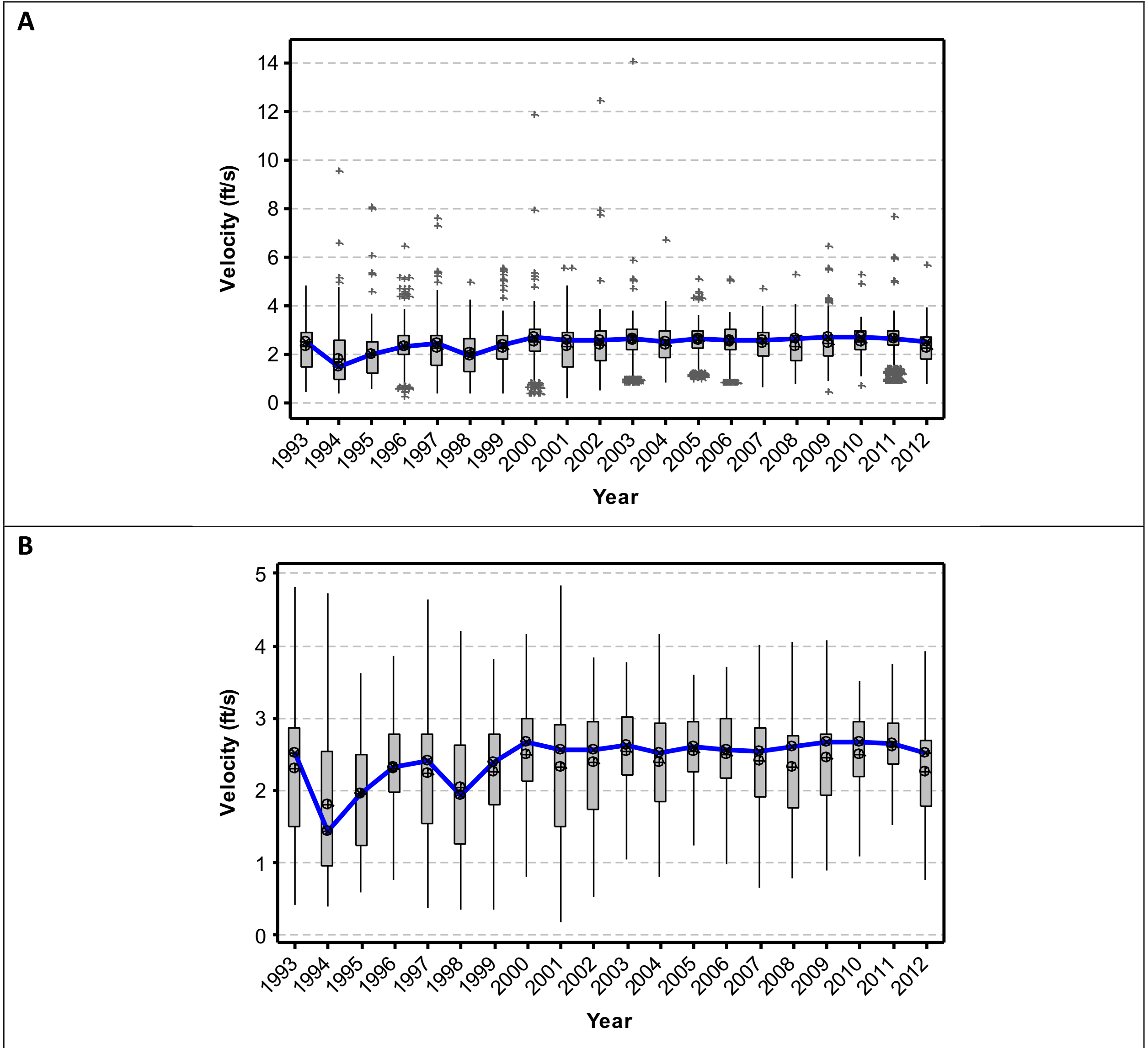


Figure 34. Primary channel velocity at the SFPF. The blue line represents the median. A - With outliers; B - Without outliers.

There were 115 records (out of 75,233 records) with velocity greater than 4 ft/s. Some of these high velocity values might be caused by the inaccurate data reported for primary channel flow, depth, and the number of open bays, on which the velocity was calculated. For example, all records with velocity greater than 7 ft/s are the cases with one bay open (21 ft wide). One record with the velocity of 6.7 ft/s showed a channel depth of 10 ft while most of the other records had a depth of about 20 ft. There were 2,292 records that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the SFPF.

3.3.2.2 TFCF

The primary channel velocity at the TFCF ranged from 0.2 to 10 ft/s[2]. The variability of velocity has decreased since 2008 (Figure 35 A). The median velocity was high in 1993 (3.4 ft/s) and low in 1994, 2008, 2009, and 2012 (about 1.5 ft/s) (Figure 35 B).

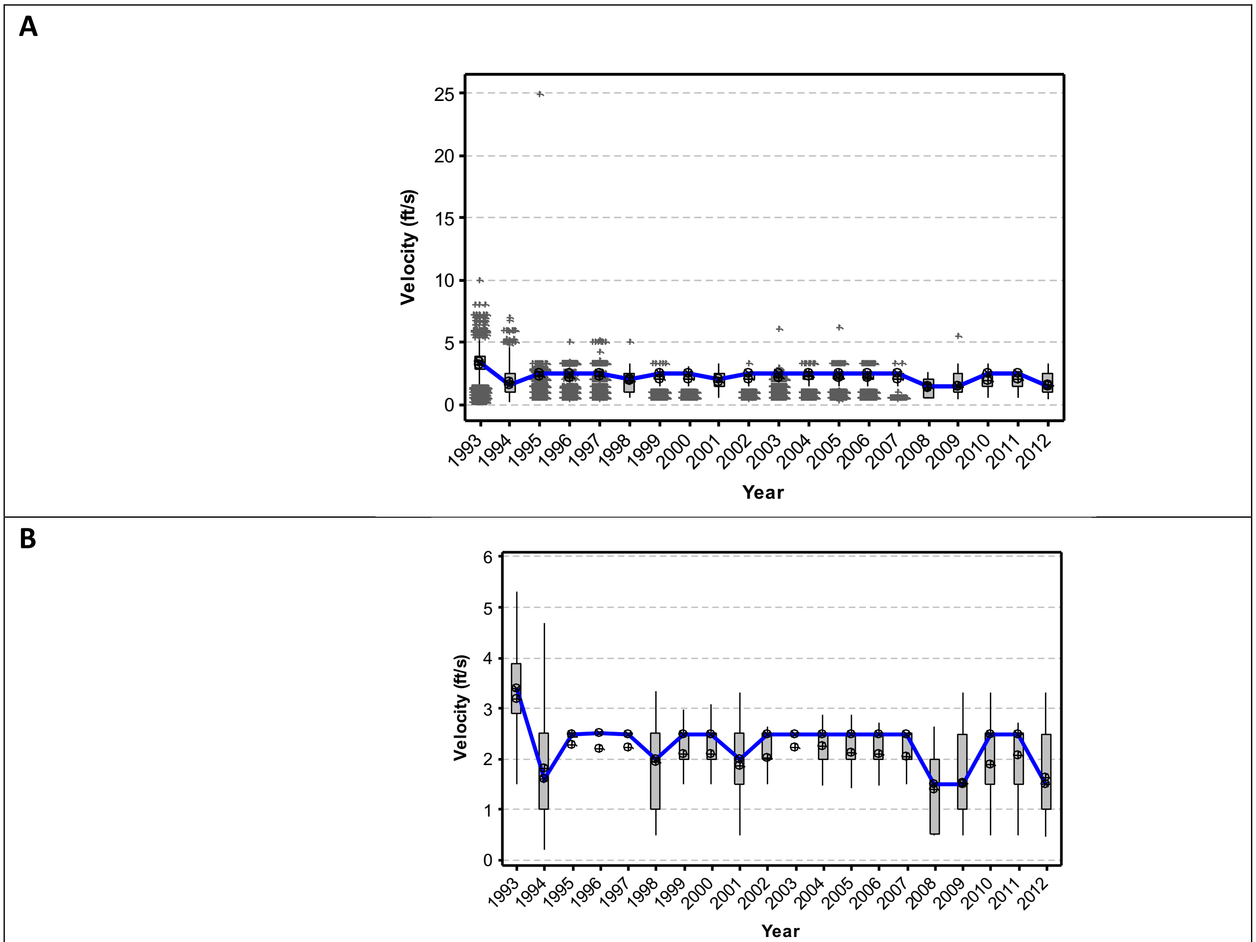


Figure 35. Primary channel velocity at the TFCF. The blue line represents the median. A - With outliers; B - Without outliers.

[2] The 25 ft/s velocity in Figure 34A is considered a measurement or data entry error because the primary channel flow was recorded as 38,015 cfs, which could not occur.

There were 1,042 records (out of 85,495 records) with velocity greater than 4 ft/s. Some of these high velocity values might be caused by the inaccurate data reported for primary channel flow, depth, or the number of open bays, on which the velocity was calculated. For example, even though there is only one bay (channel) at the TFCF, the salvage database still uses 4 “bays” with each being 21 ft wide. Therefore, the entire bay (channel) width should always be 84 ft. However, the database included 67 records with 2 bays (i.e., 42 ft) and 1172 records with 3 bays (i.e., 63 ft). There were 14,013 records (out of 85,495 records) that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the TFCF.

3.3.3 Size of Salvaged Chinook Salmon, Steelhead, and Striped Bass

The salvage database separated juvenile salmonids with clipped adipose fins from those without clipped adipose fins. As those fish with clipped adipose fins are raised and released from hatcheries, we consider them “hatchery” fish. All winter-run, spring-run, and late fall-run Chinook salmon, as well as all steelhead, released from hatcheries are adipose fin clipped. Therefore it is appropriate to identify those fish from those run categories still bearing an adipose fin as a “wild” fish. However, for fall-run Chinook salmon, only 25 percent of the hatchery production is adipose fin clipped, thus any salvaged fish in the fall-run size category with an adipose fin may be either “hatchery” or “wild”.

3.3.3.1 SFPF

Winter-run

The median size of salvaged wild winter-run juveniles from 1993 to 2012 ranged from 116-150 mm, while the median size of salvaged hatchery winter-run juveniles ranged from 135-186 mm (Figure 36). The monthly median size of salvaged wild winter-run juveniles was similar from December through March (124-135 mm), whereas it increased to 154 mm in April and 213 mm in May. The monthly median size of salvaged hatchery winter-run juveniles was similar from December through March (132-154 mm), whereas it increased to 192 mm in April and 221 mm in May (Figure 37).

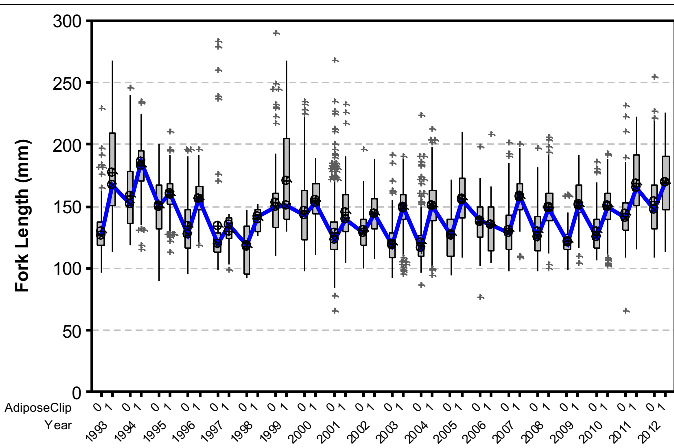


Figure 36. Size of salvaged juvenile winter-run Chinook salmon by year at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

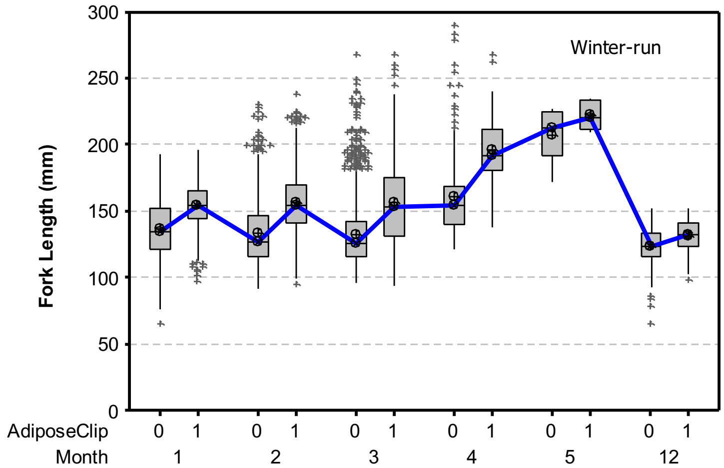


Figure 37. Size of salvaged juvenile winter-run Chinook salmon by month at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Spring-run

The median size of salvaged wild spring-run juveniles ranged from 86-110 mm, while the median size of salvaged hatchery spring-run juveniles ranged from 90-115 mm (Figure 38).

The monthly median size of salvaged wild spring -run juveniles was smallest in January and February (~60 mm), increased to 90 mm in March and April, and reached the highest (110-119 mm) in May and June. The data points each in September and October are likely to be outliers. The monthly median size of salvaged hatchery spring-run juveniles increased gradually from 90 mm in March and April, 98 mm in May, to 116 mm in June (Figure 39). The large sized juvenile fish in September or October are probably yearling spring-run.

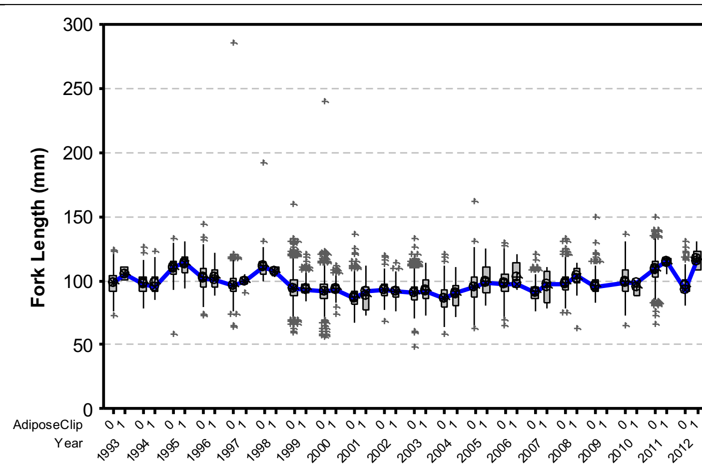


Figure 38. Size of salvaged juvenile spring-run Chinook salmon by year at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

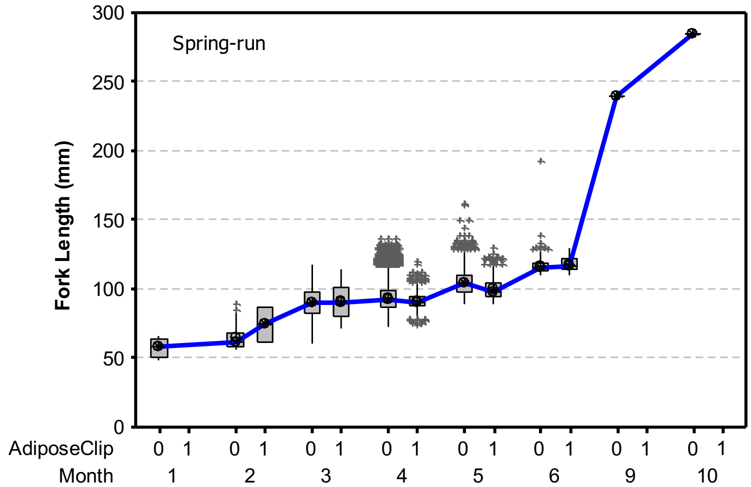


Figure 39. Size of salvaged juvenile spring-run Chinook salmon by month at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Fall-run

The size distribution of salvaged fall-run juveniles showed two peaks – one around 38 mm and the other around 88 mm (Figure 40). This may reflect the actual size distribution pattern of fall-run juveniles in the south Delta. This may also indicate a difference in louver efficiency for different fish sizes at the SFPF. Fish with sizes of about 60 mm may be more vulnerable to passage through the louver than those with smaller or larger sizes. Fish with sizes of less than 40 mm may not have swimming ability so they would be carried downstream by faster flow velocity in parallel with the channel or the line of the louver array. Fish with sizes of 40-80 mm may have an adequate swimming speed that could be near the through-louver velocity but allow them to take a position at angles perpendicular to the line of the louver arrays, resulting in easier passage through the louver. Fish with larger sizes would have stronger swimming ability and would swim away from the louver by lateral movement. This could also represent a life history pattern. Small sized fry, recently emerged from the gravel, can be easily carried downstream by high flows or forced out of their upstream habitat by high densities to rear in alternative downstream habitats, i.e., the Delta or even estuary. The second peak would represent fall-run that reared upstream and entered the Delta just prior to smolting.

The median size of salvaged fall-run juveniles ranged from 58 mm (2004 wild) to 200 mm (2010 hatchery) (Figure 41). In general, hatchery juveniles were larger than wild juveniles, particularly in 2010 and 2012 when the size of hatchery juveniles was double the size of wild juveniles. There were no salvaged hatchery fall-run juveniles reported in 2008 and 2009.

The monthly median size of salvaged fall-run juveniles with an intact adipose fin increased from 36-38 mm in January and February to 98 mm in June. The monthly median size of salvaged hatchery fall-run juveniles increased from 65 mm in March to 102 mm in June (Figure 42). It appeared that yearling fish were present in the Delta from September through December.

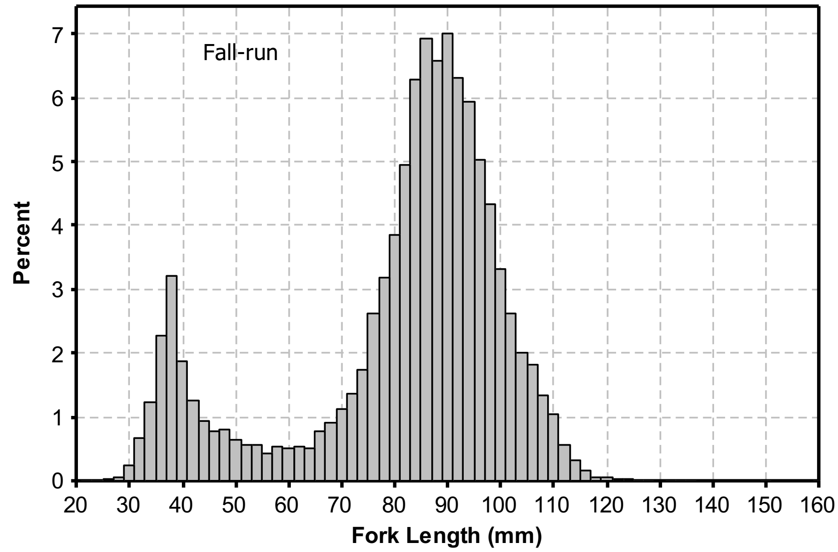


Figure 40. Size distribution of salvaged juvenile fall-run Chinook salmon from 1993 to 2012 at the SFPF

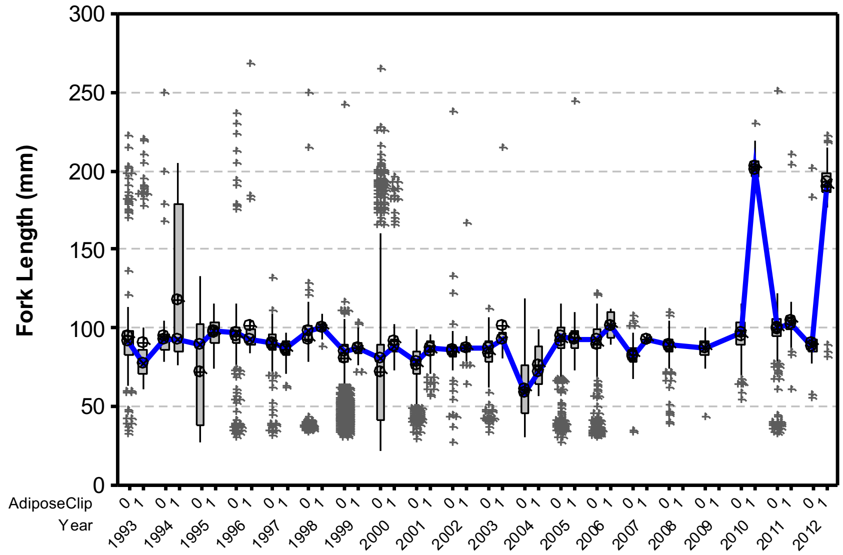


Figure 41. Median size of salvaged juvenile fall-run Chinook salmon by year at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild and hatchery fish; 1 = Hatchery fish

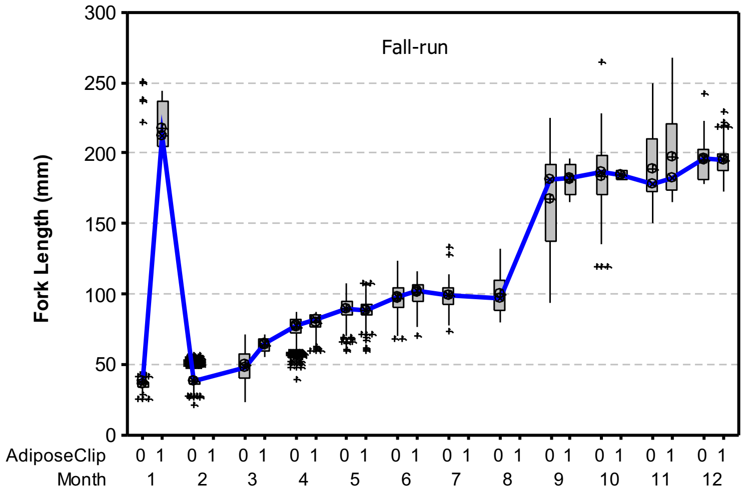


Figure 42. Median size of salvaged juvenile fall-run Chinook salmon by month at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild and hatchery fish; 1 = Hatchery fish

Late Fall-run

The median size of salvaged wild late fall-run juveniles ranged from 111 mm to 213 mm. The median size of salvaged hatchery late fall-run juveniles was larger than the wild late fall-run (Figure 43).

The monthly median size of salvaged wild late fall-run juveniles increased from 155 mm in December to 186 mm in January. There was only one wild late fall-run juvenile observed in each of the months of March, April, and August. Two fish were observed in the month of September and 5 fish in October. The monthly median size of salvaged hatchery late fall-run juveniles increased from 165 mm in December to 185 mm in January (Figure 44). One hatchery late fall-run juvenile was observed in November.

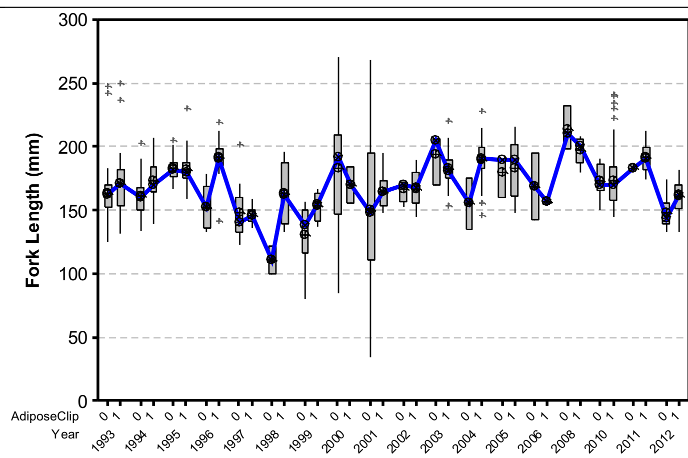


Figure 43. Median size of salvaged juvenile late fall-run Chinook salmon by year at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

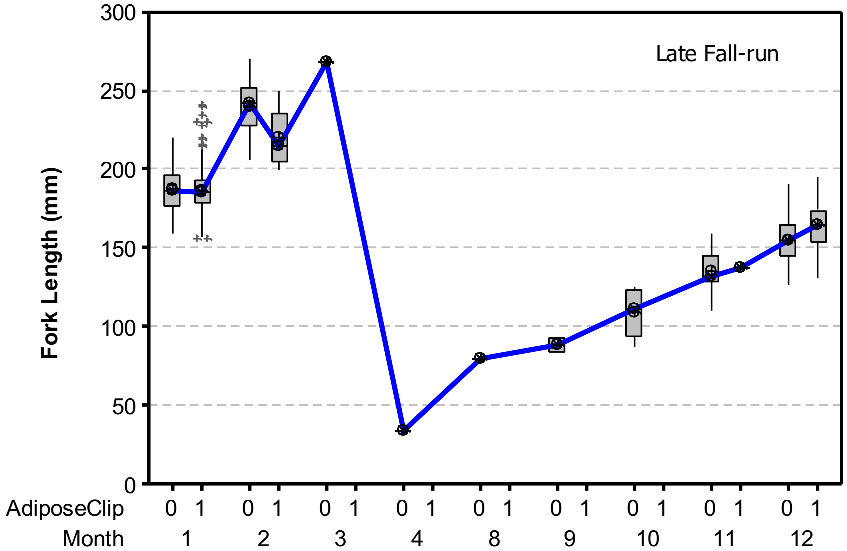


Figure 44. Median size of salvaged juvenile late fall-run Chinook salmon by month at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Steelhead

The median size of salvaged wild steelhead juveniles ranged from 227-278 mm, while the median size of salvaged hatchery steelhead juveniles ranged from 212-258 mm. There were 58 records with size > 500 mm, 13 of which showed the size of 999 mm (Figure 45).

The monthly median size of salvaged wild steelhead juveniles increased from 240 mm in January and February, to 258 mm in March, and to 272-280 mm from April through June. One wild steelhead was salvaged in each of the months of August and September, respectively. The monthly median size of salvaged hatchery steelhead juveniles increased from 232 mm in January and February, to 245-254 mm in March and April, and to 281-286 mm May and June (Figure 46).

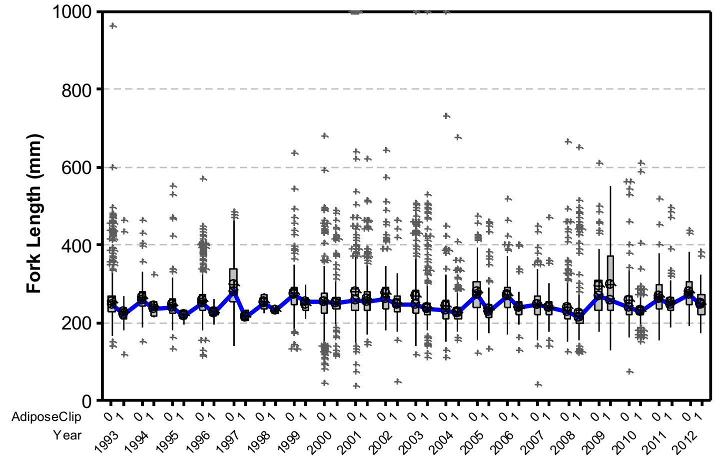


Figure 45. Median size of salvaged juvenile steelhead by year at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

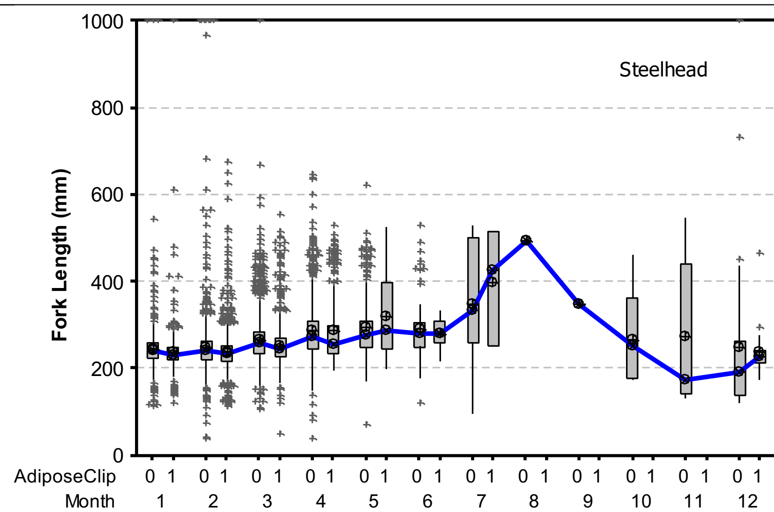


Figure 46. Median size of salvaged juvenile steelhead by month at the SFPF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Striped Bass

Mature striped bass normally ascend the Sacramento and San Joaquin Rivers for spawning in the spring months, then descend to the bay and coastal ocean waters for the summer and fall months. Some bass, however, can usually be found in the river throughout the year. Striped bass ranging from 250 to 380 mm in size were found to be particularly abundant in the Delta from May through September.

The size distribution of salvaged striped bass showed two peaks – one around 30 mm and the other around 92 mm (Figure 47). This may reflect the actual size distribution pattern of striped bass in the south Delta as a reflection of life history or behavioral movement of fish. On the other hand, this may indicate a difference in louver efficiency for different fish sizes at the SFPF. Fish with sizes of 50-75 mm may be more vulnerable to passage through the louver than those with smaller or larger sizes. Fish with sizes of less than 40 mm may not have swimming ability so they would be carried downstream by faster flow velocity in parallel with the channel or along the line of the louver array. Fish with sizes of 50-75 mm may have an adequate swimming speed that could be near the through-louver velocity but allow them to take a position at angles perpendicular to the line of the louver arrays, resulting in easier passage through the louver. Fish with larger sizes would have stronger swimming ability and would swim away from the louver by lateral movement.

The median size of salvaged striped bass ranged from 38 mm to105mm (Figure 48). About 25% of the salvaged striped bass were greater than 105 mm in size. The median size of salvaged striped bass was smallest (25 mm) in May and increased to 98 mm in October, which is a reflection of young hatching in spring and growing through the summer into the fall. The size remained at 101-113 mm from November through March and reached the largest (196 mm) in April (Figure 49), which may be a reflection of yearling fish having reduced growth through the winter due to cold water and reduced forage base, with subsequent increase in growth as the Delta water warms and the forage base increases. The larger sizes in March and April may indicate a high potential for predation in the early spring.

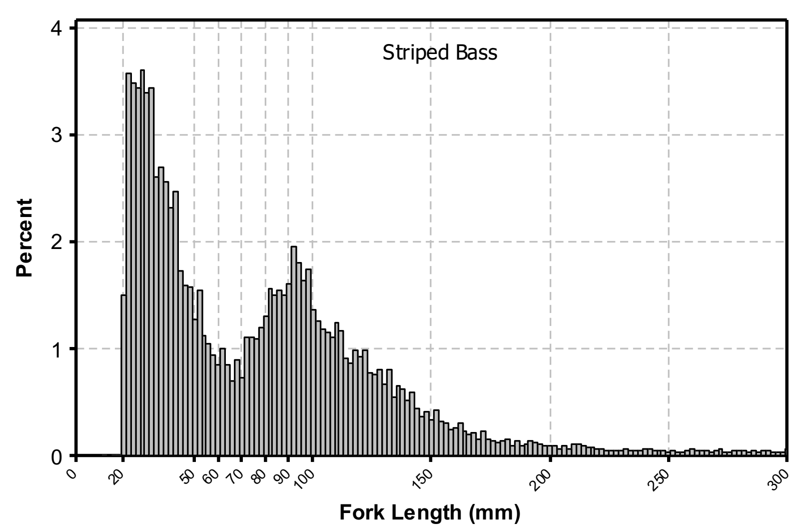


Figure 47. Size distribution of salvaged striped bass from 1993 to 2012 at the SFPF

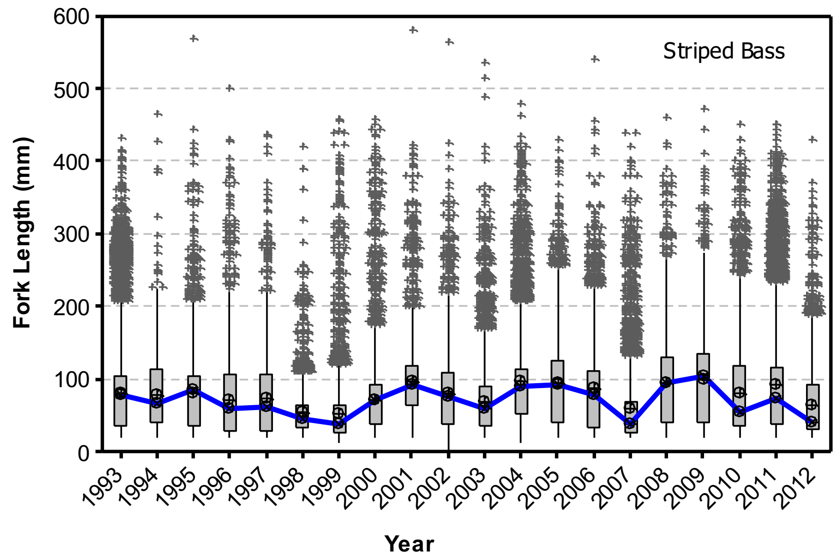


Figure 48. Size of salvaged striped bass by year at the SFPF. The blue line represents the median.

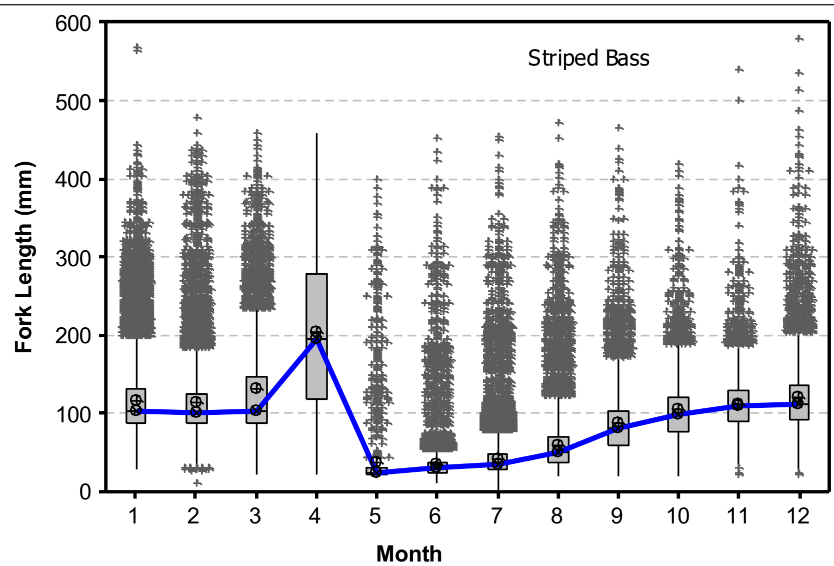


Figure 49. Size of salvaged striped bass by month at the SFPF. The blue line represents the median.

Summary

The median size of salvaged salmonid juveniles at the SFPF is in the following decreasing order: Steelhead >> Late fall-run > Winter-run > Spring-run ≈ Fall-run (Table 4). Hatchery fish seemed larger than wild fish for winter-run, fall-run, and late fall-run; smaller for steelhead; and similar for spring-run. The median size of striped bass was smaller than juvenile Chinook salmon or steelhead.

Table 4. Summary of salvaged salmonid and striped bass size (FL mm) at the SFPF from 1993 through 2012

Species	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max	N
Winter-run	Wild	134.4	0.44	24.7	118	129	147	65	290	3,197
	Hatchery	154.2	0.33	20.7	141	153	165	94	268	4,067
Spring-run	Wild	96.1	0.09	11.2	88	95	103	48	285	16,814
	Hatchery	95.8	0.24	9.3	90	94	100	62	130	1,489
Fall-run	Wild+Hatchery	80.7	0.20	23.2	74	86	94	21	265	13,936
	Hatchery	95.8	0.66	28.8	84	89	95	56	268	1,911
Late Fall-run	Wild	167.6	2.11	32.1	148	165	186	34	270	231
	Hatchery	177.1	0.60	17.4	166	179	188	131	250	837
Steelhead	Wild	260.5	0.94	67.6	228	250	277	38	999	5,135
	Hatchery	243.7	0.61	45.5	220	237	258	49	999	5,500
Striped Bass	Wild	78.5	0.17	55.2	35	69	105	12	580	108,719

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum size observed. Max = Maximum size observed. N = Number of fish. Hatchery steelhead were 100% adipose fin clipped starting in 1997. Fall-run Chinook salmon have only recently been adipose fin clipped at a 25% rate in the hatcheries.

3.3.3.2 TFCF

Winter-run

The median size of salvaged wild winter-run juveniles ranged from 118-176 mm, while the median size of salvaged hatchery winter-run juveniles ranged from 126-212 mm (Figure 50).

The monthly median size of salvaged wild winter-run juveniles was smallest (119 mm) in December and similar (126-135 mm) from January through March, whereas it increased to 161 mm in April and 215 mm in May (Figure 51). One wild fish was salvaged in June. The monthly median size of salvaged hatchery winter-run juveniles was smallest (134 mm) in December and increased to 155-165 mm within January through March. It reached 192 mm in April. One hatchery fish was salvaged in May.

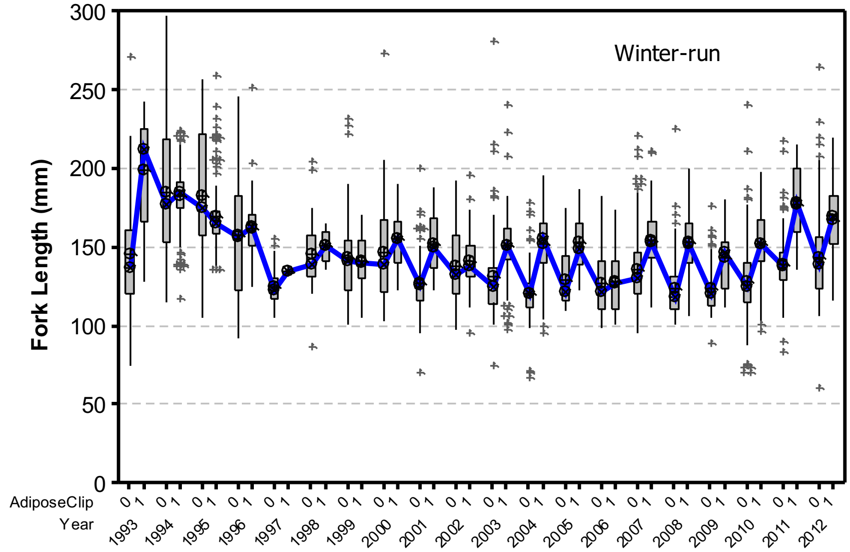


Figure 50. Size of salvaged juvenile winter-run Chinook salmon by year at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

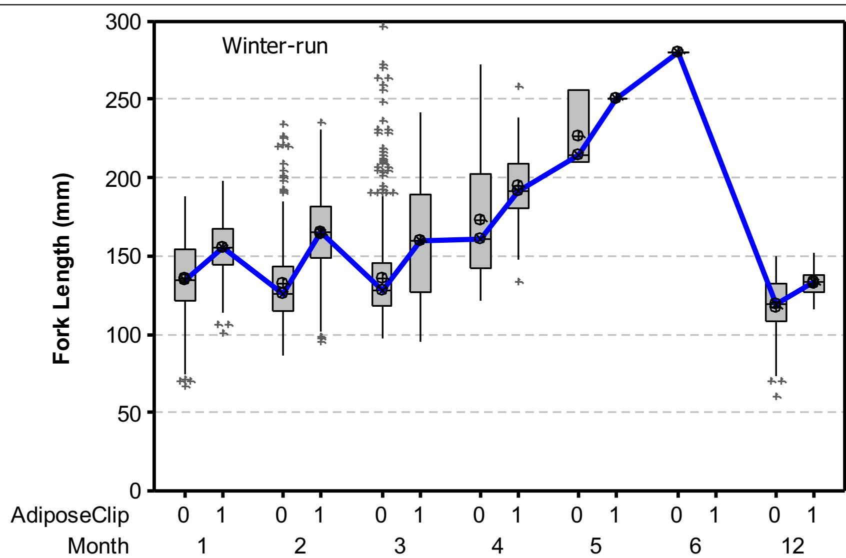


Figure 51. Size of salvaged juvenile winter-run Chinook salmon by month at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Spring-run

The median size of salvaged wild spring-run juveniles ranged from 81-108 mm, while the median size of salvaged hatchery spring-run juveniles ranged from 74-115 mm (Figure 52).

The monthly median size of salvaged wild spring -run juveniles was smallest (45 mm) in January and increased to 58 mm in February. The size was similar (86-91 mm) within March and April, increased to 104 mm in May, and reached the highest (118 mm) in June. The monthly median size of salvaged hatchery spring-run juveniles increased gradually from 88 mm in March and April, 100 mm in May, and 118 mm in June (Figure 53).

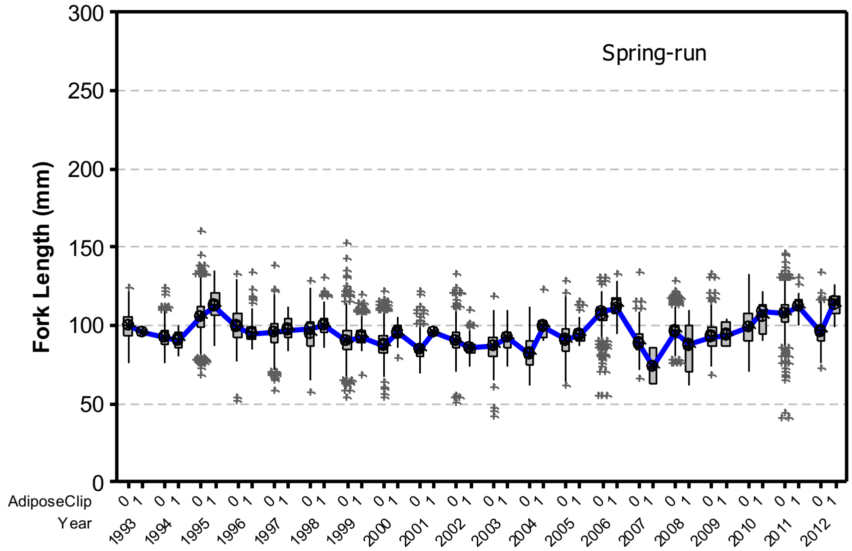


Figure 52. Size of salvaged juvenile spring-run Chinook by year salmon at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

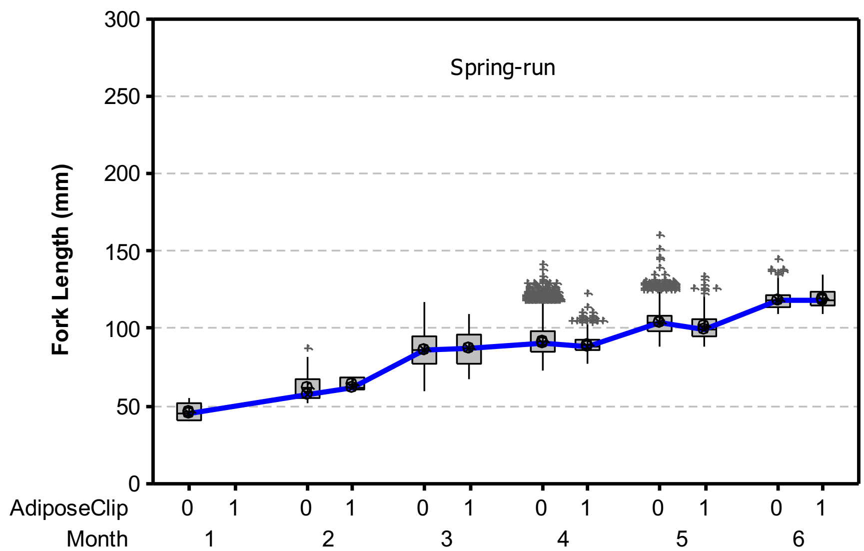


Figure 53. Size of salvaged juvenile spring-run Chinook salmon by month at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Fall-run

The size distribution of salvaged fall-run juveniles showed two peaks – one around 37 mm and the other around 90 mm (Figure 54). This may reflect the actual size distribution pattern of fall-run juveniles in the south Delta. This may also indicate a difference in louver efficiency for different fish sizes at the TFCF. Fish with sizes of about 60 mm may be more vulnerable to passage through the louver than those with smaller or larger sizes. Fish with sizes of less than 40 mm may not have sufficient swimming ability to maintain position in front of the louver face. Therefore, they would be carried downstream by faster flow velocity in parallel with the channel or the line of the louver array. Fish with sizes of 40-80 mm may have an adequate swimming speed that could be near the through-louver velocity but allow them to take a position at angles perpendicular to the line of the louver arrays, resulting in easier passage through the louver. Fish with larger sizes would have stronger swimming ability and would swim away from the louver by lateral movement. This could also represent a life history pattern. Small sized fry, recently emerged from the gravel, can be easily carried downstream by high flows or forced out of their upstream habitat by high densities to rear in alternative downstream habitats, i.e., the Delta or even estuary. The second peak would represent fall-run that reared upstream and entered the Delta just prior to smolting.

The median size of salvaged fall-run juveniles without adipose clipped ranged from 46-100 mm, while the median size of salvaged hatchery fall-run juveniles ranged from 75-195 mm (Figure 55). In 2010 and 2012, the median size of juveniles without adipose clipped was half the size of the hatchery juveniles. There were no salvaged hatchery fall-run juveniles reported in 2009.

The monthly median size of salvaged fall-run juveniles without adipose clipped increased from 36-37 mm in January and February to 98 mm in June. Salvaged fall-run juveniles without adipose clipped were larger during the time period of September to December, potentially representing yearling fall-run fish. The monthly median size of salvaged hatchery fall-run juveniles increased from 79 mm in April to 102 mm in June. Salvaged hatchery fall-run juveniles were also larger from September to December (Figure 56), which are potentially representing late releases from the hatcheries or fish that have resided in the upper river before emigrating to the Delta as yearlings.

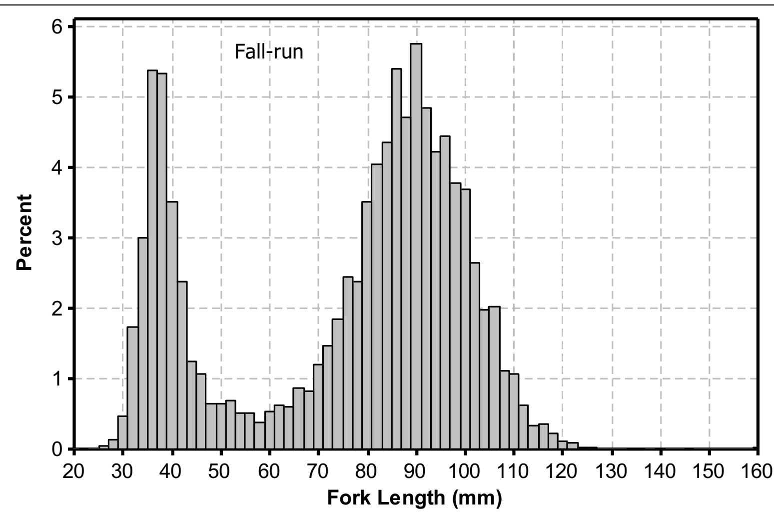


Figure 54. Size distribution of salvaged juvenile fall-run Chinook salmon at the TFCF (1993-2012)

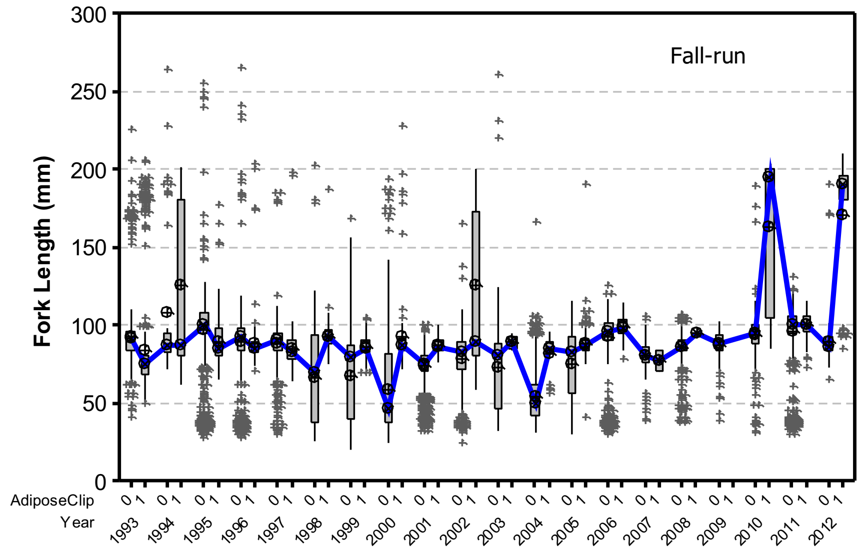


Figure 55. Size of salvaged juvenile fall-run Chinook salmon by year at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild and hatchery fish; 1 = Hatchery fish

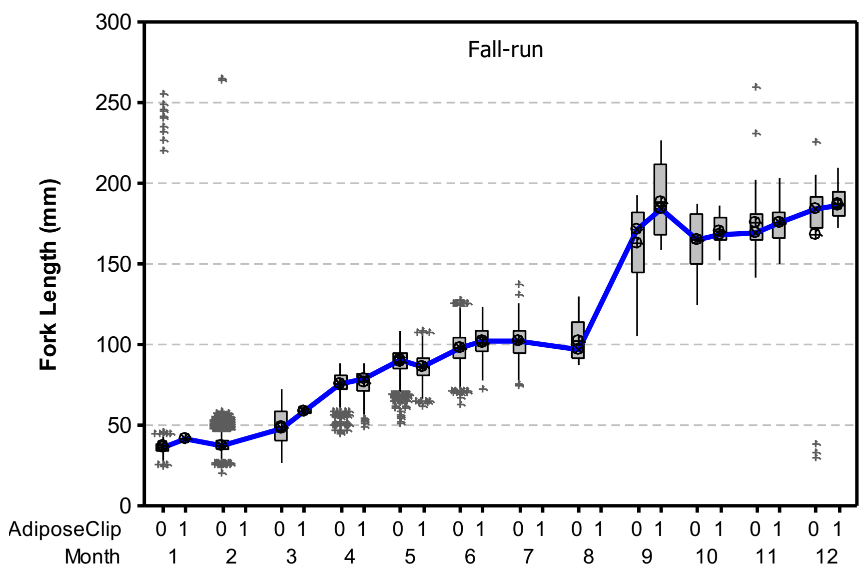


Figure 56. Monthly size distribution of salvaged juvenile fall-run Chinook salmon by month at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild and hatchery fish; 1 = Hatchery fish

Late Fall-run

The median size of salvaged wild late fall-run juveniles ranged from 113-255 mm, while the median size of salvaged hatchery late fall-run juveniles ranged from 141-196 mm (Figure 57).

The monthly median size of salvaged wild late fall-run juveniles increased from 133 mm in November, to 150 mm in December, to 186 mm in January, and to 225 mm in February (Figure 58). There was only one wild late fall-run juvenile observed in each of the months of March, April, and June at the TFCF. Two wild late fall-run fish were observed in October. The monthly median size of salvaged hatchery late fall-run juveniles increased from 166 mm in December, to 185 mm in January, and to 218 mm in February.

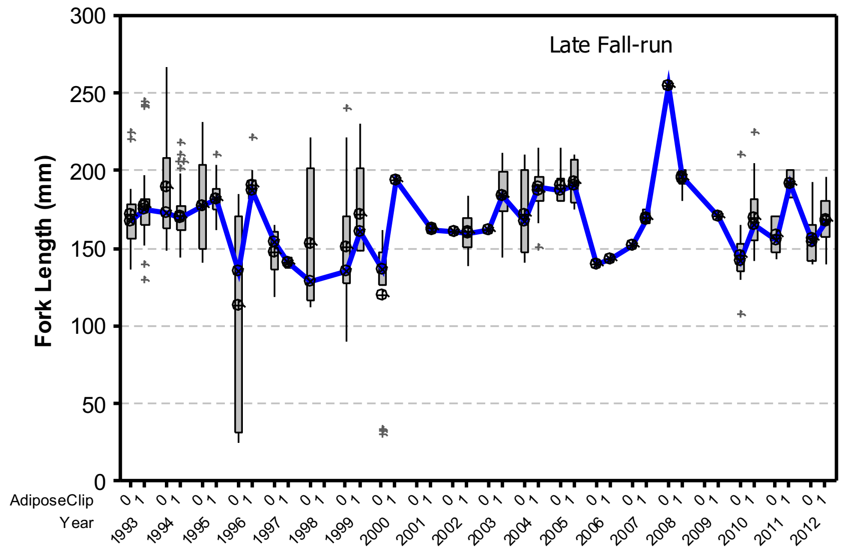


Figure 57. Size of salvaged juvenile late fall-run Chinook salmon by year at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

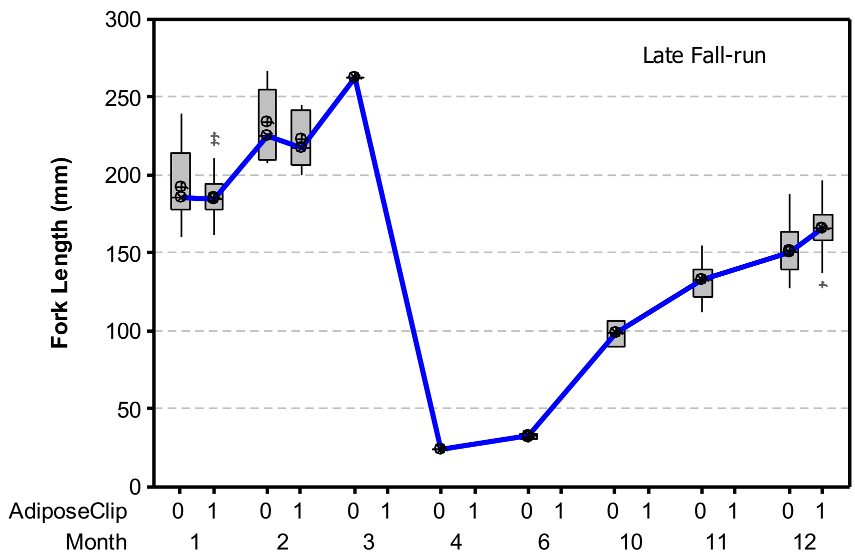


Figure 58. Monthly size distribution of salvaged juvenile late fall-run Chinook salmon by month at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Steelhead

The median size of salvaged wild steelhead juveniles ranged from 240-270 mm, while the median size of salvaged hatchery steelhead juveniles ranged from 210-255 mm. There were 4 records with salvaged steelhead having a fork length > 500 mm (Figure 59).

The monthly median size of salvaged wild steelhead juveniles increased from 238 mm in January and February, to 254 mm from March through May, and to 265 mm in June. The monthly median size of salvaged hatchery steelhead juveniles increased from 233 mm in January and February to 266 mm in May (Figure 60).

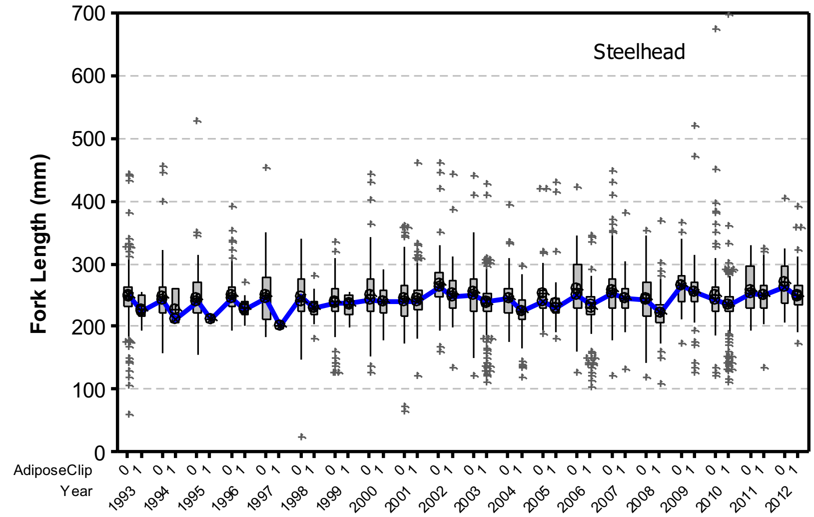


Figure 59. Annual sizes of salvaged juvenile steelhead by year at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

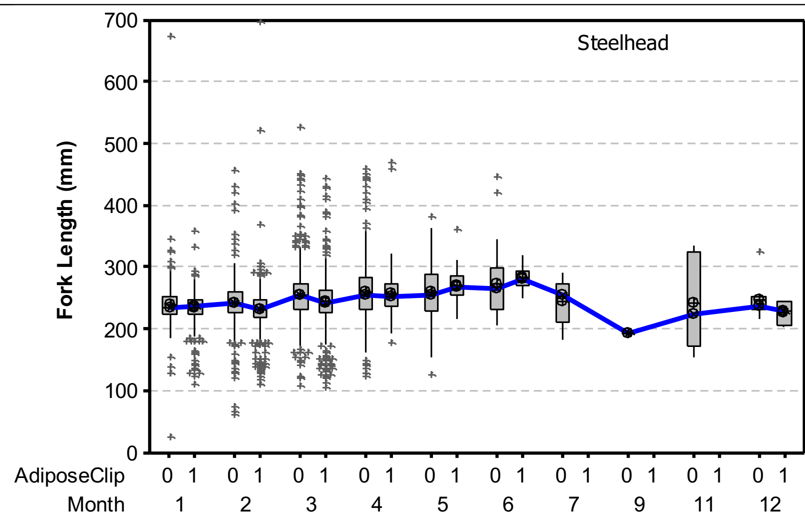


Figure 60. Monthly size distribution of salvaged juvenile steelhead by month at the TFCF. The blue line represents the median. Adipose Clip 0 = Wild fish; 1 = Hatchery fish

Striped Bass

The size distribution of salvaged striped bass showed two peaks – one around 30 mm and the other around 90 mm (Figure 61). This may reflect the actual size distribution pattern of striped bass in the south Delta. On the other hand, this may indicate a difference in louver efficiency for different fish sizes at the TFCF. Fish with sizes of 50-80 mm may be more vulnerable to passage through the louver than those with smaller or larger sizes. Fish with sizes of less than 50 mm may not have swimming ability so they would be carried downstream by faster flow velocity in parallel with the channel or the line of the louver array. Fish with sizes of 50-80 mm may have an adequate swimming speed that could be near the through-louver velocity but allow them to take a position at angles perpendicular to the line of the louver arrays, resulting in easier passage through the louver. Fish with larger sizes would have stronger swimming ability and would swim away from the louver by lateral movement.

The median size of salvaged striped bass ranged from 36 mm to119 mm (Figure 62). About 25% of the salvaged striped bass were greater than 112 mm in size.

The median size of salvaged striped bass was smallest (25 mm) in May and increased to 102 mm in October. The increasing trend reflects the life history of striped bass – spawning in spring, and 25 mm is the smallest sized fish that can be reasonably deterred by the louvers and collected. Increasing sizes also reflect the growth of each year class in the Delta waters with the progression of the summer into fall. The size remained at 103-109 mm from November through February and reached the largest (124 mm) in April (Figure 63). The large size may indicate a high potential for predation in April.

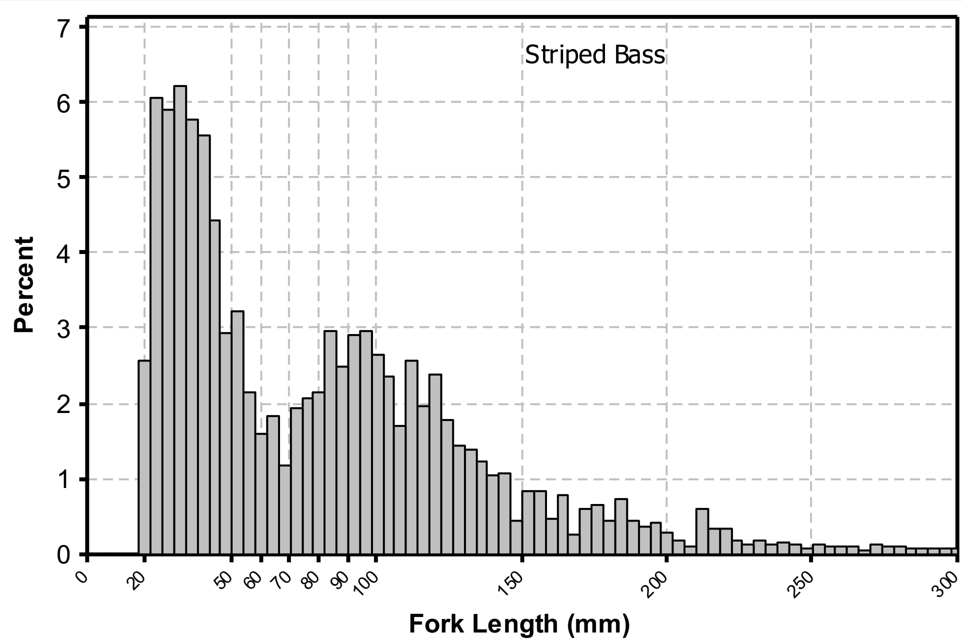


Figure 61. Size distribution of salvaged striped bass from 1993 to 2012 at the TFCF

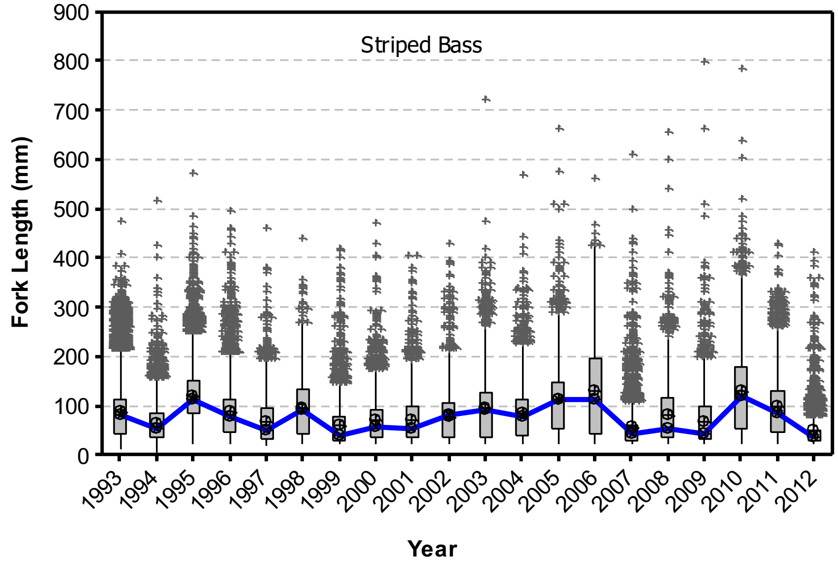


Figure 62. Annual sizes of salvaged striped bass by year at the TFCF. The blue line represents the median.

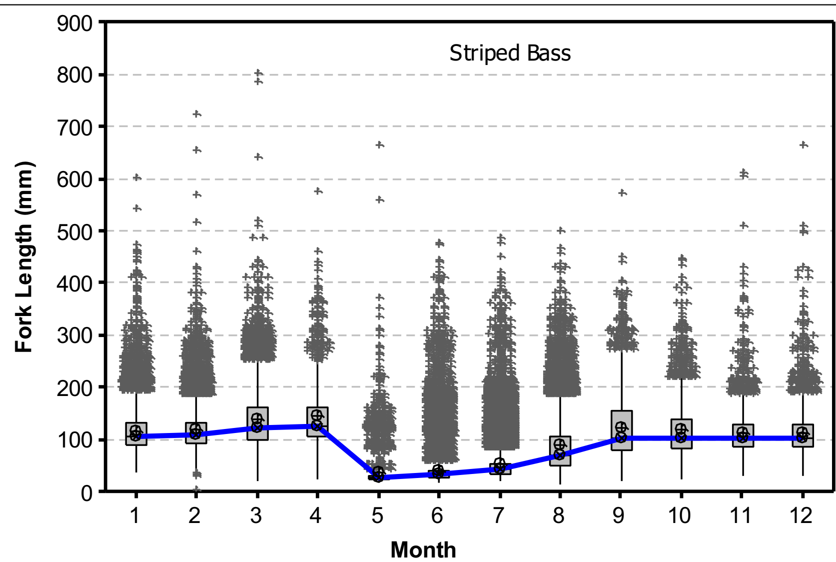


Figure 63. Monthly size distribution of salvaged striped bass by month at the TFCF. The blue line represents the median.

Summary

The median fork length of salvaged salmonid juveniles at the TFCF has the following decreasing size order: Steelhead >> Late fall-run > Winter-run > Spring-run > Fall-run (Table 5). Hatchery fish seemed larger than wild fish for winter-run, fall-run, and late fall-run; smaller for steelhead; and similar for spring-run. The median size of striped bass was smaller than juvenile Chinook salmon or steelhead.

Table 5. Summary of salvaged salmonid and striped bass size (FL mm) at the TFCF from 1993 through 2012

Species	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max	N
Winter-run	Wild	136.0	0.68	28.2	118	130	148	60	297	1,716
	Hatchery	159.2	0.51	23.3	143	158	173	95	258	2,079
Spring-run	Wild	95.2	0.08	11.5	87	95	103	41	160	18,562
	Hatchery	98.0	0.29	11.3	90	95	105	61	135	1,540
Fall-run	Wild+Hatchery	74.2	0.16	26.2	43	83	94	20	265	25,776
	Hatchery	91.7	0.45	25.2	80	86	94	41	227	3,089
Late Fall-run	Wild	155.9	2.95	37.4	138	154	172	24	267	160
	Hatchery	175.9	0.71	16.7	165	176	186	130	245	551
Steelhead	Wild	249.9	0.88	42.1	227	247	268	24	675	2,288
	Hatchery	235.8	0.54	31.0	220	235	250	104	697	3,284
Striped Bass	Wild	83.2	0.21	59.3	36	72	112	4	800	81,625

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum size observed. Max = Maximum size observed. N = Number of fish.

3.3.4 Diel Fish Salvage Pattern

3.3.4.1 SFPF

Chinook Salmon

We used the salvage rate to examine the temporal variability of Chinook salmon and steelhead salvaged at the SFPF and TFCF. Salvage rate was calculated using the following equation:

$R = S/Q$

where S is the cumulative 2-hour salvage of juveniles from 1993 to 2012, and Q is the average (cfs) of primary channel flows where fish salvage is observed during the 2-hour time period from 1993 to 2012. The cumulative 2-hour salvage was calculated by expanding raw salvage data to the 2-hour salvage data, which were added up to obtain the number of all fish salvaged at a particular 2-hour period from 1993 to 2012.

Provide in Table 6 is the cumulative 2-hour salvage of juvenile Chinook salmon (including winter-run, spring-run, fall-run, and late fall-run) at the SFPF from 1993 to 2012, together with the mean primary channel flow (cfs) and the salvage rate. .

The salvage rate was lower from 10 AM to 8 PM compared to other hours (Figure 64). The salvage rate started to increase at 10 PM and reached the highest rate at 4 am. While remaining at a high level from 4 AM to 8 AM, the salvage rate showed a sharp decrease from 8 AM to 10 AM. This diel salvage pattern reveals that (a) juvenile Chinook salmon prefer migration at night ,(b) predation at night is lower than that during the day, and/or (c) juvenile salmon avoid entrainment during the day when they can see the louvers. Studies indicated that migration of juvenile sockeye, pink, and chum salmon was nocturnal, making slow movements or holding during the day but resuming migration at dusk (Quinn 2005) (p. 222-223). It is unlikely that predation at night is lower than that during the day as the striped bass salvage data (discussed below) indicate higher salvage rates at night than those during the day, possibly indicating more striped bass present at night.

Table 6. Cumulative 2-hour salvage of juvenile Chinook salmon (all runs) at the SFPF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	35,286	4,833	7.3
4:00 AM	43,937	5,218	8.4
6:00 AM	35,662	5,496	6.5
8:00 AM	31,229	4,964	6.3
10:00 AM	17,800	4,933	3.6
12:00 PM	10,080	4,287	2.4
2:00 PM	8,395	3,989	2.1
4:00 PM	10,354	4,333	2.4
6:00 PM	8,610	4,492	1.9
8:00 PM	10,551	4,428	2.4
10:00 PM	25,677	4,552	5.6
12:00 AM	36,847	5,150	7.2

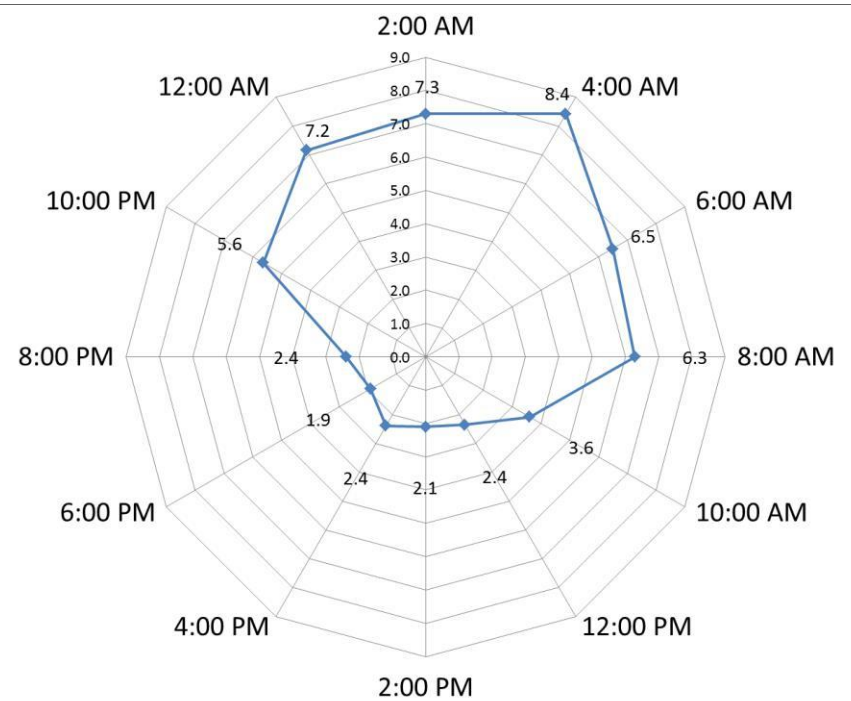


Figure 64. Diel juvenile Chinook salmon (all runs) salvage rates at the SFPF. .

Steelhead

Provide in Table 7 is the cumulative 2-hour salvage of juvenile steelhead, the mean primary channel flow (cfs), and the salvage rate. The diel juvenile steelhead salvage pattern showed lower salvage rates from late night to early morning, with the lowest at 2:00 AM and the highest at 10 PM (Figure 65).

Table 7. Cumulative 2-hour salvage of juvenile steelhead at the SFPF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	4,059	6,970	0.58
4:00 AM	5,086	6,737	0.75
6:00 AM	4,843	6,776	0.71
8:00 AM	4,443	5,936	0.75
10:00 AM	4,814	5,230	0.92
12:00 PM	3,801	4,639	0.82
2:00 PM	3,990	4,334	0.92
4:00 PM	4,807	4,829	1.00
6:00 PM	3,338	4,771	0.70
8:00 PM	4,280	4,722	0.91
10:00 PM	5,505	4,954	1.11
12:00 AM	4,292	5,809	0.74

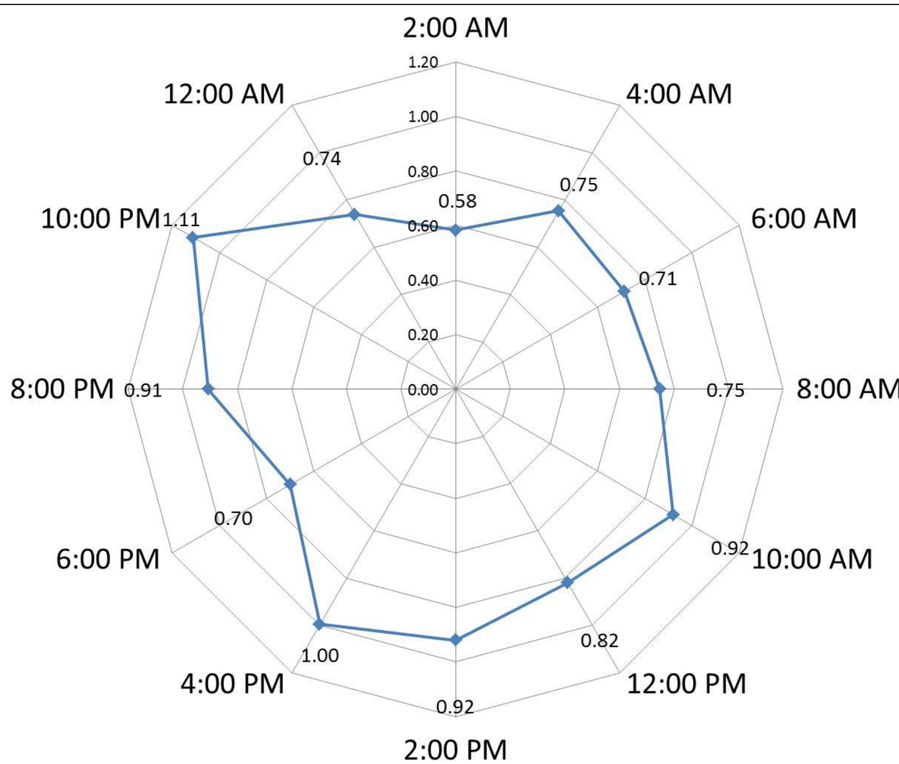


Figure 65. Diel juvenile steelhead salvage rates at the SFPF

Striped Bass

Provide in Table 7 is the cumulative 2-hour salvage of striped bass, the mean primary channel flow (cfs), and the salvage rate. The diel striped bass salvage rate was highest at 2 AM (Figure 66).

Table 8. Cumulative 2-hour salvage of striped bass at the SFPF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	994,000	6,833	145.5
4:00 AM	51,253	6,055	8.5
6:00 AM	5,753	3,490	1.6
8:00 AM	187,924	5,377	35.0
10:00 AM	29,257	4,371	6.7
12:00 PM	852	3,199	0.3
2:00 PM	96,315	4,212	22.9
4:00 PM	12,344	3,759	3.3
6:00 PM	3,235	3,185	1.0
8:00 PM	314,648	5,108	61.6
10:00 PM	110,477	4,287	25.8
12:00 AM	9,843	3,641	2.7

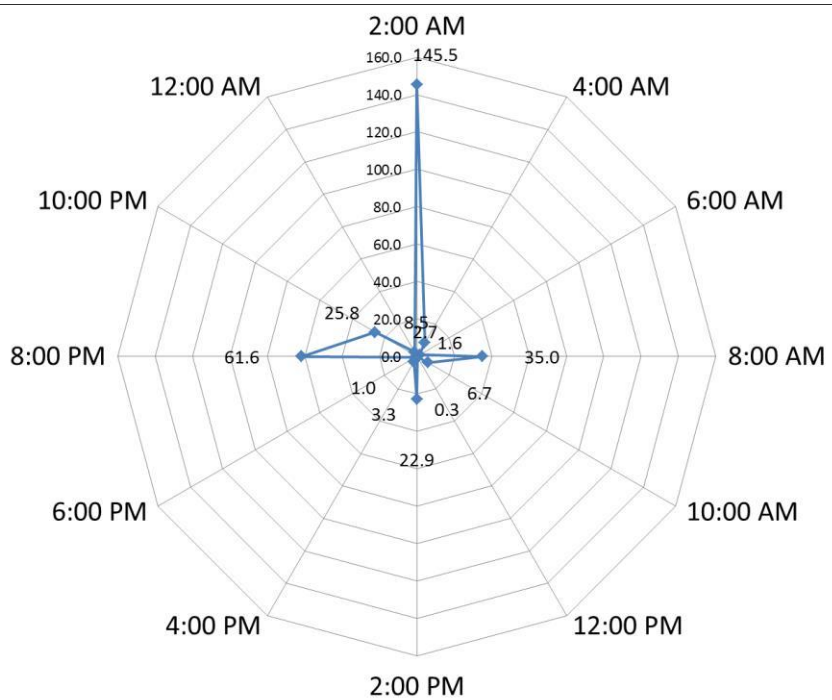


Figure 66. Diel striped bass salvage rates at the SFPF. The salvage rate, i.e., the number of salvaged fish per cfs, was calculated from the total number of salvaged fish from 1993 to 2012 divided by the mean flow (cfs) in the primary channel over the 2-hour sampling period.

3.3.4.2 TFCF

Chinook Salmon

Provided in Table 9 is the cumulative 2-hour salvage of juvenile Chinook salmon, mean primary channel flow (cfs), and salvage rate. Juvenile Chinook salvage at the TFCF was the lowest at noon, with a gradual increase from noon to 6 PM. There was a sharp increase in the salvage rate from 6 PM to 8 PM, with the highest reached at 2 AM. While remaining at a high level from 2 AM to 6 AM, the salvage rate showed a sharp decrease from 6 AM to 8 AM (Figure 67).

Table 9. Cumulative 2-hour salvage of juvenile Chinook salmon at the TFCF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	86,101	2,366	36
4:00 AM	80,536	2,356	34
6:00 AM	81,920	2,460	33
8:00 AM	57,064	2,727	21
10:00 AM	46,369	2,810	17
12:00 PM	37,369	2,781	13
2:00 PM	43,264	2,811	15
4:00 PM	52,040	2,694	19
6:00 PM	53,517	2,731	20
8:00 PM	72,138	2,547	28
10:00 PM	76,560	2,382	32
12:00 AM	71,731	2,523	28

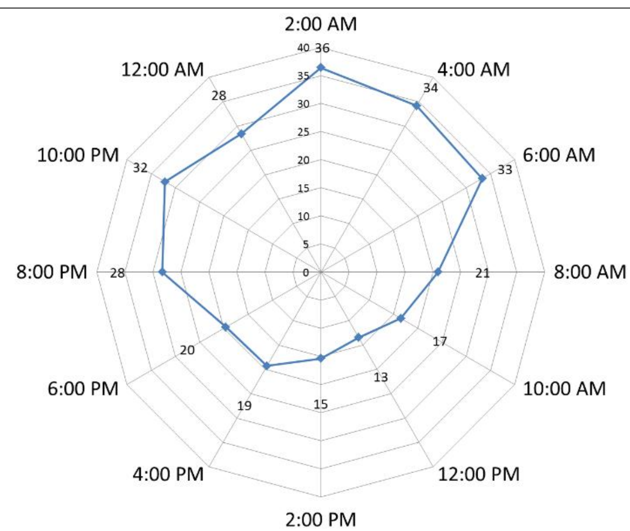


Figure 67. Diel juvenile Chinook salmon salvage rates at the TFCF. The salvage rate, i.e., the number of salvaged fish per cfs, was calculated from the total number of salvaged fish from 1993 to 2012 divided by the mean flow (cfs) in the primary channel over the 2-hour sampling period.

Steelhead

Provided in Table 10 is the cumulative 2-hour salvage of juvenile steelhead, the mean primary channel flow (cfs), and the salvage rate. The diel juvenile steelhead salvage pattern appeared to be opposite to Chinook salmon, showing lower salvage rates at night than the day, with the lowest at mid-night and the highest in the afternoon (Figure 68).

Table 10. Cumulative 2-hour salvage of juvenile steelhead at the TFCF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	3,564	3,099	1.1
4:00 AM	3,040	3,332	0.9
6:00 AM	3,952	3,145	1.3
8:00 AM	4,001	3,247	1.2
10:00 AM	3,772	3,226	1.2
12:00 PM	3,956	2,960	1.3
2:00 PM	5,609	3,399	1.7
4:00 PM	4,963	3,352	1.5
6:00 PM	6,160	3,402	1.8
8:00 PM	4,393	3,425	1.3
10:00 PM	3,324	3,222	1.0
12:00 AM	2,904	3,808	0.8

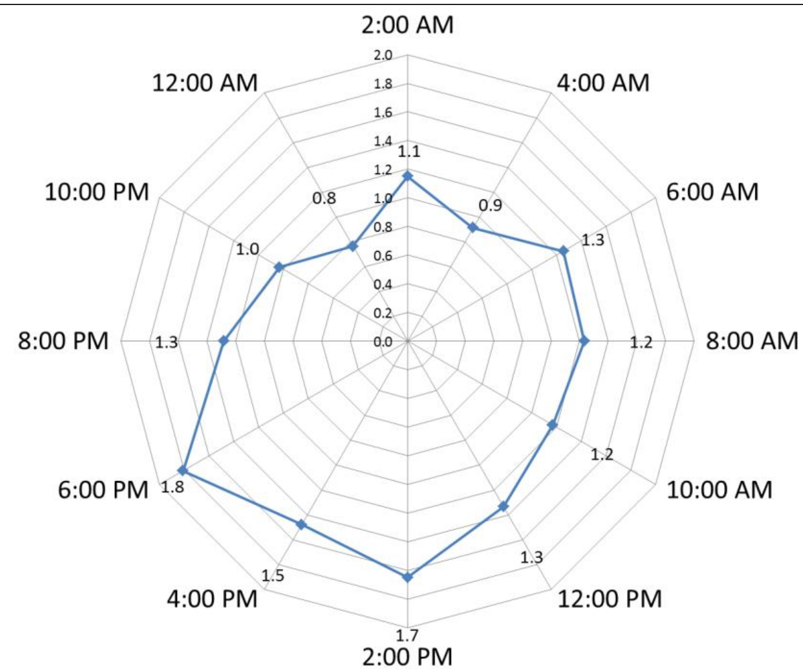


Figure 68. Diel juvenile steelhead salvage rates at the TFCF. The salvage rate, i.e., the number of salvaged fish per cfs, was calculated from the total number of salvaged fish from 1993 to 2012 divided by the mean flow (cfs) in the primary channel over the 2-hour sampling period.

Striped Bass

Salvage data for striped bass at the TFCF were provided at 4 times: 2 AM, 6 AM, 2 PM and 6 PM. Provided in Table 11 is the cumulative salvage of striped bass, the mean primary channel flow (cfs), and the salvage rate. The diel striped bass salvage rate was highest at 2 AM (Figure 69).

Table 11. Cumulative 2-hour salvage of striped bass at the TFCF from 1993 to 2012

Time	Number of Fish Salvaged	Mean Primary Channel Flow (cfs)	Salvage Rate
2:00 AM	392,304	3,261	120
4:00 AM	DI	DI	DI
6:00 AM	352,610	3,256	108
8:00 AM	DI	DI	DI
10:00 AM	DI	DI	DI
12:00 PM	DI	DI	DI
2:00 PM	212,342	3,412	62
4:00 PM	DI	DI	DI
6:00 PM	276,525	3,436	80
8:00 PM	DI	DI	DI
10:00 PM	DI	DI	DI
12:00 AM	DI	DI	DI

DI = Data insufficient for analyses

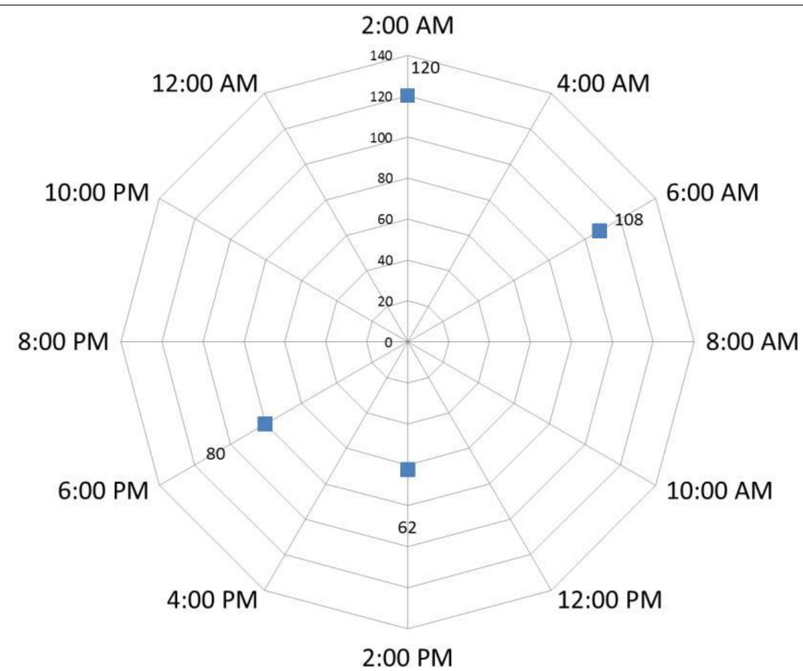


Figure 69. Diel striped bass salvage rates at the TFCF

3.3.4.3 Summary

The diel salvage rates for Chinook salmon, steelhead, and striped bass showed different magnitudes but similar patterns for the SFPF and TFCF. The salvage rates for Chinook salmon were 2-4 times higher at night than during the day. The salvage rates for steelhead showed somewhat lower rates at night than during the day, although the difference is much smaller when compared to the differences in Chinook salmon. The salvage rate for striped bass was the highest at 2 AM, based on a limited sample distribution.

Chapman *et al.* (2013) used ultrasonic telemetry to track the movement patterns of late-fall run Chinook salmon and steelhead trout smolts during their entire emigration down the Sacramento River, through the Delta and Estuary, and into the Pacific Ocean. Yearling hatchery smolts were tagged via intracoelomic surgical implantation with coded ultrasonic tags. They were then released at four upriver locations in the Sacramento River during the winters of 2007 through 2010. Late-fall run Chinook salmon smolts exhibited a significant preference for nocturnal migration in all regions of the migration route, with nighttime detections ranging from 91% in the Upper Sacramento River to 65% in the Ocean, except the Estuary that showed a 57% detection at night. In contrast, steelhead smolts migrate more uniformly throughout the day in all regions of the migration route, with nighttime detections ranging from 50% to 63%, except the Estuary that showed a 41% nighttime detection. These data show that closely related *Oncorhynchus* species, with the same ontogenetic pattern of out-migrating as yearlings, vary in migration tactic. However, they cautioned that these results may not be similar to those of other runs of Chinook salmon in the Sacramento River or to wild fish. Many studies have found physiological and behavioral differences between hatchery and wild fish, therefore, caution must be exercised when extrapolating these results from hatchery smolts to wild populations.

3.3.5 Juvenile Fish Salvage by Brood Year and Month

3.3.5.1 Winter-run Chinook Salmon

Presented in Figures 70 and 71 is the daily salvage of wild winter-run juveniles at SFPF and TFCF, respectively.

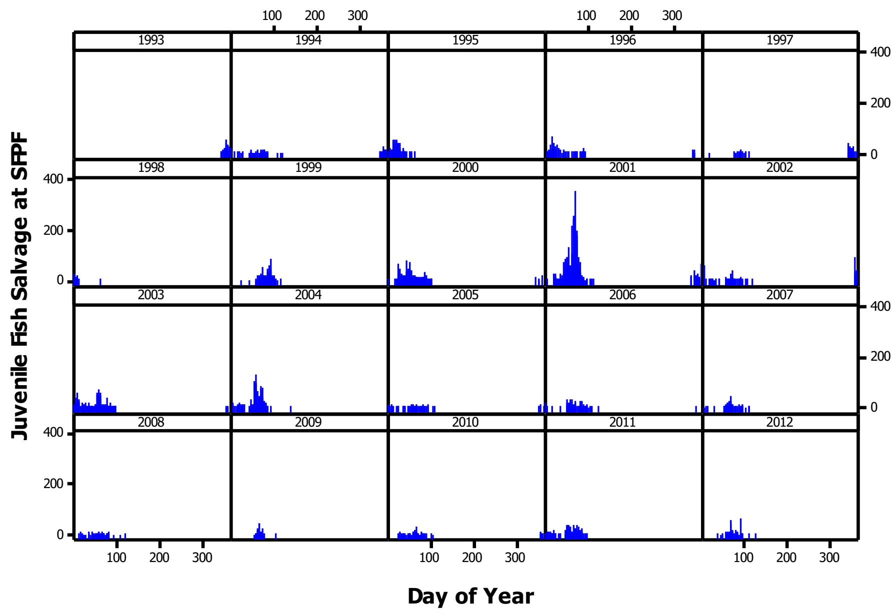


Figure 70. Daily salvage of wild juvenile winter-run Chinook salmon at SFPF from August 1, 1993 to May 21, 2012

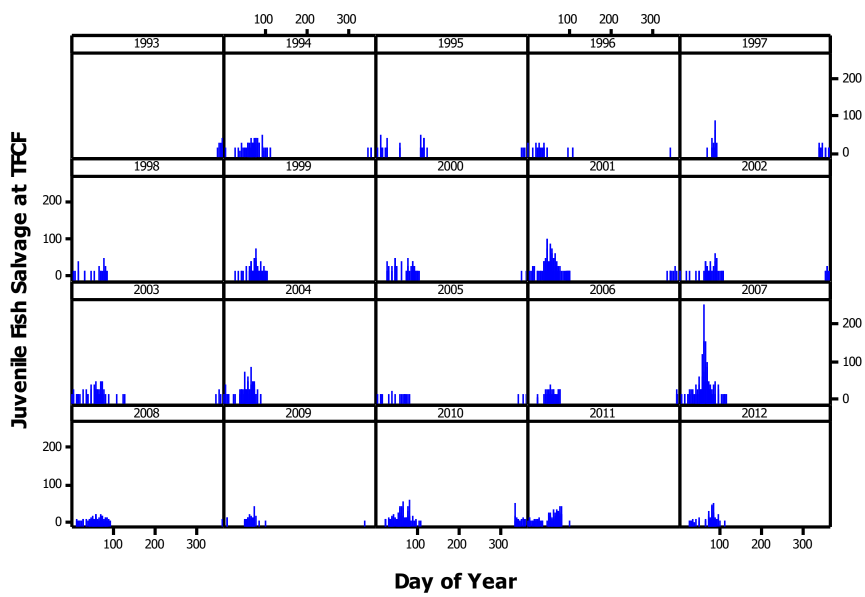


Figure 71. Daily salvage of wild juvenile winter-run Chinook salmon at TFCF from August 1, 1993 to May 21, 2012

Presented in Figures 72 through 74 is the mean daily salvage of wild winter-run juveniles from 1993 to 2012 at SFPF, TFCF, and combined respectively. Winter-run juvenile salvage occurred in December, increased in mid-February, reached the highest in late February and early March, and finally faded away in April.

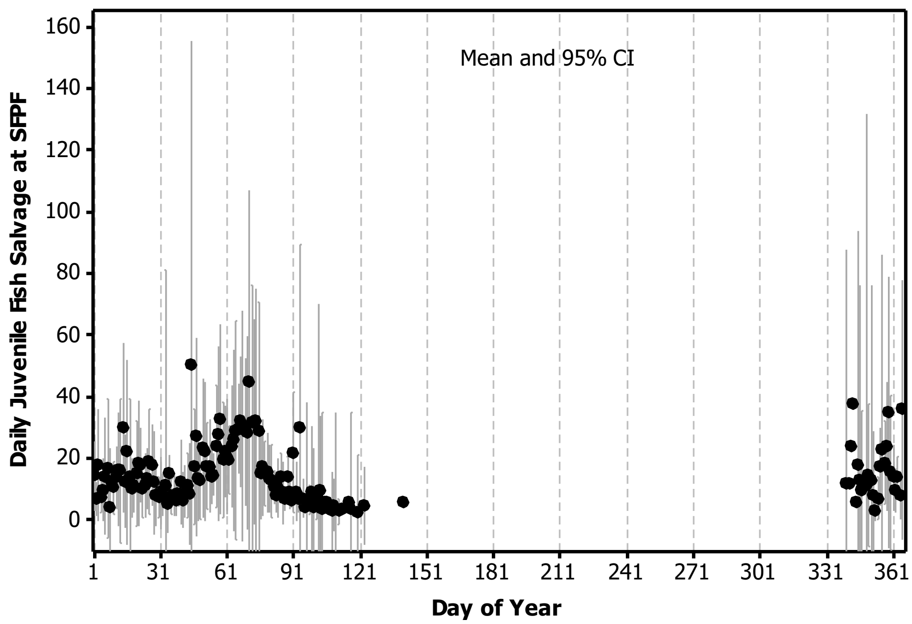


Figure 72. Mean daily juvenile salvage of wild winter-run Chinook salmon at SFPF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval.

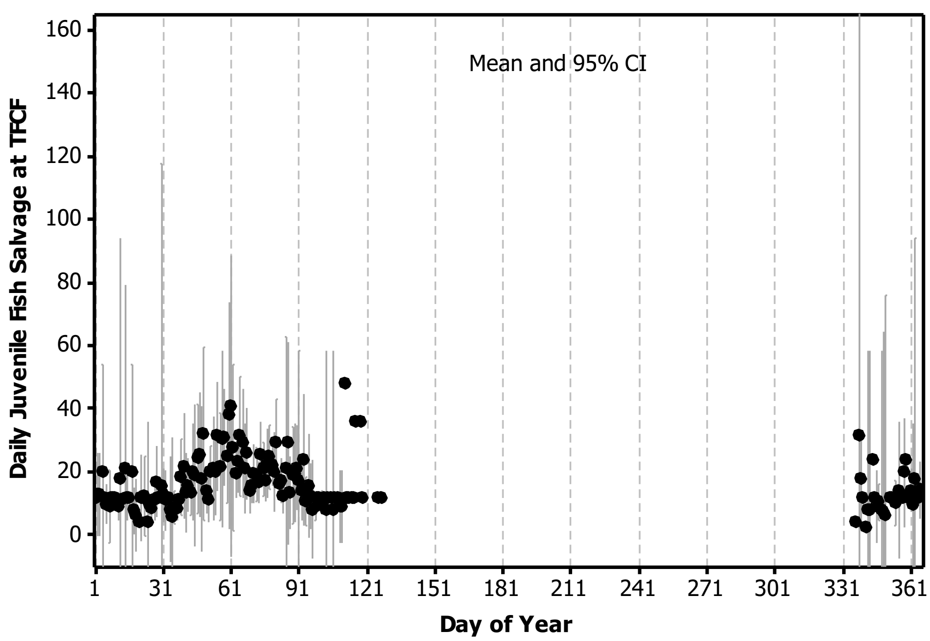


Figure 73. Mean daily juvenile salvage of wild winter-run Chinook salmon at TFCF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval.

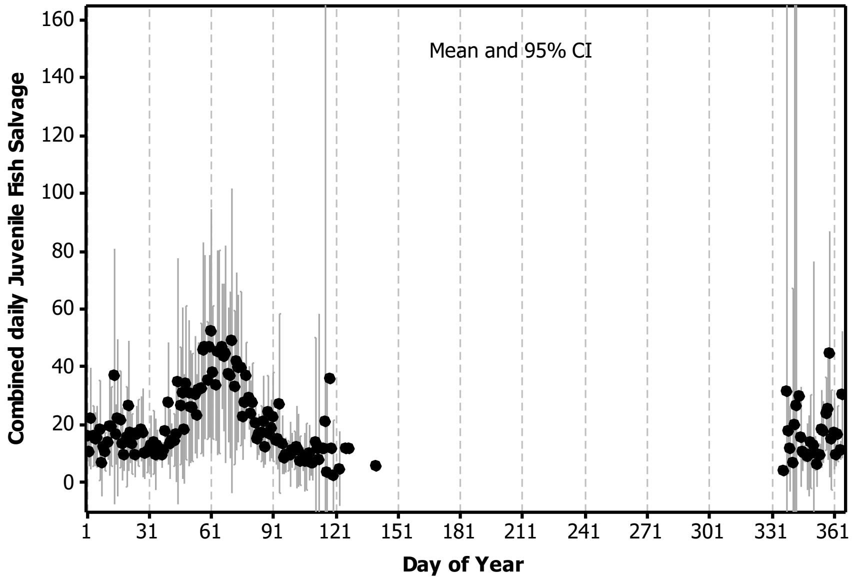


Figure 74. Combined mean daily juvenile salvage of wild winter-run Chinook salmon at SFPF and TFCF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval.

The combined yearly (brood year) winter-run Chinook salmon salvage showed a decreasing trend from 1993 to 1996. This is the year (1996) in which winter-run salvage was the lowest on record. The salvage then increased from 1996 to 2003, with the highest salvage on record occurring in 2002. The winter-run salvage showed a sharp decrease from 2003 to 2004 (Figure 75). The proportion of wild winter-run Chinook salmon in salvage accounted for 18% (2007) to 100% (1996) of the yearly combined winter-run salvage, with an average of 54% (Table 12).

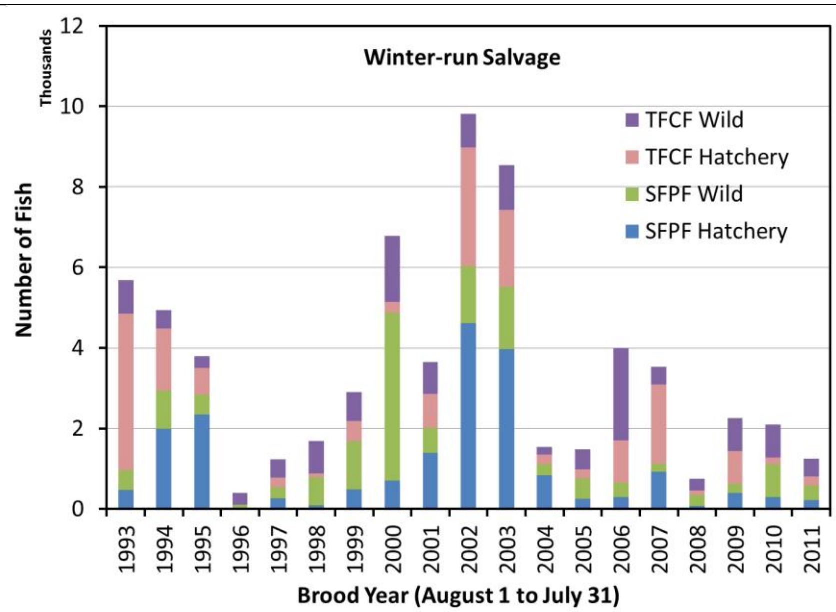


Figure 75. Juvenile winter-run Chinook salmon salvage by brood year

Table 12. Juvenile winter-run Chinook salmon salvage data summary by brood year

Brood Year	SFPF		TFCF		Combined			%Wild
	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Total	
1993	468	495	3,885	842	4,353	1,337	5,689	23
1994	2,000	952	1,536	456	3,536	1,408	4,944	28
1995	2,343	493	672	288	3,015	781	3,796	21
1996	1	97	0	300	1	397	398	100
1997	270	270	240	456	510	726	1,236	59
1998	90	704	84	803	174	1,507	1,681	90
1999	489	1,196	492	720	981	1,916	2,897	66
2000	698	4,184	264	1,644	962	5,828	6,790	86
2001	1,398	626	828	804	2,226	1,430	3,656	39
2002	4,621	1,422	2,940	828	7,561	2,250	9,811	23
2003	3,965	1,560	1,908	1,104	5,873	2,664	8,537	31
2004	831	279	240	188	1,071	467	1,538	30
2005	249	510	228	492	477	1,002	1,479	68
2006	292	376	1,032	2,304	1,324	2,680	4,004	67
2007	923	205	1,962	449	2,885	654	3,539	18
2008	78	282	100	287	178	569	747	76
2009	397	240	806	814	1,203	1,054	2,257	47
2010	292	828	150	833	442	1,661	2,102	79
2011	222	372	209	447	431	819	1,249	66
Mean	1,033	794	925	740	1,958	1,534	3,492	54
Median	468	495	492	720	1,071	1,337	2,897	59

The monthly salvage of hatchery winter-run Chinook salmon was highest in January, followed by February, March, and December. The monthly salvage of wild winter-run Chinook salmon was highest in March, followed by February, January, and December. The number of hatchery winter-run Chinook salmon salvaged in January was much higher than the wild winter-run (Figure 76 and Table 13). The mean salvage was always greater than the median salvage, indicating a positively skewed distribution of the winter-run salvage data.

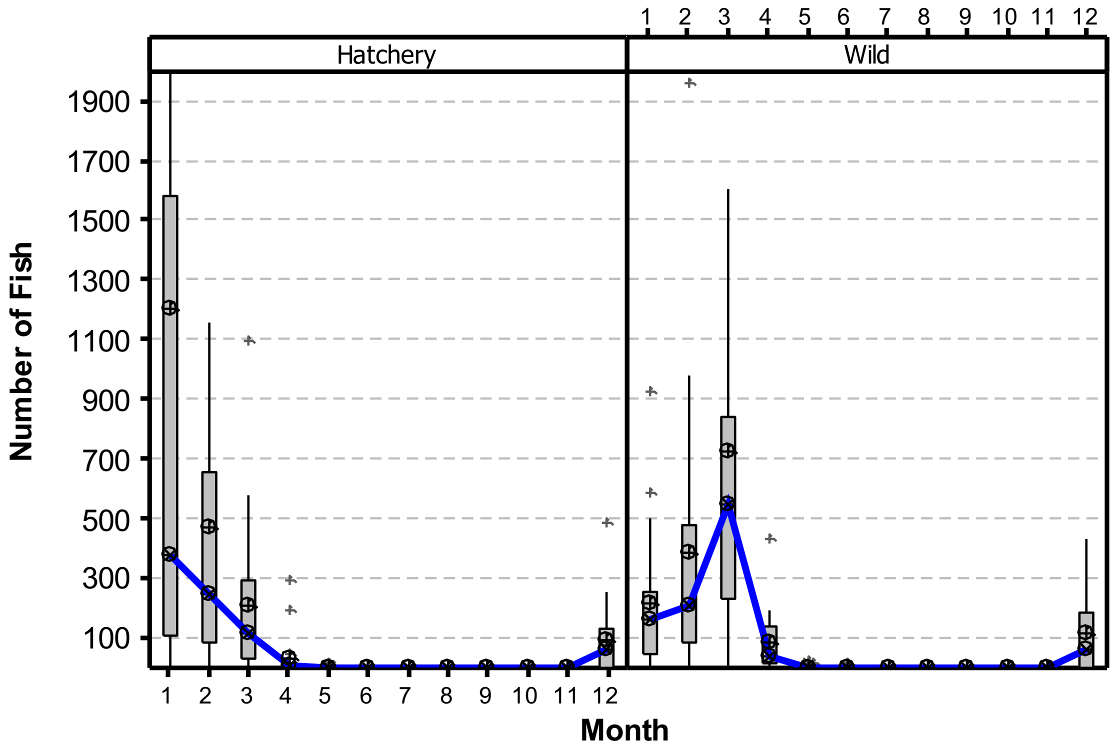


Figure 76. Juvenile winter-run Chinook salmon salvage by month summarized from salvage data from 1993 through 2012. The blue line represents the median.

Table 13. Juvenile winter-run Chinook salmon salvage data summary by month

Month	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max
1	Hatchery	1,201	384	1,717	106	376	1,578	0	6,347
1	Wild	217	53	238	44	159	251	1	924
2	Hatchery	467	141	633	85	250	654	0	2,775
2	Wild	385	106	473	86	206	482	0	1,959
3	Hatchery	207	59	263	28	118	296	0	1,093
3	Wild	727	177	789	234	548	838	4	3,567
4	Hatchery	32	17	74	0	6	19	0	290
4	Wild	86	23	103	18	42	141	0	430
5	Hatchery	1	1	3	0	0	1	0	12
5	Wild	3	1	6	0	0	5	0	24
6	Hatchery	0	0	0	0	0	0	0	0
6	Wild	1	1	3	0	0	0	0	12
7	Hatchery	0	0	0	0	0	0	0	0
7	Wild	0	0	0	0	0	0	0	0
8	Hatchery	0	0	0	0	0	0	0	0
8	Wild	0	0	0	0	0	0	0	0
9	Hatchery	0	0	0	0	0	0	0	0
9	Wild	0	0	0	0	0	0	0	0
10	Hatchery	0	0	0	0	0	0	0	0
10	Wild	0	0	0	0	0	0	0	0
11	Hatchery	0	0	0	0	0	0	0	0
11	Wild	0	0	0	0	0	0	0	0
12	Hatchery	89	26	116	1	63	129	0	482
12	Wild	115	33	149	1	60	184	0	434

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum. Max = Maximum.

3.3.5.2 Spring-run Chinook salmon

Presented in Figures 77 and 78 is the daily salvage of wild spring-run juveniles at SFPF and TFCF, respectively.

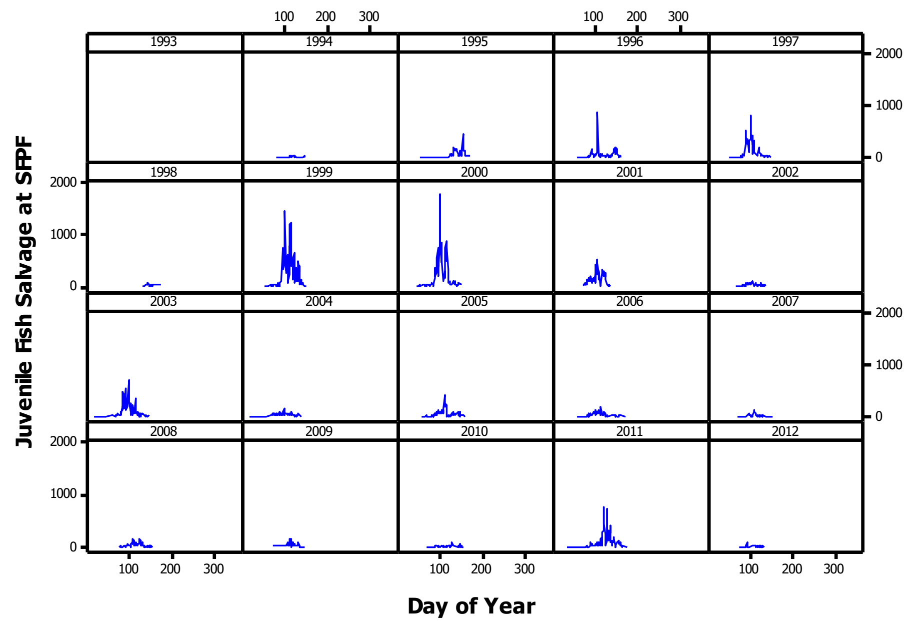


Figure 77. Daily salvage of wild juvenile spring-run Chinook salmon at SFPF from August 1, 1993 to May 21, 2012

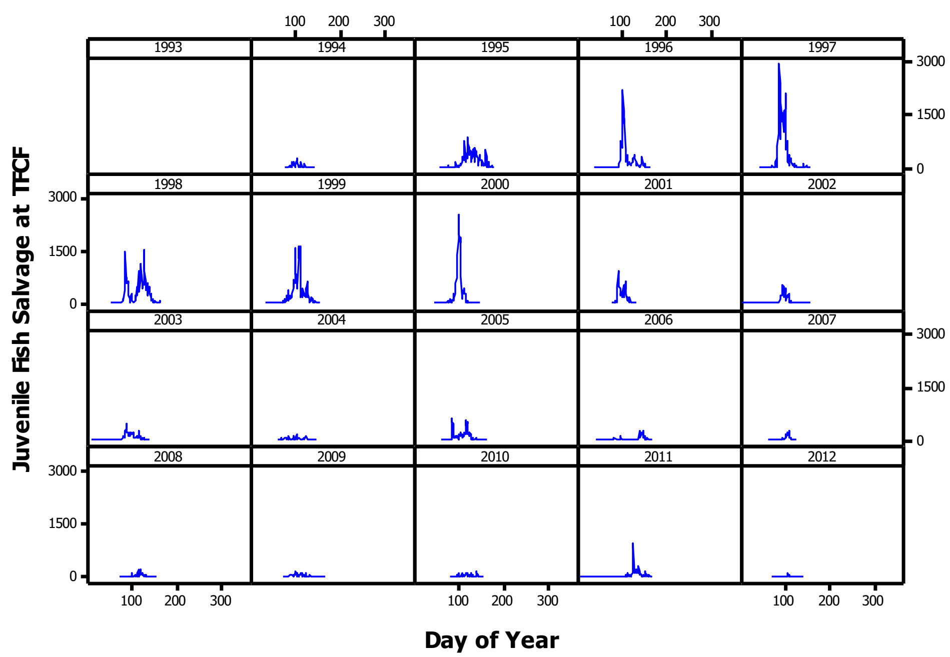


Figure 78. Daily salvage of wild juvenile spring-run Chinook salmon at TFCF from August 1, 1993 to May 21, 2012

Presented in Figures 79 through 81 is the mean daily salvage of wild spring-run juveniles from 1993 to 2012 at SFPF, TFCF, and combined respectively. Spring-run juvenile salvage occurred in February, increased in mid-March, reached the highest in mid-April, and finally faded away in June.

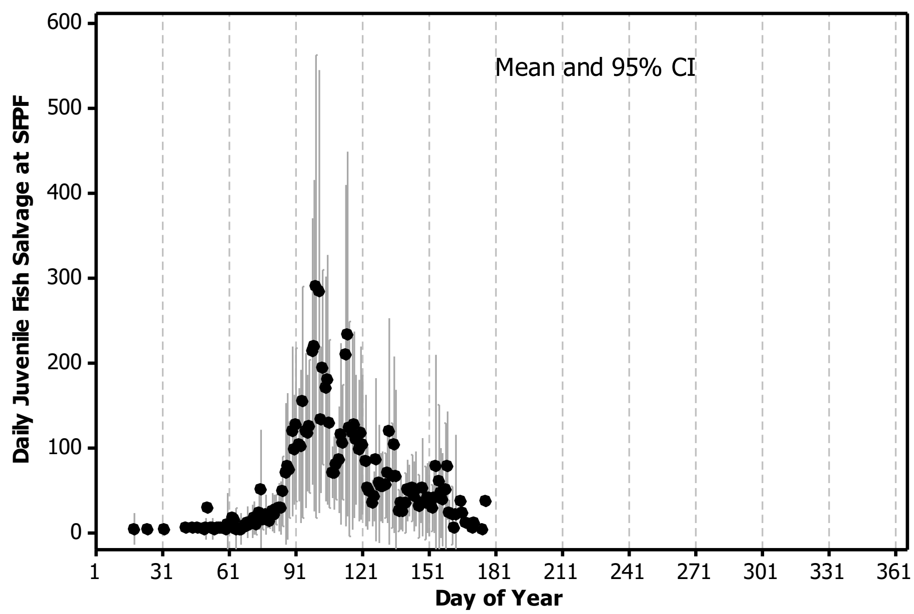


Figure 79. Mean daily juvenile salvage of wild spring-run Chinook salmon at SFPF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval

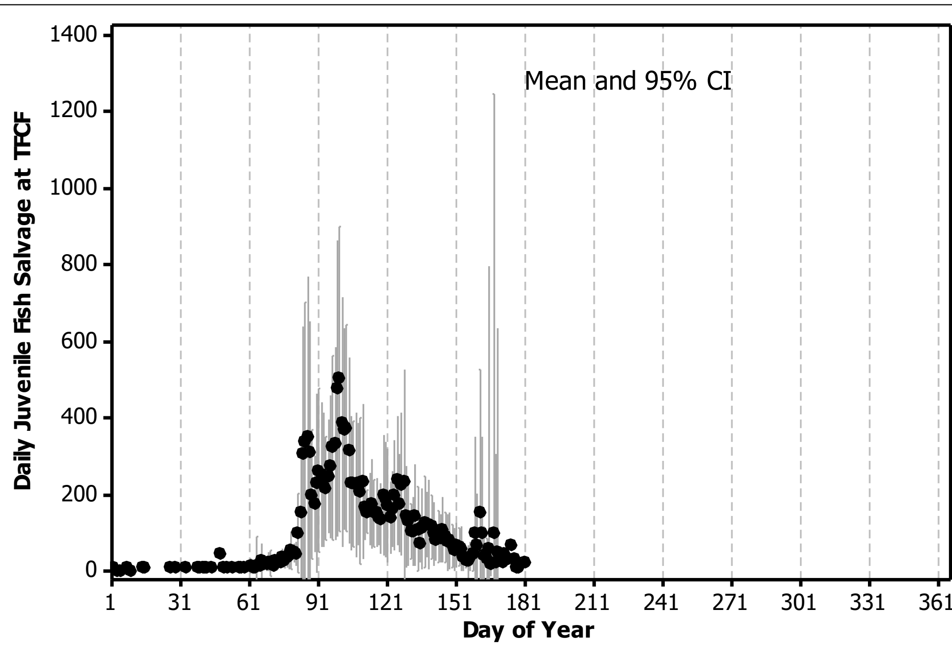


Figure 80. Mean daily juvenile salvage of wild spring-run Chinook salmon at TFCF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval

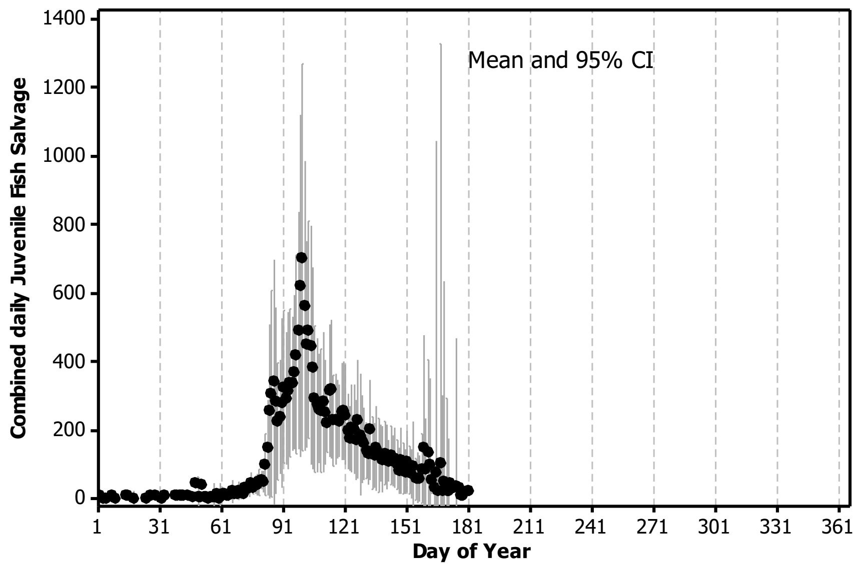


Figure 81. Combined mean daily juvenile salvage of wild spring-run Chinook salmon at SFPF and TFCF from August 1, 1993 to May 21, 2012. Dots are the mean and bars are the 95% confidence interval

The combined yearly spring-run Chinook salmon salvage increased from 1993 to 1998 that had the highest salvage. The salvage showed a sharp decrease from 1999 to 2000, with the lowest salvage in 2011 and (Figure 82). The wild spring-run Chinook salmon salvage accounted for 75% (2001) to 100% (2008) of the yearly spring -run salvage, with an average of 92% (Table 14). Note that salvaged juvenile fish were classified as spring-run based on the length-at-date criteria, but not on genetic analyses. Some of fall-run (wild or unclipped hatchery) juveniles could be classified as spring-run if their sizes fall into the category of spring-run juveniles.

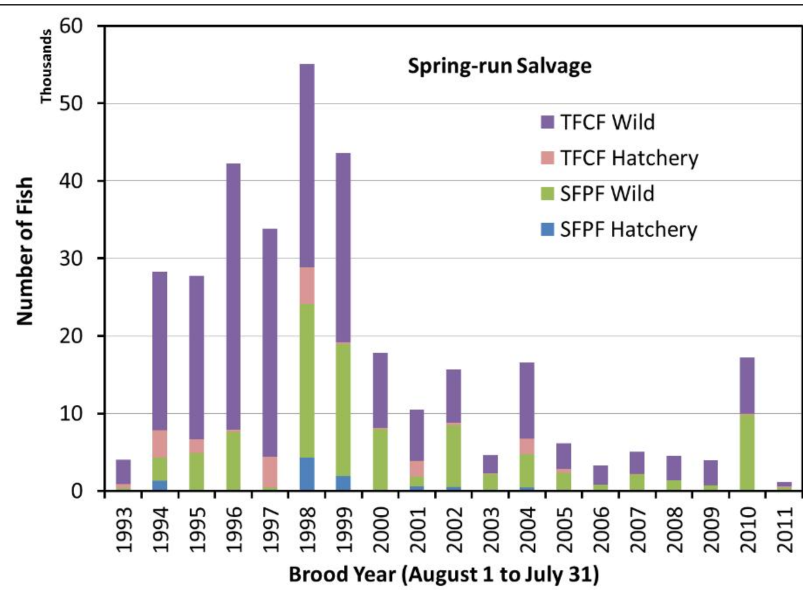


Figure 82. Juvenile spring-run Chinook salmon salvage by brood year

Table 14. Juvenile spring-run Chinook salmon salvage data summary by brood year

Brood Year	SFPF		TFCF		Combined			%Wild
	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Total	
1993	114	275	504	3,147	618	3,422	4,040	85
1994	1,295	3,006	3,549	20,436	4,844	23,442	28,286	83
1995	157	4,765	1,728	21,084	1,885	25,849	27,734	93
1996	39	7,593	264	34,338	303	41,931	42,234	99
1997	38	421	3,916	29,492	3,954	29,913	33,867	88
1998	4,358	19,736	4,762	26,211	9,120	45,947	55,067	83
1999	1,948	17,010	254	24,408	2,202	41,418	43,620	95
2000	144	7,865	120	9,708	264	17,573	17,837	99
2001	612	1,234	2,040	6,600	2,652	7,834	10,486	75
2002	531	7,974	324	6,864	855	14,838	15,693	95
2003	120	2,097	84	2,346	204	4,443	4,647	96
2004	459	4,333	1,933	9,810	2,392	14,143	16,535	86
2005	45	2,286	556	3,258	601	5,544	6,145	90
2006	6	796	24	2,484	30	3,280	3,310	99
2007	48	2,084	59	2,854	107	4,938	5,045	98
2008	0	1,391	15	3,148	15	4,539	4,554	100
2009	12	717	30	3,231	42	3,948	3,990	99
2010	138	9,663	136	7,294	274	16,957	17,231	98
2011	46	428	92	607	138	1,035	1,173	88
Mean	532	4,930	1,073	11,438	1,605	16,368	17,973	92
Median	120	2,286	264	6,864	601	14,143	15,693	95

The monthly salvage of hatchery spring-run Chinook salmon was highest in May, followed by April and March. The monthly salvage of wild spring -run Chinook salmon was highest in April, followed by March and May. The number of wild spring-run Chinook salmon salvaged in March, April, and May was higher than the hatchery spring-run (Figure 83 and Table 15). The mean salvage was always greater than the median salvage, indicating a positively skewed distribution of the winter-run salvage data.

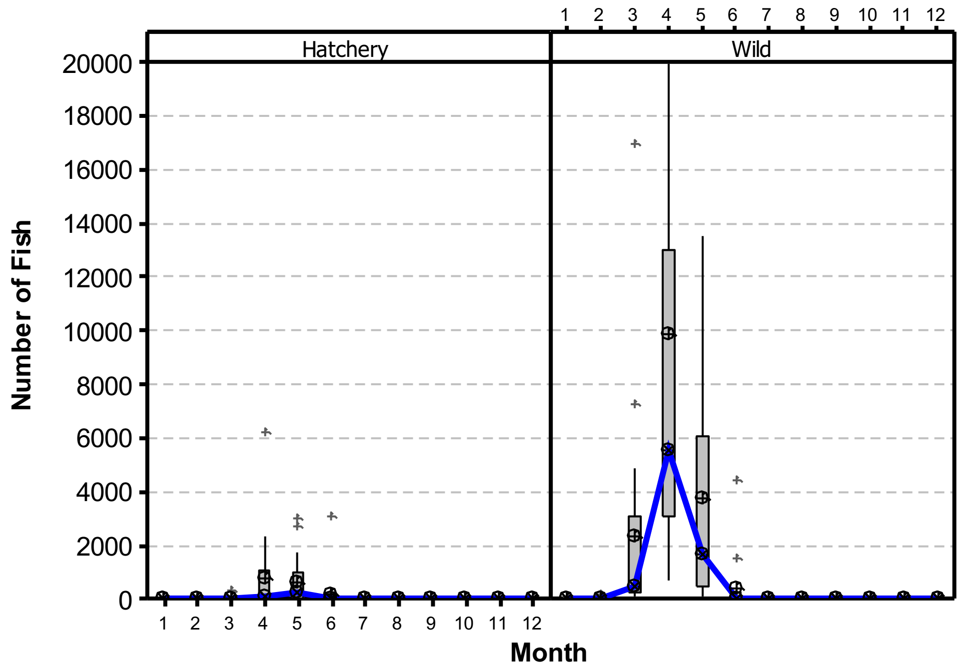


Figure 83. Juvenile spring-run Chinook salmon salvage by month summarized from salvage data from 1993 through 2012. The blue line represents the median.

Table 15. Juvenile spring-run Chinook salmon salvage data summary by month

Month	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max
1	Hatchery	0	0	0	0	0	0	0	0
1	Wild	5	3	12	0	0	0	0	42
2	Hatchery	1	1	4	0	0	0	0	12
2	Wild	20	8	34	0	9	20	0	136
3	Hatchery	32	13	60	0	14	46	0	267
3	Wild	2,347	883	3,947	234	428	3,052	52	16,967
4	Hatchery	711	323	1,444	7	51	1,078	0	6,179
4	Wild	9,907	2,427	10,855	3,046	5,539	13,048	705	37,783
5	Hatchery	618	200	895	27	213	1,009	0	2,980
5	Wild	3,703	992	4436	449	1,626	6,074	111	13,513
6	Hatchery	181	153	683	0	0	35	0	3,071
6	Wild	373	225	1005	1	24	247	0	4,382
7	Hatchery	0	0	0	0	0	0	0	0
7	Wild	0	0	0	0	0	0	0	0
8	Hatchery	0	0	0	0	0	0	0	0
8	Wild	0	0	0	0	0	0	0	0
9	Hatchery	0	0	0	0	0	0	0	0
9	Wild	0	0	1	0	0	0	0	6
10	Hatchery	0	0	0	0	0	0	0	0
10	Wild	0	0	2	0	0	0	0	8
11	Hatchery	0	0	0	0	0	0	0	0

11	Wild	0	0	0	0	0	0	0	0
12	Hatchery	0	0	0	0	0	0	0	0
12	Wild	0	0	0	0	0	0	0	0

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum. Max = Maximum.

3.3.5.3 Fall-run

The combined yearly fall-run Chinook salmon salvage increased from 1993 to 1997 that had the highest salvage. The salvage showed a step decrease from 1997 to 2001. The lowest salvage was in 2011 (Figure 84). The wild fall-run Chinook salmon salvage accounted for 63% (2001) to 100% (2007 and 2008) of the yearly fall-run salvage, with an average of 91% (Table 16). Note that some of the hatchery origin fall-run juveniles could be classified as wild because only 25 percent of the hatchery released fall-run juveniles were adipose fin clipped.

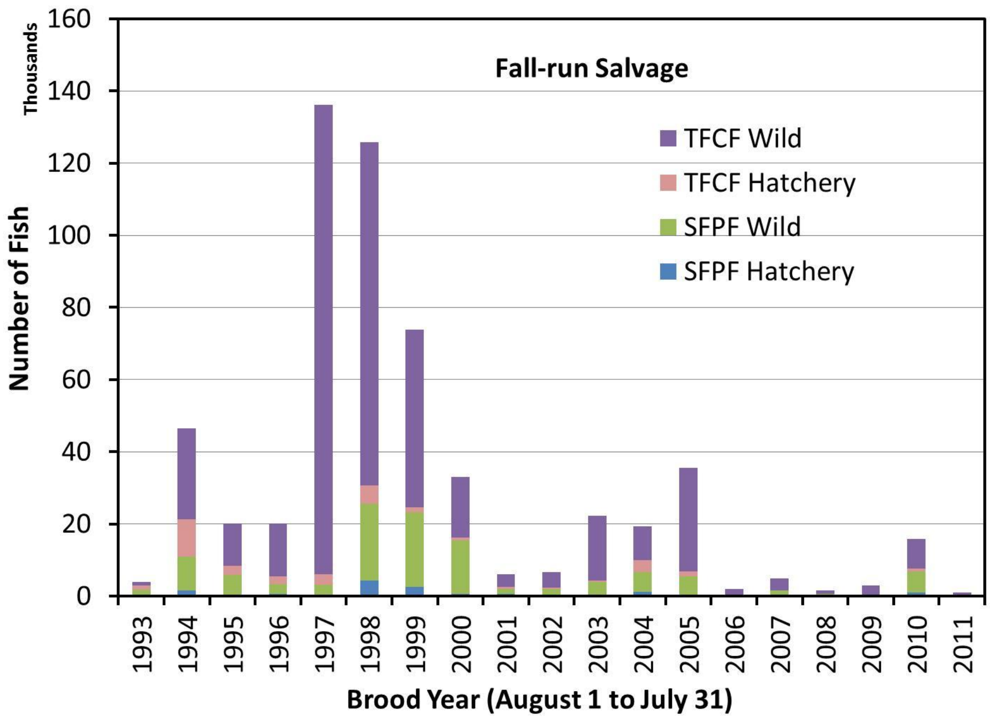


Figure 84. Juvenile fall-run Chinook salmon salvage by brood year. The "wild" group includes those fish released from hatcheries without adipose clipped.

Table 16. Juvenile fall-run Chinook salmon salvage data summary by brood year

Brood Year	SFPF		TFCF		Combined			%Wild
	Hatchery	Wild*	Hatchery	Wild*	Hatchery	Wild*	Total	
1993	237	1,605	1,200	835	1,437	2,440	3,876	63
1994	1,664	9,216	10,367	25,312	12,031	34,528	46,559	74
1995	179	5,752	2,508	11,772	2,687	17,524	20,211	87

1996	609	2,716	2,088	14,774	2,697	17,490	20,187	87
1997	119	3,108	2,840	130,154	2,959	133,262	136,221	98
1998	4,277	21,376	5,012	95,078	9,289	116,454	125,743	93
1999	2,462	20,731	1,416	49,292	3,878	70,023	73,901	95
2000	615	14,905	702	16,764	1,317	31,669	32,986	96
2001	611	1,369	528	3,614	1,139	4,983	6,122	81
2002	31	1,978	353	4,320	384	6,298	6,682	94
2003	110	3,892	276	17,959	386	21,851	22,237	98
2004	1,101	5,526	3,309	9,386	4,410	14,912	19,322	77
2005	112	5,366	1,311	28,793	1,423	34,159	35,582	96
2006	4	377	24	1,629	28	2,006	2,034	99
2007	0	1,542	4	3,285	4	4,827	4,831	100
2008	0	625	0	982	0	1,607	1,607	100
2009	0	454	20	2,393	20	2,847	2,867	99
2010	900	6,001	736	8,202	1,636	14,203	15,838	90
2011	20	447	40	489	60	936	996	94
Mean	687	5,631	1,723	22,370	2,410	28,001	30,411	91
Median	179	3,108	736	9,386	1,423	14,912	19,322	94

*The "wild" group includes those fish released from hatcheries without adipose fins clipped.

The monthly salvage of hatchery fall-run Chinook salmon was highest in May, followed by April and June. The monthly salvage of fall-run Chinook salmon without adipose clipped was highest in May, followed by June, April, March, February, and January. The number of fall-run Chinook salmon without adipose clipped was higher than the hatchery fall-run (Figure 85 and Table 17). The mean salvage was always greater than the median salvage, indicating a positively skewed distribution of the fall-run salvage data.

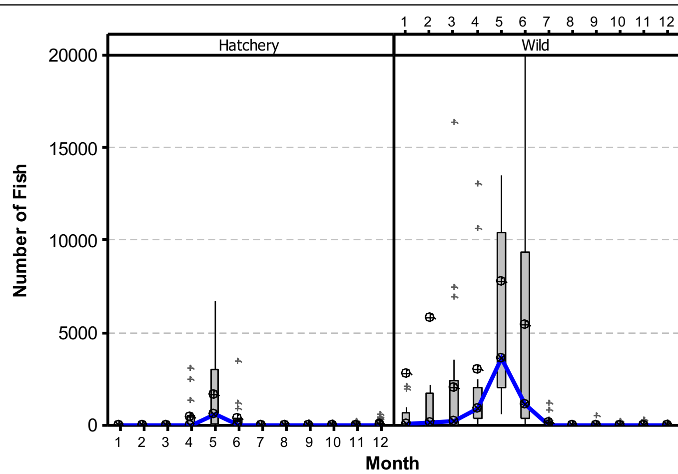


Figure 85. Juvenile fall-run Chinook salmon salvage by month summarized from salvage data from 1993 through 2012. The "wild" group includes those fish released from hatcheries without adipose clipped. . The blue line represents the median.

Table 17. Juvenile fall-run Chinook salmon salvage data summary by month

Month	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max
1	Hatchery	3	2	7	0	0	0	0	24
1	Wild*	2,817	2,455	10,979	4	46	661	0	49,386
2	Hatchery	0	0	0	0	0	0	0	0
2	Wild	5,816	2,951	13,195	24	132	1,728	0	38,737
3	Hatchery	9	6	27	0	0	0	0	108
3	Wild	2,009	907	4,055	37	205	2,397	0	16,344
4	Hatchery	482	193	865	0	38	515	0	3,085
4	Wild	2,987	1,208	5,404	361	941	2,027	47	20,680
5	Hatchery	1,670	458	2,047	64	628	3,043	0	6,682
5	Wild	7,755	2,301	10,290	2,034	3,585	10,390	571	42,592
6	Hatchery	351	177	794	0	25	297	0	3,435
6	Wild	5,416	1,794	8,023	373	1,153	9,321	30	28,607
7	Hatchery	0	0	0	0	0	0	0	0
7	Wild	134	68	306	0	12	80	0	1,180
8	Hatchery	0	0	0	0	0	0	0	0
8	Wild	11	5	21	0	0	12	0	72
9	Hatchery	8	8	36	0	0	0	0	162
9	Wild	31	27	120	0	0	0	0	538
10	Hatchery	11	8	34	0	0	0	0	148
10	Wild	20	10	47	0	0	14	0	194
11	Hatchery	22	12	54	0	0	9	0	197
11	Wild	29	16	70	0	1	21	0	264
12	Hatchery	77	38	172	0	0	12	0	570
12	Wild	16	8	38	0	0	12	0	155

*The “wild” group includes those fish released from hatcheries without adipose clipped.
SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum. Max = Maximum.

3.3.5.4 Late Fall-run

The combined yearly late fall-run Chinook salmon salvage increased from 1993 to 1994 that had the highest salvage. The salvage showed a sharp decrease from 1994 to 1995. There was no late fall-run salvage in 2008 (Figure 86). The wild late fall-run Chinook salmon salvage accounted for 5% (2002 and2003) to 91% (1996) of the yearly late fall-run salvage, with an average of 37% (Table 18).

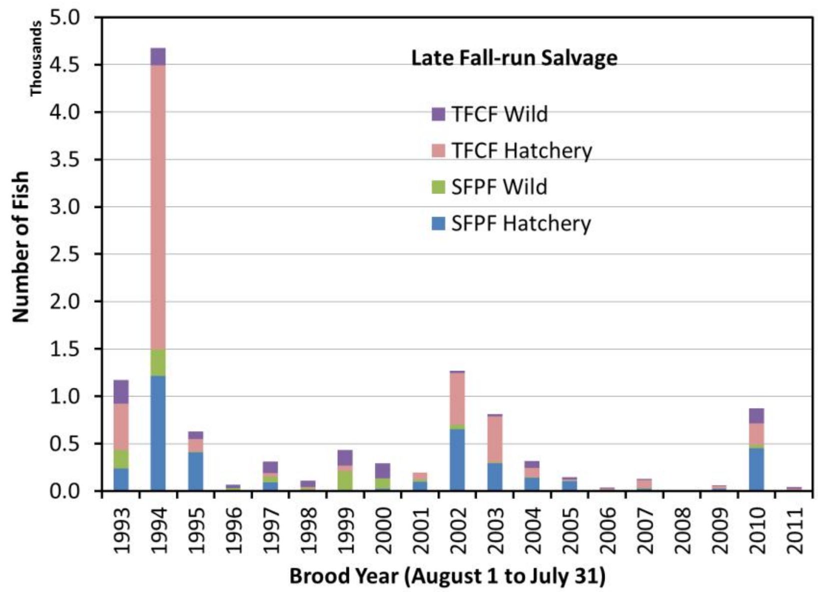


Figure 86. Juvenile late fall-run Chinook salmon salvage by brood year

Table 18. Juvenile late fall-run Chinook salmon salvage data summary by brood year

Brood Year	SFPF		TFCF		Combined			%Wild
	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Total	
1993	238	196	488	252	726	448	1,174	38
1994	1,213	281	3,000	180	4,213	461	4,674	10
1995	412	4	132	84	544	88	632	14
1996	6	23	0	36	6	59	65	91
1997	91	60	40	120	131	180	311	58
1998	8	21	12	72	20	93	113	82
1999	13	196	60	168	73	364	437	83
2000	24	113	0	156	24	269	293	92
2001	100	22	72	0	172	22	194	11
2002	656	45	543	24	1,199	69	1,268	5
2003	296	12	480	25	776	37	813	5
2004	138	12	96	72	234	84	318	26
2005	102	10	12	24	114	34	148	23
2006	3	1	24	12	27	13	40	33
2007	24	10	80	16	104	26	130	20
2008	0	0	0	0	0	0	0	
2009	26	0	28	8	54	8	62	13
2010	453	36	224	160	677	196	873	22
2011	0	0	25	20	25	20	44	45
Mean	200	55	280	75	480	130	610	37
Median	91	21	60	36	114	69	293	25

The monthly salvage of hatchery and wild late fall-run Chinook salmon was highest in December, followed by January. Late fall-run juveniles were typically released from the Coleman National Fish Hatchery in December and January. The number of the salvaged hatchery late fall-run Chinook salmon was higher than the wild late fall-run (Figure 87and Table 19). The mean salvage was always greater than the median salvage, indicating a positively skewed distribution of the late fall-run salvage data.

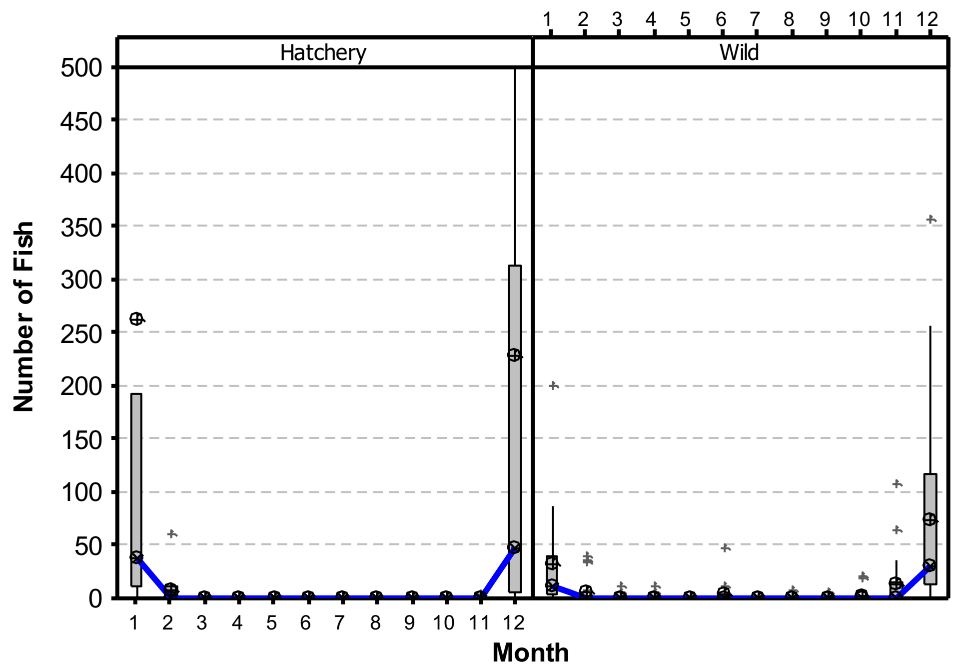


Figure 87. Juvenile late fall -run Chinook salmon salvage by month summarized from salvage data from 1993 through 2012. The blue line represents the median.

Table 19. Juvenile late fall -run Chinook salmon salvage data summary by month

Month	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max
1	Hatchery	262	128	571	12	37	192	0	2,469
1	Wild	32	10	47	4	12	41	0	199
2	Hatchery	7	3	14	0	0	11	0	60
2	Wild	6	3	13	0	0	1	0	39
3	Hatchery	0	0	0	0	0	0	0	0
3	Wild	1	1	3	0	0	0	0	12
4	Hatchery	0	0	0	0	0	0	0	0
4	Wild	1	1	3	0	0	0	0	12
5	Hatchery	0	0	0	0	0	0	0	0
5	Wild	0	0	0	0	0	0	0	0
6	Hatchery	0	0	0	0	0	0	0	0
6	Wild	3	2	11	0	0	0	0	48
7	Hatchery	0	0	0	0	0	0	0	0

7	Wild	0	0	0	0	0	0	0	0
8	Hatchery	0	0	0	0	0	0	0	0
8	Wild	0	0	2	0	0	0	0	8
9	Hatchery	0	0	0	0	0	0	0	0
9	Wild	0	0	1	0	0	0	0	6
10	Hatchery	0	0	0	0	0	0	0	0
10	Wild	3	1	6	0	0	2	0	21
11	Hatchery	0	0	1	0	0	0	0	4
11	Wild	13	6	27	0	0	15	0	107
12	Hatchery	227	94	421	7	48	313	0	1,744
12	Wild	73	22	98	12	30	116	0	356

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum. Max = Maximum.

3.3.5.5 Steelhead

The combined yearly steelhead salvage increased from 1993 to 1995, with a sharp decrease in 1996 that had the lowest salvage. The salvage increased during the period of 1999-2003 except 2001, with the highest salvage in 2000 and 2002 (Figure 88). The salvage showed a sharp decrease from 2003 to 2004. The wild steelhead salvage accounted for 17% (2002) to 100% (1996) of the yearly steelhead salvage, with an average of 52% (Table 20). Prior to 1997, hatchery steelhead were not clipped routinely. After 1997, all hatchery steelhead were clipped.

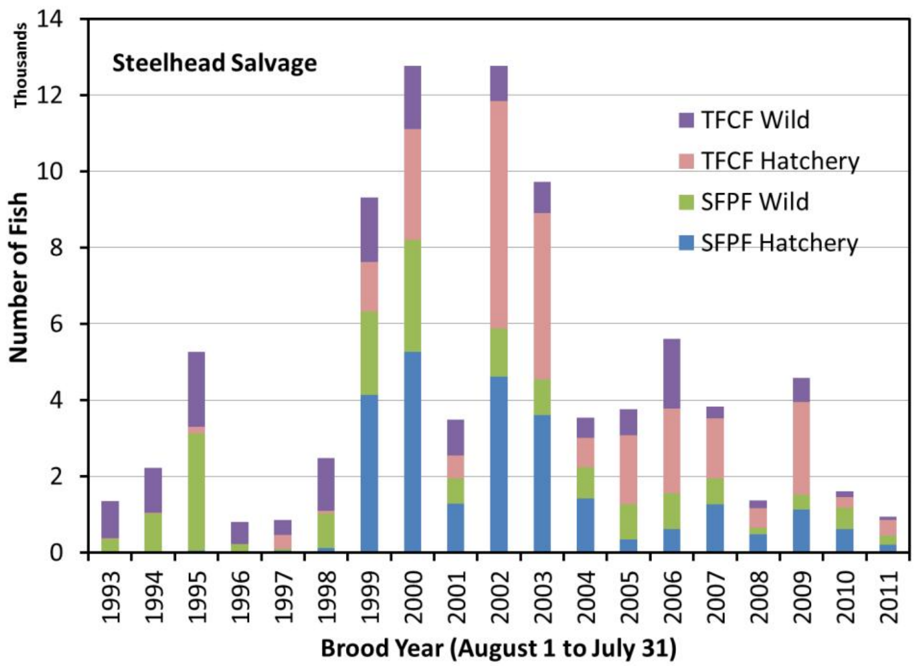


Figure 88. Juvenile steelhead salvage by brood year

Table 20. Juvenile steelhead salvage data summary by brood year

Brood Year	SFPF		TFCF		Combined			%Wild
	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Total	
1993	25	333	25	962	50	1,295	1,345	96
1994	32	993	12	1,188	44	2,181	2,225	98
1995	50	3,087	168	1,954	218	5,041	5,259	96
1996	1	229	-	576	1	805	806	100
1997	60	48	348	408	408	456	864	53
1998	117	902	70	1,390	187	2,292	2,480	92
1999	4,141	2,185	1,291	1,690	5,432	3,875	9,307	42
2000	5,263	2,948	2,904	1,656	8,167	4,604	12,771	36
2001	1,281	673	588	948	1,869	1,621	3,490	46
2002	4,616	1,261	5,964	924	10,580	2,185	12,765	17
2003	3,613	941	4,344	828	7,957	1,769	9,726	18
2004	1,414	821	780	528	2,194	1,349	3,543	38
2005	351	913	1,812	687	2,163	1,600	3,763	43
2006	612	947	2,220	1,824	2,832	2,771	5,603	49
2007	1,267	675	1,576	309	2,843	984	3,827	26
2008	483	171	511	197	994	368	1,363	27
2009	1,126	401	2,421	627	3,547	1,028	4,574	22
2010	609	571	268	165	877	736	1,613	46
2011	200	249	405	93	605	342	946	36
Mean	1,330	966	1,353	892	2,682	1,858	4,540	52
Median	609	821	588	828	1,869	1,600	3,543	43

The monthly salvage of hatchery and wild steelhead was highest in February and March, followed by January and April. The number of the salvaged hatchery steelhead was similar to the wild steelhead. Hatchery releases of steelhead juveniles typically occur in January and February. Wild steelhead juveniles in the Sacramento River basin emigrate during the January to March period, while juveniles in the San Joaquin River basin emigrate during the April and May period. The mean salvage was always greater than the median salvage, indicating a positively skewed distribution of the steelhead salvage data.

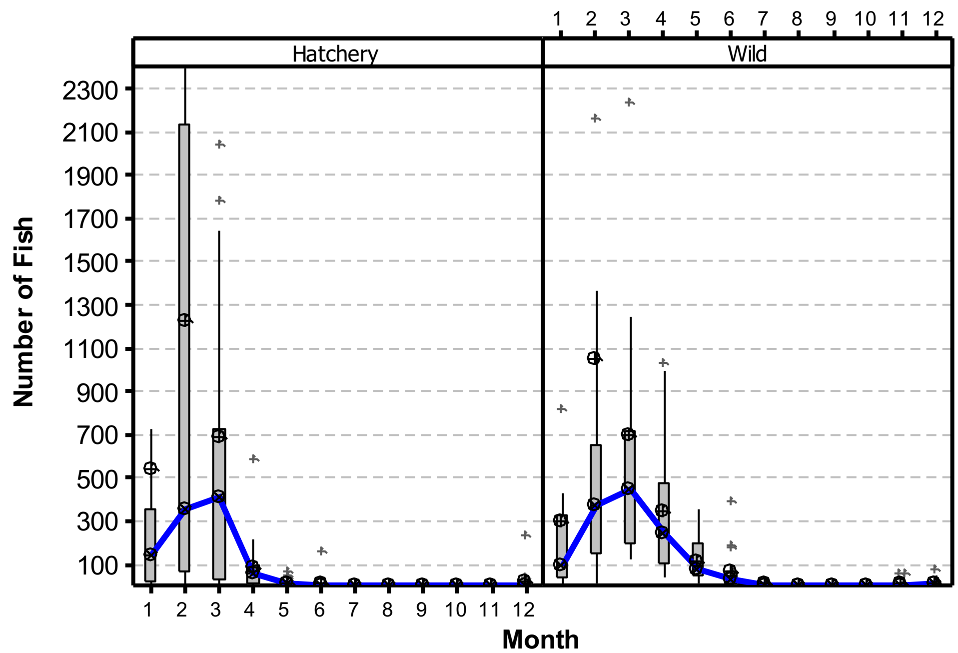


Figure 89. Juvenile steelhead salvage by month summarized from salvage data from 1993 through 2012. The blue line represents the median.

Table 21. Juvenile steelhead salvage data summary by month

Month	Origin	Mean	SE	SD	Q1	Median	Q3	Min	Max
1	Hatchery	540	363	1,625	18	141	356	0	7,391
1	Wild	301	139	620	33	92	324	0	2,791
2	Hatchery	1,226	376	1,681	68	349	2,139	0	5,698
2	Wild	1,049	547	2,444	149	370	651	9	11,173
3	Hatchery	689	211	943	24	404	726	0	3,723
3	Wild	697	192	857	192	449	713	120	3,677
4	Hatchery	87	30	132	8	59	93	0	585
4	Wild	344	72	321	100	239	473	36	1,035
5	Hatchery	13	4	18	0	7	15	0	65
5	Wild	113	21	95	49	71	191	12	352
6	Hatchery	10	8	36	0	0	8	0	162
6	Wild	61	21	93	12	24	68	0	388
7	Hatchery	0	0	1	0	0	0	0	5
7	Wild	6	2	9	0	3	12	0	30
8	Hatchery	0	0	0	0	0	0	0	0
8	Wild	0	0	1	0	0	0	0	4
9	Hatchery	0	0	0	0	0	0	0	0
9	Wild	1	0	2	0	0	0	0	10
10	Hatchery	0	0	0	0	0	0	0	0
10	Wild	1	0	2	0	0	2	0	4
11	Hatchery	0	0	0	0	0	0	0	0

11	Wild	8	4	18	0	0	10	0	60
12	Hatchery	14	12	52	0	0	0	0	234
12	Wild	13	4	19	0	5	18	0	77

SE = Standard error of the mean. SD = Standard deviation. Q1 = First quartile, i.e., 25% of the data are less than or equal to this value. Q3 = Third quartile, i.e., 75% of the data are less than or equal to this value. Min = Minimum. Max = Maximum.

3.3.6 Chinook and Steelhead Salvage during Predator Removal Operations at the SFPF

The number of Chinook salmon and steelhead salvaged from predator removal operations at the SFPF is summarized in Table 22. These salvage numbers were very small compared to the yearly Chinook salmon or steelhead salvage.

Table 22. Juvenile salmonid salvage from predator removal operations at the SFPF

Year	Chinook Salmon	Steelhead
1999	182	6
2000	224	204
2001	93	142
2002	109	51
2003	535	142
2004	133	96
2005	50	15
2006	55	6
2007	65	46
2008	80	21
2009	45	9
2010	53	52
2011	190	28
2012	36	9

3.3.7 Striped Bass

To be consistent with salmonids, the yearly striped bass salvage is also expressed in brood year. The combined yearly striped bass salvage decreased from 1993 to 1997 and increased from 1997 to 2001.The salvage showed a decreasing trend from 2001 to 2008, followed by a gradual increase from 2008 to 2011 (Figure 90). On average, the number of striped bass salvaged at the SFPF was slightly higher than that at the TFCF (Table 23).

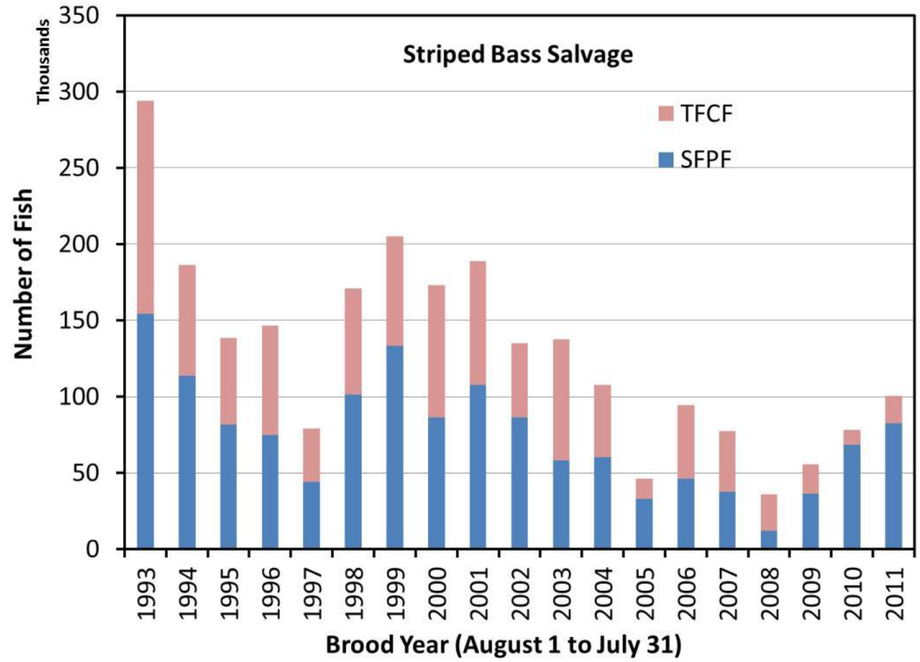


Figure 90. Striped bass salvage by brood year

Table 23. Striped bass salvage data summary by year

Brood Year	SFPF	TFCF	Combined	%SFPF
1993	154,470	139,314	293,784	53
1994	113,514	72,642	186,156	61
1995	81,463	56,928	138,391	59
1996	74,706	71,998	146,704	51
1997	44,209	34,746	78,955	56
1998	101,194	69,809	171,003	59
1999	133,215	71,742	204,957	65
2000	86,194	86,784	172,978	50
2001	107,733	80,945	188,677	57
2002	86,355	48,696	135,051	64
2003	58,129	79,334	137,463	42
2004	60,153	47,433	107,586	56
2005	32,970	13,260	46,230	71
2006	46,014	48,426	94,440	49
2007	37,545	39,819	77,364	49
2008	12,070	23,849	35,919	34
2009	36,245	19,323	55,568	65
2010	68,374	10,001	78,375	87
2011	82,367	17,884	100,251	82
Mean	74,575	54,365	128,940	58
Median	74,706	48,696	135,051	55

Striped bass salvage occurred year round, with the lowest salvage in April and the highest salvage in July. The second highest was in June, followed by August (Figure 91 and Table 24). The lowest salvage number in April corresponds to the largest size of salvaged striped bass. Striped bass spawn in the Delta when water temperature is above ~60 ^oF and salvage is observed when larval striped bass grow bigger than 20 mm. By July many of the YOY striped bass are big enough to be salvaged efficiently. By fall these YOY fish are moving downstream in the Delta to the estuary, leaving older fish in the Delta waters.

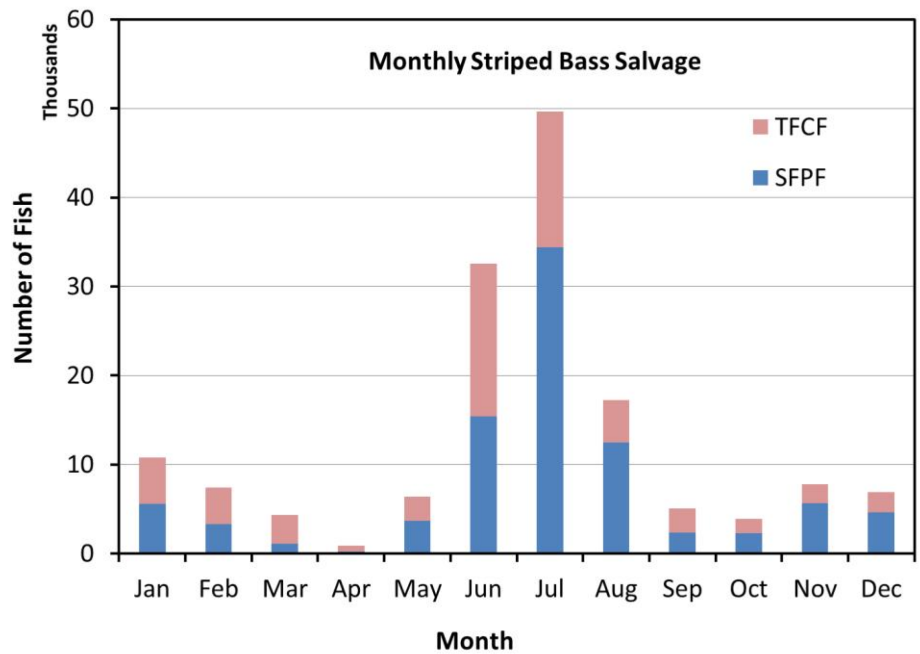


Figure 91. Striped bass salvage by month summarized from salvage data from 1993 through 2012

Table 24. Striped bass salvage data summary by month

Month	Mean	Standard Deviation	Median
January	10,764	18,365	4,158
February	7,386	8,104	5,198
March	4,343	5,294	1,876
April	878	739	651
May	6,195	9,074	2,590
June	32,584	31,646	25,045
July	49,666	57,909	35,188
August	17,266	24,757	9,897
September	5,035	5,884	3,289
October	3,918	3,953	2,347
November	7,785	6,735	5,329
December	6,813	5,497	5,704

3.3.8 Juvenile Fish Salvage Data Summary

Salvage data for Chinook salmon, steelhead, and striped bass are summarized in Table 25. On average, the annual Chinook salmon salvage is about 10 times the annual number of steelhead salvaged. The ratio of the annual striped bass salvage to annual salmonid salvage ranged from 0.5 to 22.7, with an average of 4.8. Summarized in Table 26 are salvage data for wild Chinook and steelhead and Table 27 for hatchery Chinook and steelhead.

Table 25. Salvage data summary for Chinook salmon, steelhead, and striped bass

Brood Year	Chinook*			Steelhead			Salmonid Total	Striped Bass	SB/SM **
	Wild	Hatchery	Combined	Wild	Hatchery	Combined			
1993	7,647	7,133	14,780	1,295	50	1,345	16,125	293,784	18.2
1994	59,839	24,624	84,463	2,181	44	2,225	86,688	186,156	2.1
1995	44,242	8,131	52,373	5,041	218	5,259	57,632	138,391	2.4
1996	59,877	3,007	62,884	805	1	806	63,690	146,704	2.3
1997	164,081	7,554	171,635	456	408	864	172,499	78,955	0.5
1998	164,001	18,603	182,604	2,292	187	2,480	185,084	171,003	0.9
1999	113,721	7,134	120,855	3,875	5,432	9,307	130,162	204,957	1.6
2000	55,339	2,567	57,906	4,604	8,167	12,771	70,677	172,978	2.4
2001	14,269	6,189	20,458	1,621	1,869	3,490	23,948	188,677	7.9
2002	23,455	9,999	33,454	2,185	10,580	12,765	46,219	135,051	2.9
2003	28,995	7,239	36,234	1,769	7,957	9,726	45,960	137,463	3.0
2004	29,606	8,107	37,713	1,349	2,194	3,543	41,256	107,586	2.6
2005	40,739	2,615	43,354	1,600	2,163	3,763	47,117	46,230	1.0
2006	7,979	1,409	9,388	2,771	2,832	5,603	14,991	94,440	6.3
2007	10,445	3,100	13,545	984	2,843	3,827	17,371	77,364	4.5
2008	6,715	193	6,908	368	994	1,363	8,270	35,919	4.3
2009	7,857	1,319	9,176	1,028	3,547	4,574	13,750	55,568	4.0
2010	33,016	3,028	36,044	736	877	1,613	37,657	78,375	2.1
2011	2,809	653	3,462	342	605	946	4,408	100,251	22.7
Mean	46,033	6,453	52,486	1,858	2,682	4,540	57,026	128,940	4.8
Median	29,606	6,189	36,234	1,600	1,869	3,543	45,960	135,051	2.6

*Sum of winter-run, spring-run, fall-run, and late fall-run.

**Ratio of the number of salvaged striped bass (SB) over the number of salvaged salmonids (SM), representing the ratio of predator over prey.

Table 26. Data summary for wild Chinook* and steelhead

Brood Year	Winter -run	Spring-run	Fall-run	Late Fall-run	Chinook Total	Steelhead	%WR	%SR	%FR	%LFR
1993	1,337	3,422	2,440	448	7,647	1,295	17.5	44.7	31.9	5.9
1994	1,408	23,442	34,528	461	59,839	2,181	2.4	39.2	57.7	0.8
1995	781	25,849	17,524	88	44,242	5,041	1.8	58.4	39.6	0.2
1996	397	41,931	17,490	59	59,877	805	0.7	70.0	29.2	0.1
1997	726	29,913	133,262	180	164,081	456	0.4	18.2	81.2	0.1
1998	1,507	45,947	116,454	93	164,001	2,292	0.9	28.0	71.0	0.1
1999	1,916	41,418	70,023	364	113,721	3,875	1.7	36.4	61.6	0.3
2000	5,828	17,573	31,669	269	55,339	4,604	10.5	31.8	57.2	0.5
2001	1,430	7,834	4,983	22	14,269	1,621	10.0	54.9	34.9	0.2
2002	2,250	14,838	6,298	69	23,455	2,185	9.6	63.3	26.9	0.3
2003	2,664	4,443	21,851	37	28,995	1,769	9.2	15.3	75.4	0.1
2004	467	14,143	14,912	84	29,606	1,349	1.6	47.8	50.4	0.3
2005	1,002	5,544	34,159	34	40,739	1,600	2.5	13.6	83.8	0.1
2006	2,680	3,280	2,006	13	7,979	2,771	33.6	41.1	25.1	0.2
2007	654	4,938	4,827	26	10,445	984	6.3	47.3	46.2	0.2
2008	569	4,539	1,607	-	6,715	368	8.5	67.6	23.9	0.0
2009	1,054	3,948	2,847	8	7,857	1,028	13.4	50.2	36.2	0.1
2010	1,661	16,957	14,203	196	33,016	736	5.0	51.4	43.0	0.6
2011	819	1,035	936	20	2,809	342	29.1	36.9	33.3	0.7
Mean	1,534	16,368	28,001	130	46,033	1,858	8.7	43.0	47.8	0.6
Median	1,337	14,143	14,912	69	29,606	1,600	6.3	44.7	43.0	0.2

*Classification of Chinook salmon runs is based on the length at date criteria, not on genetic analyses. Therefore, the numbers of winter-run, spring-run, fall-run, and late fall-run in the table may not represent the true identification of these runs.

Table 27. Data summary for hatchery Chinook and steelhead

Brood Year	Winter -run	Spring-run	Fall-run	Late Fall-run	Chinook Total	Steelhead	%WR	%SR	%FR	%LFR
1993	4,353	618	1,437	726	7,133	50	61.0	8.7	20.1	10.2
1994	3,536	4,844	12,031	4,213	24,624	44	14.4	19.7	48.9	17.1
1995	3,015	1,885	2,687	544	8,131	218	37.1	23.2	33.0	6.7
1996	1	303	2,697	6	3,007	1	0.0	10.1	89.7	0.2
1997	510	3,954	2,959	131	7,554	408	6.8	52.3	39.2	1.7
1998	174	9,120	9,289	20	18,603	187	0.9	49.0	49.9	0.1
1999	981	2,202	3,878	73	7,134	5,432	13.8	30.9	54.4	1.0
2000	962	264	1,317	24	2,567	8,167	37.5	10.3	51.3	0.9
2001	2,226	2,652	1,139	172	6,189	1,869	36.0	42.9	18.4	2.8
2002	7,561	855	384	1,199	9,999	10,580	75.6	8.6	3.8	12.0
2003	5,873	204	386	776	7,239	7,957	81.1	2.8	5.3	10.7
2004	1,071	2,392	4,410	234	8,107	2,194	13.2	29.5	54.4	2.9
2005	477	601	1,423	114	2,615	2,163	18.2	23.0	54.4	4.4
2006	1,324	30	28	27	1,409	2,832	94.0	2.1	2.0	1.9
2007	2,885	107	4	104	3,100	2,843	93.1	3.5	0.1	3.4
2008	178	15	-	-	193	994	92.2	7.8	0.0	0.0
2009	1,203	42	20	54	1,319	3,547	91.2	3.2	1.5	4.1
2010	442	274	1,636	677	3,028	877	14.6	9.0	54.0	22.4
2011	431	138	60	25	653	605	65.9	21.1	9.2	3.8
Mean	1,958	1,605	2,410	480	6,453	2,682	44.6	18.8	31.0	5.6
Median	1,071	601	1,423	114	6,189	1,869	37.1	10.3	33.0	3.4

3.4 Juvenile Fish Loss at the Water Export Facilities

Juvenile fish loss refers to the number of fish lost after entering Clifton Court Forebay (CCF) through the radial gates for the Banks Pumping plant or swimming across the trash boom for the Jones Pumping Plant in front of the trash racks. The fish loss is back calculated using the fish salvage data. Described below is the process for calculating the fish loss.

3.4.1 Quantifying Juvenile Fish Loss at the SFPF

3.4.1.1 System Fish Loss at the SFPF

One of the major differences between the Federal and state pumping facilities is that the state facility has a large forebay (i.e., CCF) where there is high juvenile fish mortality presumably as a result of predation. The surface area of CCF is 2,180 acres and the storage capacity is 31,260 acre-ft. The previously estimated striped bass abundance in CCF was about 200,000 (Brown *et al.* 1995). The juvenile fish survival rate at CCF (S_{CCF}) is defined as the percentage of juvenile fish that survive traveling the distance between the radial gates located at the entrance to CCF and the trash boom in front of the SFPF (Figure 92). The radial gates are normally operated on a daily basis and are opened on the highest high tide when the greatest head differential occurs between the West Canal and forebay elevations (Morinaka 2011). The gates remain in the open position until the daily volumetric allotment of water to export is reached. The trash boom located near the SFPF entrance deflects large floating debris (e.g., logs, water hyacinth, etc.) at the top of the water column towards a conveyor for disposal on the south side of the intake channel. The trash boom is a floating structure with a leading edge extending 0.5 meters below the water surface.

Fish passing the trash boom will encounter the trash rack between the trash boom and the primary louver array. The trash rack is a large structure with vertical grating that spans the entire width of the primary channel. Larger fish and debris are prevented from entering the facility through the trash rack's vertical 5.1 cm (2 in) wide openings. An automated cleaner is used to remove debris accumulated on the face of the trash rack and deposits the debris into trash containers on each side of the channel (Morinaka 2011). Predation of juvenile fish is expected to occur in the channel between the trash boom and the trash rack.

Fish that successfully pass through the trash rack enter the primary louver section of the SFPF. The channel narrows and is divided by center walls into 7 bays (Figure 29). A series of wing gates located at the upstream end of each bay in front of the primary louvers are used to regulate the velocity of the water approaching the louvers. A series of louver panels are arranged in a v-shaped configuration to guide fish into bypasses located at the apex of the configuration. The louver design is based upon the behavior of the fish and their desire to avoid passing through the hydrodynamic turbulence in front of the louver slats. The louvers consist of vertical slats spaced 2.5 cm (1 in) apart that are oriented 15 degrees relative to the direction of water flow. This orientation creates turbulence along the face of the louvers to elicit an avoidance reaction and encourages fish movement towards the bypasses (Morinaka 2011). Predation of juvenile fish is expected to occur in the channel between the trash rack and the entry of the primary bypasses.

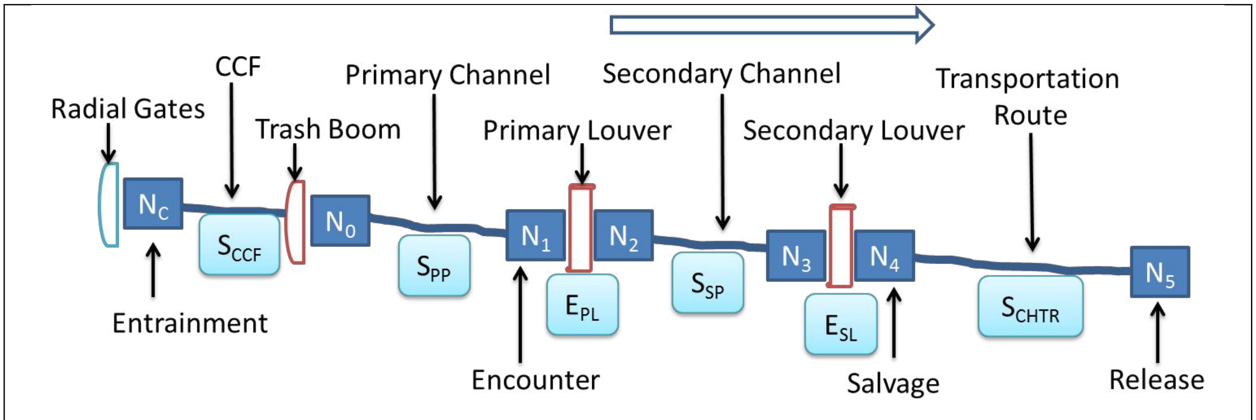


Figure 92. Schematic diagram of fish movement at the SFPF

N_C = Number of fish entrained, i.e., passing through the radial gates
N_0 = Number of fish passing through the trash boom
N_1 = Number of fish encountering the primary louver
N_2 = Number of fish successfully routed to the secondary channel, i.e., not passing through the primary louver
N_3 = Number of fish encountering the secondary louver
N_4 = Number of fish successfully routed to the holding tank, i.e., salvaged
N_5 = Number of fish released downstream after transportation
S_{CCF} = Clifton Court Forebay survival rate
S_{PP} = Primary channel predation survival rate
E_{PL} = Primary louver efficiency
S_{SP} = Secondary channel predation survival rate
E_{SL} = Secondary louver efficiency
S_{CHTR} = Collection, handling, transportation, and release survival rate

Fish move down current along the face of the louver panels until they encounter the primary bypass opening. The primary bypass opening is nominally 12–inches wide and is the depth of the primary channel. However, the bypass is bisected in half by the centerline wall in each of the primary bays, resulting in a primary bypass width of 6-inches. After entering the primary bypasses, fish move through 122 cm (48 in) diameter pipes, the fish are now in the secondary channels of the SFPF (Figure 29). The secondary channels are used to reduce the volume of water, concentrate the fish, and guide the fish into the secondary bypasses. There are two types of designs for the secondary channel. The original (old) secondary channel uses a series of louver panels identical to the primary louvers to guide fish into the bypass. The old secondary channel has been in use since the SFPF started salvaging fish in 1968. The new secondary channel uses a system of 2 bays consisting of panels of perforated plate (4 mm openings) to guide fish into the secondary bypasses. DWR started using the new secondary channel in the early 1990's (Morinaka 2011).

Some of the fish in the secondary channel will be lost through predation and passing through the secondary louvers. The surviving fish in the secondary channel will then enter the secondary bypasses that lead to fish holding tanks (Figure 29). There are a total of 7 holding tanks, with 4 located in the old building and 3 located in the new building.

All salmonids were only measured during the length counts (normally at 0100 and 1300 hours) prior to December 1992 for salmon and prior to February 1993 for steelhead. After those periods, both salmon and steelhead were measured at every routine fish count. Prior to July

1992, all fish were only identified to species twice a day (0100 and 1300 counts) and the other fish counts were only used to enumerate total fish collected. Therefore, if a salmon or steelhead was not collected at 0100 or 1300 of a particular day, it was not salvaged that day (Personal Communication, Jerry Morinaka, June 24, 2013).

The length of time fish are held in the holding tanks at the SFPF varies according to species of fish, numbers of fish, size of fish, and water temperature, but the maximum holding period does not exceeds 24 hours. Fish are trucked and returned to the Delta at two release sites located on Sherman Island, one on the San Joaquin River and the other on the Sacramento River. Both sites are considered to be outside the immediate influence of the SWP and CVP pumps.

The number of fish lost in the entire process is defined as the number of fish entering the system (passing radial gates at CCF) minus the number of fish salvaged and released at downstream sites. The loss of juveniles is calculated from the juvenile salvage data. The number of fish lost through the SFPF system (including CCF), Ψ_S, is given by

$$\Psi_S = N_4\left(\frac{1}{S_{CCF}S_{PP}E_{PL}S_{SP}E_{SL}} - S_{CHTR}\right) \qquad \text{Equation 1}$$

3.4.1.2 Additional Fish Loss from Facility Maintenance or Predator Removal at the SFPF

There may be additional fish losses when louver cleaning or predator removal operations occur. At the SFPF, the primary louvers are scheduled to be cleaned once a week but may be cleaned more frequently when there are higher debris loads on the louvers. A gantry crane moves horizontally and vertically across the primary channel, and slowly lifts each louver panel one at a time for cleaning. As each panel is lifted, high pressure water jets are used to wash off debris from the louver. The DWR worker operating the gantry crane also uses a scraper to remove freshwater sponges from the louver panel as it is being raised. The wing gates upstream of the primary louvers are closed during the primary louver cleaning process so there is no additional fish lost during the cleaning activities due to fish entering the bays from upstream. This action, however, would allow large predators to enter the primary channel from the downstream side of the louvers when they are raised for cleaning.

To clean the secondary louvers (old secondary channel), and secondary perforated plates (new secondary channel) at the SFPF, the secondary channel is drained to a level of about 15 to 20 cm by closing the primary bypass valves and removing water from the channel using the return water pumps. After draining a secondary channel, debris is removed from the louver panels using a fire hose from above. The wing gates are not closed during the secondary louver cleaning process. Fish may either remain in front of the primary louvers or pass through them toward the export pumps. The secondary louvers are cleaned whenever a predator removal action is conducted or more frequently if there is a buildup of debris.

Predator removal operations at the SFPF are performed once a week (Tuesday) to remove predators in the secondary channel and use the same method to dewater the secondary channels as does the cleaning process. Prior to 2000, workers climbed down into the secondary channels, netted all fish remaining in the channel, and removed the fish from the channel. Starting in the early 2000's, workers did not enter the secondary channel to remove fish because the secondary channels were considered a confined space and special training and equipment was required for worker safety to enter them. Instead, surging water from the bypass pipes is used to flush fish from the drained secondary channel into a receiving holding tank. All fish are counted in the predator removal, but only predatory fish ≥ 150 mm FL are measured.

The fish loss through facility maintenance or predator removal, ψ_M, may be calculated as:

$$\Psi_M = \rho\Psi_S \quad \text{Equation 2}$$

where ρ is the additional loss coefficient.

If it takes 60 minutes to complete one cycle of predator removal, the additional fish loss from the predator removal operation (secondary louver cleaning) would be 0.6% of the system fish loss, assuming that all fish in front of the primary louver would be lost during the process (Table 28).

Table 28. Summary of louver cleaning or predator removal operations at the SFPF

	Primary Louver Cleaning	Secondary Louver Cleaning	Predator Removal in Secondary Channel
Frequency	Once a week or more	Once a week or more	Once a week, Tue.
Duration (minutes)	~120	~60	~60
Operation	Wing gates are closed and no fish would encounter the primary louver.	Concurs with the predator removal operation in the secondary channel.	Wing gates are open but primary bypasses are closed. Encountered fish stay in the primary channel and may go through the louver and get lost.
Additional Fish Loss	Yes 1.2%	Yes	Yes 0.6%

Therefore, the total fish loss at the SFPF, Ψ_T, is

$$\Psi_T = \Psi_S + \Psi_M \approx \Psi_S$$
$$= N_4\left(\frac{1}{S_{CCF}S_{PP}E_{PL}S_{SP}E_{SL}} - S_{CHTR}\right) \quad \text{Equation 3}$$

3.4.1.3 Studies for Estimating Chinook Salmon Loss at the SFPF

Gingras (1997) summarized eight studies conducted from 1976 through 1993 for juvenile Chinook salmon. Two groups of juvenile fish were released – one at the radial gates of CCF and the other at the trash boom of the SFPF. Fish were then recovered in the holding tanks from both release groups. First, the facility survival rates (S_F) were calculated from the number of fish recovered from the trash boom release group. Based on the experimental design of and data analysis for the studies,

$$S_F = S_{PP}E_{PL}S_{SP}E_{SL} \quad \text{Equation 4}$$

The facility survival rates were then used to calculate the CCF survival rates (S_{CCF}) based on the number of fish recovered from the radial gate release group.

Equation 3 then becomes

$$\Psi_T = N_4\left(\frac{1}{S_{CCF}S_F} - S_{CHTR}\right) = N_4\left(\frac{1}{S_S} - S_{CHTR}\right) \quad \text{Equation 5}$$

where $S_S = S_{CCF}S_F$, the entire system survival rate.

Summarized in Table 29 are the CCF and facility survival rates based on 6 studies for Chinook salmon juveniles at the SFPF (Gingras 1997). The results from the 1976 and 1978 studies were not included as the 1976 study did not have fish release at the trash boom and therefore the facility survival rate was not available. Although the 1978 study did have fish released at the trash boom, no facility survival rate for 1978 was found in the Gingras' report. In order to calculate the CCF survival rate, both the 1976 and 1978 studies used "published" louver efficiencies, which may not have incorporated predation and other losses through the facility.

Note that both the CCF and facility survival rates may be at the high end because of the large number of fish released at both radial gates and trash boom that would lead to relatively low predation rates, compared to the average number of juveniles that normally may occur at CCF or the facility.

Table 29. Summary of CCF and facility survival rates for Chinook salmon juveniles at the SFPF

Study Year	Number of fish released at radial gates	Number of fish released at trash boom	S_F Survival from trash boom to holding tank	S_{CCF} Survival from radial gates to trash boom	S_S Survival through entire system
April 1984	13,493	5,853	0.668	0.367	0.245
April 1985	11,606	5,915	0.358	0.255	0.091
June 1992	21,894	3,199	0.200	0.013	0.003
December 1992	10,729	1,782	0.675	0.232	0.156
April 1993	10,332	2,518	0.253	0.046	0.012
November 1993	10,015	1,170	0.747	0.006	0.004
Mean	13,012	3,406	0.483	0.153	0.085
SD	4,527	1,293	0.241	0.152	0.099
SE of the Mean	1,848	528	0.098	0.062	0.041

3.4.1.4 Studies for Estimating Steelhead Loss at the SFPF

Steelhead PIT tag studies were conducted in 2007 to quantify the CCF survival rate (from the radial gates to the trash rack) and the facility survival rate (from the trash rack to salvage release sites) (Clark *et al.* 2009). The studies used nearly 1,200 juvenile steelhead obtained from the Mokelumne River Fish Hatchery. The CCF survival rate was quantified using 922 PIT tagged steelhead released immediately upstream of the radial gates. The facility survival rate was quantified using PIT tagged steelhead released downstream of the trash rack into the SFPF primary louver bays. Surviving PIT tagged steelhead were detected post salvage by antennae installed at the SFPF salvage release sites on the discharge pipes. All steelhead detected by the PIT tag antenna were assumed to be in live steelhead and not within predators.

The CCF survival rate was 0.18 and was calculated from recoveries of the PIT tagged steelhead released immediately upstream of the radial gates prior to entry into the forebay. This survival rate is similar to the CCF survival rate for Chinook salmon (0.15). Because some released steelhead were able to emigrate from CCF and move into the Old River, the survival rate became 0.22 after correction with the estimated percent emigration (i.e., participation). This also assumes that the steelhead detected in Old River were not in predators, but represented intact steelhead that did not participate in the study. The facility survival rate was found to be 0.74, with a participation adjusted rate being 0.82. This facility survival rate is higher than that for Chinook salmon (0.48). The combined CCF and facility survival rate (i.e., system survival rate) and the adjusted system survival rate were 0.13 and 0.18, respectively (Table 30). This system survival rate for steelhead is double the survival rate for Chinook salmon.

Table 30. Summary of CCF and facility survival rates for steelhead juveniles at the SFPF

Methodology	S_{CCF} Survival from radial gates to trash Rack	S_F Survival from trash rack to holding tank	S_S Survival from radial gates to holding tank
Apparent Study Result	0.18	0.74	0.13
Participation Adjusted Result	0.22	0.82	0.18

We also summarized the survival data at the SFPF for steelhead juveniles that were surgically implanted with acoustic tags prior to release at the radial gates from 2005 to 2007 (Clark *et al.* 2009). Acoustic tagged juveniles were also released at the trash boom in 2007.The survival rate was obtained from the number of juveniles detected at the trash boom and the number of juveniles detected in the holding tank (Table 31), with the assumption that these detections represent live steelhead and not tags within predators. These data also have been adjusted for study participation by using the number of fish that had moved into the system but subsequently moved out of the system. The mean CCF survival rate was 0.26, which is similar to that from the PIT tag study. The mean facility survival rate was 0.367, which is less than half the survival rate from the PIT tag study. The system survival rate was 0.095, which is similar to the system survival rate of Chinook salmon. Because the number of steelhead released was low, the estimated steelhead survival rates from these studies could bias to the low end.

Table 31. Survival rates for steelhead juveniles from acoustic tag studies conducted at the SFPF

Study Year	Number of fish entering from radial gates to the system	Number of fish passing trash boom	Number of fish detected in holding tank	S_{CCF} Survival from radial gates to trash boom	S_F Survival from trash boom to holding tank	S_S Survival from radial gates to holding tank
2005	26	10	4	0.385	0.400	0.154
2006	23	10	2	0.435	0.200	0.087

2007	44	4	2	0.091	0.500	0.045
2007①		13	12	ND	0.923	ND
Mean	26.5	9.3	5.0	0.260	0.367②	0.095
SD	12.9	3.8	4.8	0.186	0.153	0.055

ND = No Data. SD = Standard deviation
①Acoustic tagged fish were released at the trash boom.
②The survival rate (0.923) from the 2007 trash boom release group was excluded.

3.4.1.5 Current Method for Quantifying Fish Loss at the SFPF

Currently, the following equation is used to calculate the fish loss:

$$\Psi'_T = N_4\left(\frac{1}{S'_{CCF}E_L} - S_{CHTR}\right) = N_4\left(\frac{1}{S'_S} - S_{CHTR}\right) \qquad \text{Equation 6}$$

where $E_L = E_{PL}E_{SL}$ and is the combined primary and secondary louver efficiency.

There are a few problems using Equation 6 to quantify the fish loss.

(1) This equation uses 0.25 for the Clifton Court Forebay survival rate (S_{CCF}), which was the average survival rate from three studies: 0.12 in 1978, 0.37 in 1984, and 0.25 in 1985 (Brown *et al.* 1995, Gingras 1997). There were four more studies conducted for Chinook salmon after 1985 and the survival rates from those additional studies were lower than 0.25. Use of 0.25 will underestimate the loss.

(2) This equation assumes that both primary and secondary channel predation survival rates (S_{PP} and S_{SP}) are 1, *i.e.*, no predation occurs in the primary and secondary channels. This will underestimate the loss as there is predation in the primary and secondary channels.

(3) The combined louver efficiency (E_L) is the "real" louver efficiency as it was obtained from the number of fish recovered from behind the louvers and the number of fish recovered in the holding tank. E_L is calculated using the following equations:

    E_L = 0.630+0.0494*Primary Channel Velocity (for fish <100 mm) or
    E_L = 0.568+0.0579* Primary Channel Velocity (for fish >100 mm).

    We searched for all possible documents or publications that may help our understanding of how these two regression equations were derived. Unfortunately, as described below, what we found does not provide support for these two equations. As Jahn pointed out, how the values of the regression coefficients in the equations were derived remains a mystery (Jahn 2011).

    These two equations were first reported in a document entitled "*Agreement Between the Department of Water Resources and the Department of Fish and Game to Offset Direct Fish Losses in Relation to the Harvey O. Banks Delta Pumping Plant,*" which was signed by the directors of the two departments on December 30, 1986. Appendix A of the Agreement stated:

> "Regression equations predicting screening [louver] efficiencies for different length intervals of fish, based on primary water velocity (fps), were developed from data collected during a field testing program at the fish facility in 1970-71."

Details about the 1970 and 1971 studies and relevant data can be found in the Memorandum Report (Department of Water Resources and Department of Fish and Game 1973) and a workshop publication by Skinner (1974). Brown *et al*. indicated that these two equations were developed by the Department of Fish and Game and that the calculated efficiencies were typically in the range of 0.7-0.8 (Brown *et al.* 1995).

The louver efficiency study results for Chinook salmon were presented in Tables 1 to 7 in the Memorandum Report. However, the report provided no data for the 100-125 mm fish group from the 1971 study. For this analysis, we divided the data into two groups: 50-100 mm and 100-125 mm fish sizes, and reorganized and presented them in Table 32.The last two columns in Table 32 represent combined louver efficiencies from the 1970 and 1971 study results. The combined louver efficiency for 50-100 mm *appeared* to increase with approach velocity, with $R^2 = 0.67$. However, the correlation is not statistically significant ($p = 0.181$) (Figure 93). There was no correlation between the combined louver efficiency and velocity for the 100-125 mm group ($p = 0.361$). The mean combined louver efficiency for all fish sizes was 0.75.

Table 32. Louver efficiency results from the studies conducted in 1970 and 1971 at the SFPF

Approach Velocity		Primary Louver						Secondary Louver						Combined Efficiency	
		1970		1971		Average		1970		1971		Average			
Range	Mean	50-100	100-125	50-100	100-125	50-100	100-125	50-100	100-125	50-100	100-125	50-100	100-125	50-100	100-125
1.5-2.0	1.75	0.77	0.70	0.93	ND	0.85	0.70	0.9	0.97	0.96	ND	0.93	0.97	0.791	0.679
2.0-2.5	2.25	0.80	0.65	0.92	ND	0.86	0.65	0.9	1.00	ND	ND	0.90	1.00	0.774	0.650
2.5-3.0	2.75	0.83	0.69	0.90	ND	0.87	0.69	0.92	0.92	0.94	ND	0.93	0.92	0.804	0.635
3.0-3.5	3.25	0.84	0.84	0.90	ND	0.87	0.84	0.96	1.00	ND	ND	0.96	1.00	0.835	0.840
Mean		0.81	0.72	0.91	ND	0.86	0.72	0.92	0.97	0.95	ND	0.93	0.97	0.801	0.701

ND = No Data

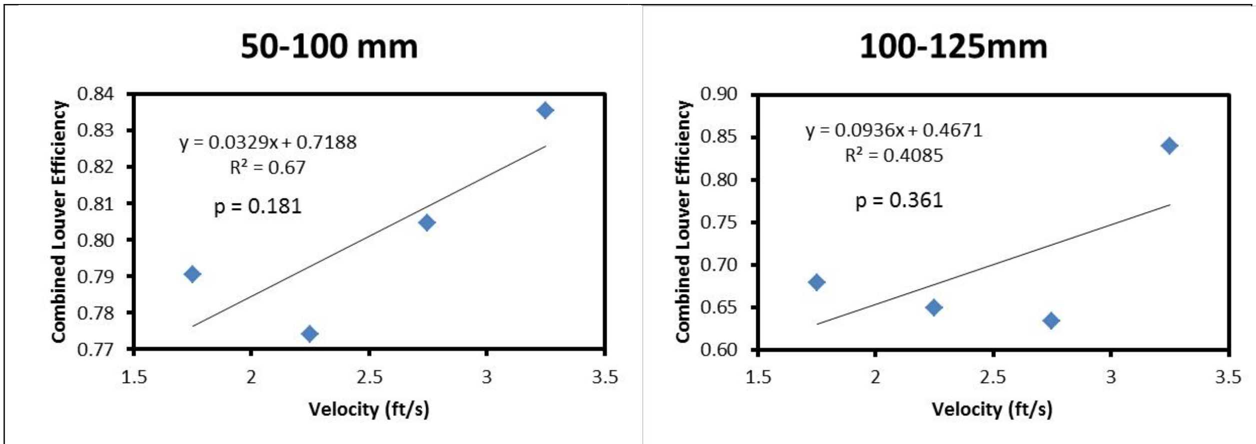


Figure 93. Relationship between combined louver efficiency and approach velocity based on the 1970 and 1971 studies

The primary louver and secondary louver efficiencies as a function of fish size are presented in Table 33. As fish size increase, the primary louver efficiency showed a V-shape pattern, while the secondary louver efficiency increased gradually. However, the combined louver efficiencies showed no difference between the two groups of fish size: the group with fish sizes < 100 mm and the other group with fish sizes > 100 mm (Figure 94).

Table 33. Primary and secondary louver efficiencies for Chinook salmon juveniles at the SFPF*

FL (mm)	Primary Louver	Secondary Louver	Combined
50.1-75	0.83	0.87	0.72
75.1-100	0.79	0.92	0.73
100.1-125	0.67	0.94	0.63
>125.1	0.86	0.97	0.83
Mean	0.79	0.93	0.73

*These data were derived from the 1970 study and no such data available from the 1971 study.

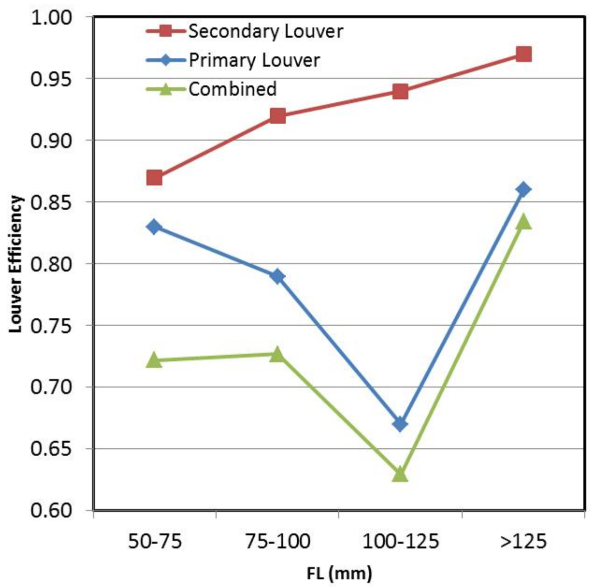


Figure 94. Primary and secondary louver efficiencies for Chinook salmon juveniles at the SFPF

(4) There were no data available for steelhead juveniles until 2009 (Clark *et al.* 2009).

3.4.1.6 Comparison of New Method with Current Method

Assuming S_{CHTR} =1, Equations 5 and 6 become:

$$\Psi_T = N_4\left(\frac{1}{S_S} - 1\right) = N_4K \qquad \text{Equation 7}$$

where K = $\left(\frac{1}{S_S} - 1\right)$ and is a coefficient for calculating the total fish loss given fish salvage data.

The K values are presented in Table 34 for Chinook salmon and Table 35 for steelhead.

The Chinook salmon loss based on the current method is 35% of the loss estimated from the new method. The steelhead loss from the current method is similar to the loss from the PIT method but only half the loss from the acoustic tag method.

Table 34. Comparison of the new method with the current method for quantifying the loss of Chinook salmon juveniles at the SFPF

Method	S_{CCF} Survival from radial gates to trash boom	S_F Survival from trash boom to holding tank	S_S Survival from radial gates to holding tank	K
New Method ①	0.153	0.483	0.074	12.53
Current Method	0.25 ②	0.75 ③	0.188	4.33

① Based on 6 studies from 1984-1993.
② Based on 3 studies in 1978, 1984, and1985.
③ Combined louver efficiency with no predation included.

Table 35. Comparison of the new method with the current method for quantifying the loss of steelhead juveniles at the SFPF

Method		S_{CCF}	S_F	S_S	K
New Method ①	PIT	0.22	0.82	0.180	4.54
	Acoustic Tag	0.260	0.367	0.095	9.48
Current Method ②		0.25	0.75	0.188	4.33

① Clark *et al*. 2009
② Assumed to be the same as Chinook

3.4.2 Quantifying Juvenile Fish Loss at the TFCF

3.4.2.1 System Fish Loss at the TFCF

After passing the trash boom at the TFCF, fish continue their journey within the primary channel, which is defined as the channel between the trash boom and the primary bypasses. Fish will encounter the primary louver where some of the fish may pass through the louver and be lost to the system. The fish that have survived within the primary channel and primary louver and have entered into one of the four bypass inlets will go to the secondary channel, which is defined as the channel between the outlet of the primary bypasses, and the secondary louvers where additional fish may be lost to the system by passing through the secondary louver array slats. The fish that have successfully survived the secondary channel and secondary louver and have passes into the secondary bypass are collected (salvaged) in the holding tanks. Finally, the salvaged fish are trucked to a release site located several miles downstream of the TFCF in the western Delta for release. Some of the fish will die during the handling and trucking operations (Figure 95).

The number of fish lost in the entire process is defined as the number of fish entering the system (passing the trash rack at the TFCF) minus the number of fish salvaged and released at the downstream site. The loss of juveniles is calculated from the juvenile salvage data. The system fish loss at the TFCF, Ψ_S, is given by

$$\Psi_S = N_4\left(\frac{1}{S_{PP}E_{PL}S_{SP}E_{SL}} - S_{CHTR}\right) \qquad \text{Equation 8}$$

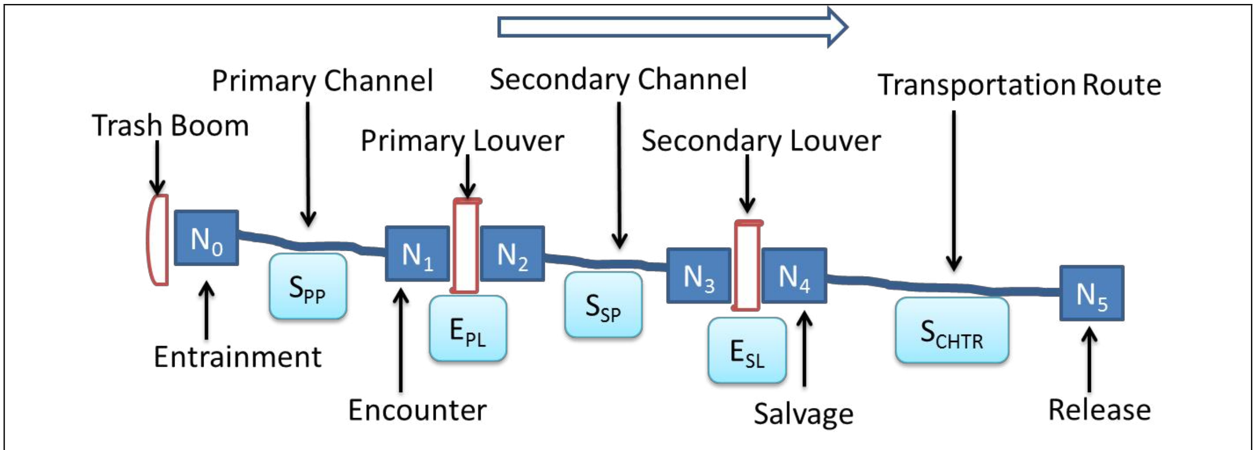


Figure 95. Diagram of fish movement at the TFCF

N_0 = Number of fish entrained, i.e., passing through the trash boom
N_1 = Number of fish encountering the primary louver
N_2 = Number of fish successfully routed to the secondary channel, i.e., not passing through the primary louver
N_3 = Number of fish encountering the secondary louver
N_4 = Number of fish successfully routed to the holding tank, i.e., salvaged
N_5 = Number of fish released downstream after transportation
S_{PP} = Primary channel predation (pre-screen) survival rate
E_{PL} = Primary louver efficiency
S_{SP} = Secondary channel predation survival rate
E_{SL} = Secondary louver efficiency
S_{CHTR} = Collection, handling, transportation, and release survival rate

3.4.2.2 Additional Fish Losses from Facility Maintenance or Predator Removal at the TFCF

There are additional fish losses when louver cleaning or predator removal operations occur. The cleaning operations at the TFCF are conducted once per day for both primary and secondary louvers during the salmonid season. The primary louvers are composed of 36 panels, 8 ft wide and 23 ft tall each. When the primary louvers are cleaned, one louver panel at a time is raised into the air, creating a gap (8 ft by 23 ft) with no fish guidance, and the bypass for that section of louvers is closed. It takes on average 129.7 minutes to complete the cleaning cycle of 36 panels of primary louvers (Jahn 2011) (Table 36).

When the secondary louvers are cleaned, all four bypasses are closed. Fish may either remain in front of the louvers or pass through them toward the export pumps. It takes on average 49.3 minutes to complete the cleaning cycle of the secondary louvers (Jahn 2011) (Table 36).

There were no regular predator removal operations at the TFCF, unless for special studies.

Table 36. Summary of louver cleaning or predator removal operations at the TFCF

	Primary Louver Cleaning	Secondary Louver Cleaning	Predator Removal in Secondary Channel
Frequency	Once per day	Once per day	
Duration (minutes)	129.7	49.3	
Operation	One primary bypass is closed and one panel of louver is lifted, creating a gap with no louver.	All 4 primary bypasses are closed. Fish in front of the louvers will pass through them.	Not performed unless for special studies
Additional Fish Loss	Can be estimated based on frequency and duration.	Can be estimated based on frequency and duration.	

The total time for daily louver cleaning is 179 minutes, i.e., about 3 hours. It is reasonable to assume that all fish, which have entered the primary channel in front of the primary louvers, would be lost during the louver cleaning. Karp *et al.* observed in the 1993 louver efficiency studies that the primary louver efficiency (and thus the entire system efficiency) may dramatically drop to 0% during times when the primary louvers are lifted for cleaning (Karp *et al.* 1995). The additional fish loss resulting from the louver cleaning would be 14.3% of the system fish loss calculated from Equation 8. The total fish loss is the sum of these two values. Therefore, the total fish loss at the TFCF, Ψ_T, is given by

$$\Psi_T = \Psi_S + \Psi_M = N_4\left(\frac{1}{S_{PP}E_{PL}S_{SP}E_{SL}} - S_{CHTR}\right)(1+\rho) \qquad \text{Equation 9}$$

3.4.2.3 Studies for Estimating Chinook Salmon Loss at the TFCF

Karp *et al.* conducted juvenile salmon survival studies through the TFCF system using hatchery juvenile Chinook salmon in 1993 (Karp *et al.* 1995). In each of the six studies, juvenile salmon were released at 6 locations, including those at the trash boom, trash rack, and secondary channel (near the head of the channel). The number of fish released at the trash boom, trash rack, secondary channel was about 250 (about 200 fish on April 15, 1993). This release level may represent a relatively high fish density that would occur in the channel, implying a possibly low predation rate through the system. This is contrast to the lower number of released fish from the most recent studies where 100 fish were released at a time (Bridges *et al.* 2013).

We define the primary channel survival rate (S_{PC}) as the rate from the trash boom to the head of the secondary channel, which is the product of the primary channel predation survival rate (S_{PP}) and the primary louver efficiency (E_{PL}):

$$S_{PC} = S_{PP}E_{PL} \qquad \text{Equation 10}$$

We define the secondary channel survival rate (S_{SC}) as the ratio of the number of fish recovered in the holding tank to the number of fish released at the head of the secondary channel, which is the product of the secondary channel predation survival rate (S_{SP}) and the secondary louver efficiency (E_{SL}):

$$S_{SC} = S_{SP}E_{SL} \quad \text{Equation 11}$$

We define the system survival rate (S_S) as the ratio of the number of fish recovered in the holding tank to the number of fish released at the trash boom, which is the product of the primary channel survival rate (S_{PC}) and the secondary channel survival rate (S_{SC}):

$$S_S = S_{PC}S_{SC} \quad \text{Equation 12}$$

Using Equations 10-12, Equation 9 becomes:

$$\Psi_T = N_4\left(\frac{1}{S_{PC}S_{SC}} - S_{CHTR}\right)(1+\rho) \quad \text{Equation 13}$$

Karp *et al.* reported physical conditions at the time of fish release and during the time period of fish recovery (3-5 hours). The physical parameters include release time (day or night), tide stage, water temperature, and velocities in the primary and secondary channels (Karp *et al.* 1995) (Table 37).

Table 37. Physical conditions for each of the six survival studies at the TFCF in 1993

Date of Release	Flow Velocity (m/s)		Tide Stage	Water Temperature (°C)	Time of release	Mean Size (mm)
	Primary Channel	Secondary Channel				
14-Apr-93	0.70 (high)	0.64	Flood	14	13:30	74.2
15-Apr-93	0.79 (high)	0.73	Ebb	17	10:00	
12-May-93	0.09 (low)	0.70	Flood	17	12:00	94.0
13-May-93	0.09 (low)	0.70	Flood	17	12:00	
25-May-93	0.58 (median)	0.67	Flood	19	21:10	97.4
26-May-93	0.55 (median)	0.67	Flood	19	21:10	

As the flow velocity in the primary channel showed substantial impacts to survival rates, we divided the six datasets into two groups: low velocity (0.09 m/s) (*i.e.*, the May 12 and 13 studies), and high velocity (0.55-0.79 m/s) (*i.e.*, the other four studies). Summarized in Table 38 are juvenile Chinook salmon survival rates in primary and secondary channels and the entire system based on the 1993 studies (Karp *et al.* 1995). All test fish collected at holding tanks were counted.

Table 38. Summary of survival rates for juvenile Chinook salmon at the TFCF (Karp *et al.* 1995)

Section	Low Velocity	Median Velocity	High Velocity
Trash Boom to Trash Rack (prefacility)	0.303	1.089	0.937
Trash Rack to Secondary Channel (Primary Channel and Louver)	0.209	0.761	0.663
Secondary Channel to Holding Tank (Secondary Louver)	0.956	0.906	0.865

Holding Tank to Count (Tank survival)	0.990	1.000	0.965
Trash Boom to Holding Tank (System Survival)	0.058	0.749	0.490

Bridges *et al.* (2013) reported on the most recent juvenile Chinook salmon survival studies at the TFCF, which were conducted in 2009. Dye marked juveniles were released before and after striped bass were removed in both primary and secondary channels. The studies consisted of six pre- or post-removal trials (releases), each of which had 100 fish released at the trash rack and 40 fish released at the head of secondary channel. Survived fish were collected in a sieve net behind the secondary louver and in a holding tank. The mean flow velocity in the primary channel was 0.18 m/s for the pre-removal trials and 0.20 m/s for the post-removal trials.
These study results (Table 39) show that the predation rate (1-S_{PP}) from the trash rack to the primary louver in the primary channel was 0.51, much higher than the previously presumed 0.15. The predation rate in the secondary channel was low (<0.03). The secondary louver efficiency was consistent among trials, with a mean of 0.95, which is similar to the result (0.96) from the 1958 study by Bates *et al*. (1960). The overall system survival rate without predator removal was 0.277, which is in the middle of the rates between the low and high flow velocities (Table 38) in the study by Karp *et al*. (1995).

After predator removal, the system survival rate for Chinook salmon increased from 0.277 to 0.558 (Table 39). During predator removal activities, 52 striped bass were removed from the primary channel on April 22, 2009, with a mean folk length of 620 mm. Nine striped bass were removed from the secondary channel, with a mean folk length of 428-620 mm. The combined total mass of the 61 striped bass was approximately 176 kg (388 lbs), and the mean weight was 2.89 kg (6.36 lbs) per fish (Bridges *et al.* 2013).

The striped bass collected in the primary channel, secondary channel, and holding tanks showed different sizes. Striped bass collected in the primary channel are the largest, followed by those in the secondary channel and holding tank. Larger fish have the ability to maintain their position, while smaller fish get pushed downstream with flow and end up in the holding tanks.

Table 39. Chinook salmon survival study results at the TFCF in 2009

Pre-predator Removal Replicates on 4/21/2009							
	A	B	C	D	E	F	G
			A *B			D * E	C * F
Trials	S_{PP} Primary Channel Predation Survival Rate	E_{PL} Primary Louver Efficiency	S_{PC} Primary Channel Survival	S_{SP} Secondary Channel Predation Survival Rate	E_{SL} Secondary Louver Efficiency	S_{SC} Secondary Channel Survival	S_S System Survival
1	0.711	0.611	0.434	1.000	0.921	0.921	0.400
2	0.396	0.611	0.242	0.975	0.974	0.950	0.230
3	0.336	0.611	0.205	0.975	1.000	0.975	0.200
4	0.551	0.611	0.337	1.025	0.927	0.950	0.320

5	0.375	0.611	0.229	0.900	0.971	0.874	0.200
6	0.569	0.611	0.348	0.975	0.914	0.891	0.310
Mean	0.490	0.611	0.299	0.975	0.951	0.927	0.277
Post-predator Removal Replicates on 4/23/2009							
1	1.000	0.540	0.540	1.025	0.976	1.000	0.540
2	1.000	0.721	0.721	0.900	0.879	0.791	0.570
3	1.000	0.654	0.654	0.975	0.973	0.949	0.620
4	1.000	0.493	0.493	1.075	1.000	1.075	0.530
5	1.000	0.579	0.579	0.975	0.974	0.950	0.550
6	1.000	0.682	0.682	0.950	0.833	0.791	0.540
Mean	1.000	0.611	0.611	0.983	0.939	0.926	0.558

S_{SP} = Secondary louver participation (SLP) of Secondary Release after Overnight Collection (Table 9 in Bridges *et al*. 2013)
E_{SL} = Secondary louver efficiency (SLE) from Secondary Release (Table 9 in Bridges *et al*. 2013)
S_S = Whole facility efficiency (WFE) after Overnight Collection (Table 9 in Bridges *et al*. 2013)
$S_{SC} = S_{SP} \times E_{SL}$
Pre-removal E_{PL} = Mean post-removal E_{PL} that was calculated from post-removal S_{SP}, E_{SL}, and S_S, assuming the post-removal S_{PP} = 1 (*i.e.*, no predation in the primary channel after predator removal)
Pre-removal S_{PP} was calculated from pre-removal E_{PL}, S_{SP}, E_{SL}, and S_S.
$S_{PC} = S_{PP} \times E_{PL}$
Red numbers indicate efficiencies greater than 100%

3.4.2.4 Studies for Estimating Steelhead Loss at the TFCF

There were few steelhead studies at the TFCF. Bowen *et al*. (2004) reported that the secondary louver efficiency for steelhead juveniles was 1.0 although the total number of steelhead juveniles they observed was 22 in the study.

Assuming that steelhead juvenile survival at the TFCF is similar to that at the SFPF, we may apply the SFPF facility survival rates from the PIT (0.82) or acoustic tag (0.367) studies to the TFCF.

3.4.2.5 Current Method for Quantifying Fish Loss at the TFCF

Currently, the following equation is used to calculate the fish loss at the TFCF:

$$\Psi'_T = N_4\left(\frac{1}{S'_{PP}E_L} - S_{CHTR}\right) \qquad \text{Equation 14}$$

where $E_L = E_{PL}E_{SL}$ and is the combined primary and secondary louver efficiency, and S'_{pp} = primary channel predation survival to the primary louvers.

There are a few problems regarding this equation.

(1) The primary channel predation survival (S'_{PP}) is assumed to be 0.85 for Chinook salmon, which is an agreed-upon value provided in an anonymous document[3]. There was no information available about how this value was derived. This assumption will lead to underestimation of fish loss. As shown in Table 39, the primary channel predation survival rate was 0.49.

(2) This equation assumes that the secondary channel predation survival (S_{SP}) is 1, *i.e.*, no predation occurs in the secondary channel. This could underestimate the loss as there may be predation in the secondary channel related to the presence of large predators.

(3) The issues related to the combined louver efficiency (E_L) have been discussed in the SFPF section.

(4) This equation does not include the loss from facility maintenance (*e.g.*, louver cleaning).

3.4.2.6 Comparison of the New Method with the Current Method

Assuming S_{CHTR} =1, Equation 13 becomes:

$$\Psi_T = N_4\left(\frac{1}{S_S} - 1\right)(1+\rho) = N_4 K \qquad \text{Equation 15}$$

The K values are presented in Table 40 for Chinook salmon and Table 41 for steelhead. At the high primary channel velocity, the Chinook salmon loss based on the current method is 38% of the loss estimated from the new method. While at the low primary channel velocity, it is only 3% of the loss estimated from the new method.

Table 40. Comparison of the new method with the current method for quantifying the loss of Chinook salmon juveniles at the TFCF

Method	Primary Channel Velocity	S_S	ρ	K
New Method	Low	0.056	0.143	19.27
	Median	0.277	0.143	2.98
	High	0.432	0.143	1.50
	Mean	0.255	0.143	3.34
Current Method①		0.638	0	0.57

① Based on the presumed pre-screen loss rate of 0.15 and the combined SFPF louver efficiency of 0.75.

For steelhead, we use the system survival rates from the PIT and acoustic studies at the SFPF since there were no system survival data available at the TFCF.

[3] Chinook Salmon Loss Estimation for Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility. Available at ftp://ftp.delta.dfg.ca.gov/salvage/Salmon Loss Estimation

Table 41. Comparison of the new method with the current method for quantifying the loss of steelhead juveniles at the TFCF

Method		S_S	*p*	K
New Method	PIT	0.82	0.143	0.25
	Acoustic Tag	0.367	0.143	1.97
	Mean	0.594	0.143	0.78
Current Method①		0.638	0	0.57

① Assumed to be the same as Chinook.

3.4.3 Summary of the New Methods for Quantifying Juvenile Fish Loss

In general, when the number of juveniles in the system is low, vulnerability to predation is high, which may lead to physically lower fish counts in salvage, which then sequentially leads to a lower fish loss estimate through the equations used for calculating loss. Juvenile fish loss would be underestimated under low-number conditions. This would be particularly true at the SFPF because of the presence of Clifton Court Forebay where juvenile mortality is high.

The losses of juvenile Chinook salmon and steelhead at the SFPF and TFCF should be quantified using Equation 15 with the K values provided in Table 42. In this report, we calculated fish losses using the K values under the high fish density or primary channel velocity conditions. Note that the calculated fish losses may bias to low estimates.

Table 42. K values for quantifying the fish losses of Chinook salmon and steelhead

Facility	Fish Density or Primary Channel Velocity	Chinook	Steelhead
SFPF	Low	No Data	9.48
	High	12.53	4.54
TFCF	Low	19.27	1.97
	Median	2.98	No Data
	High	1.50	0.25

3.4.4 Juvenile Chinook Salmon and Steelhead Loss

We computed juvenile Chinook salmon and steelhead losses using those new equations developed above. Juvenile winter-run Chinook salmon loss was highest in 2002 and lowest in 1996. The loss showed sharp decreases from 1995 to 1996 and 2003 to 2004 (Figure 96). Majority of the loss occurred at the SFPF.

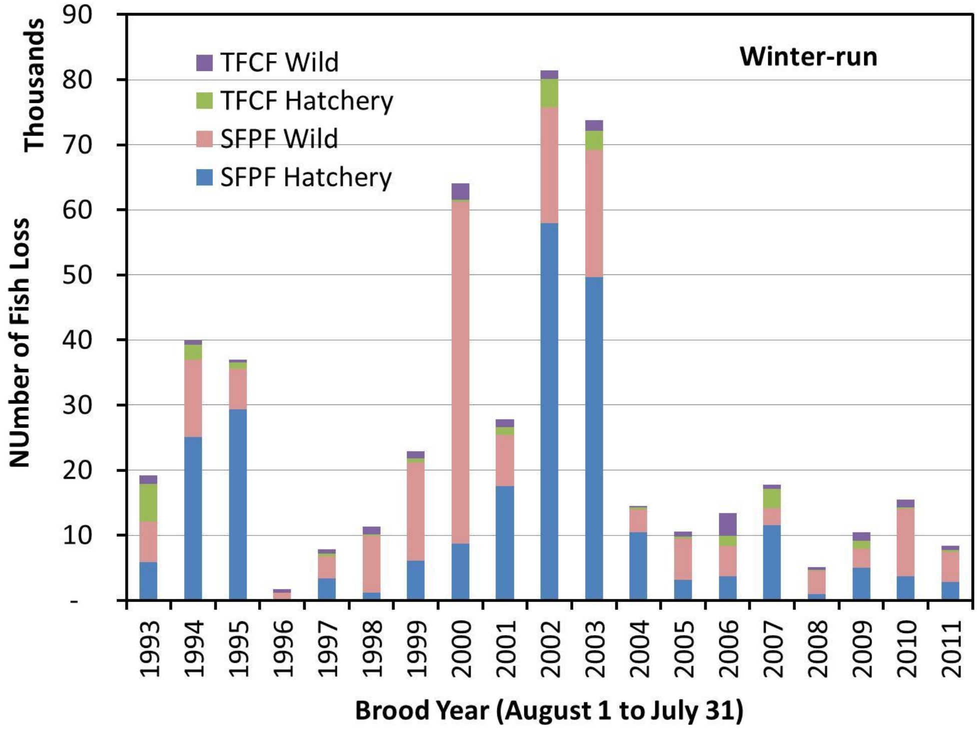


Figure 96. Juvenile winter-run loss by brood year

Juvenile spring-run Chinook salmon loss was highest in 1998 and lowest in 2011. The loss has been low since 2005 except for 2010 (Figure 97). Majority of the loss were wild fish and occurred at the SFPF.

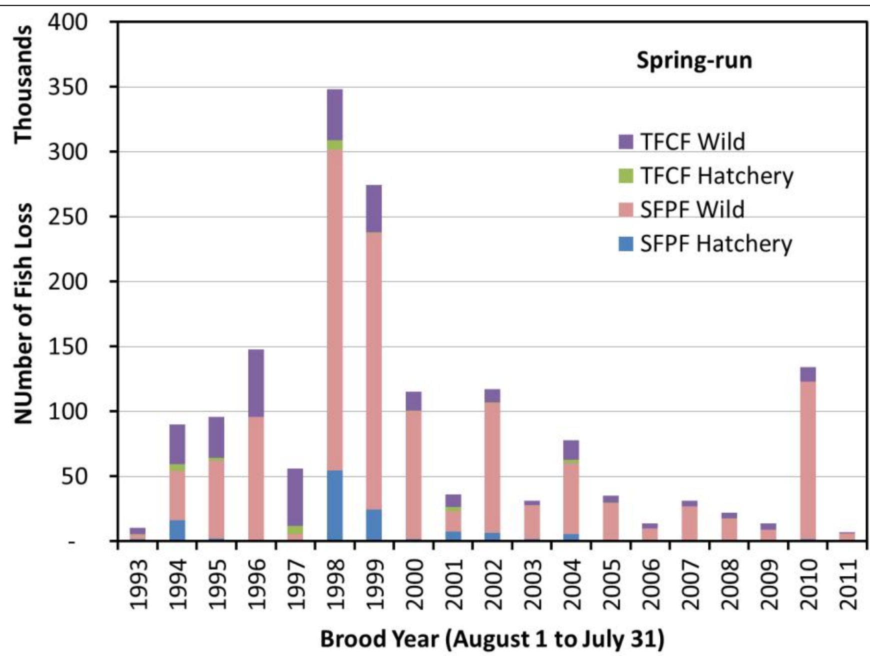


Figure 97. Juvenile spring-run loss by brood year

Juvenile fall-run Chinook salmon loss was highest in 1998 and lowest in 2011. The loss has been low since 2006 except 2010 (Figure 98). Majority of the loss occurred at the SFPF except 1997.

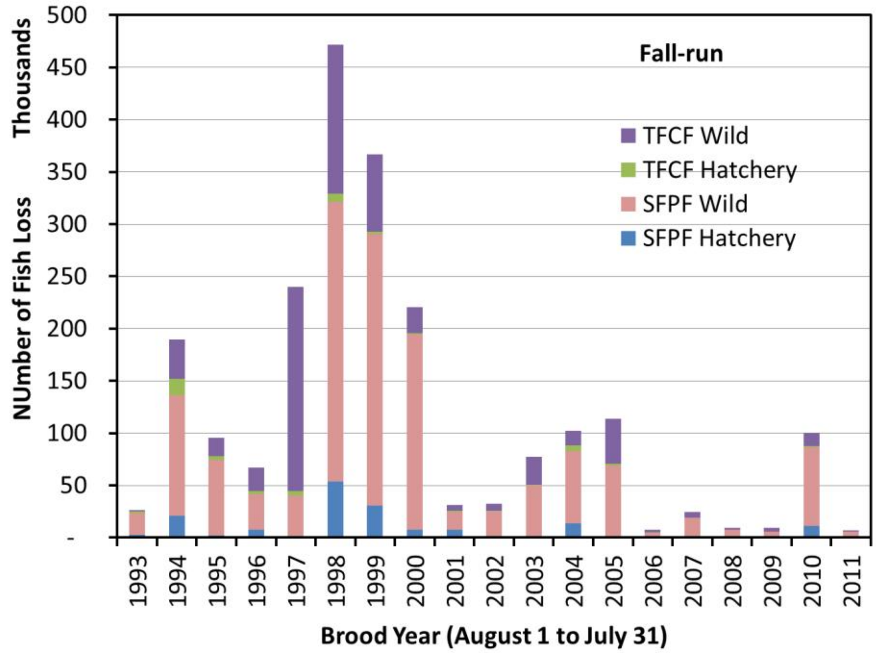


Figure 98. Juvenile fall-run loss by brood year. Some fall-run Chinook salmon juveniles counted as "wild" were hatchery fish without adipose clipped.

Juvenile late fall-run Chinook salmon loss was highest in 1994 and lowest in 2011 (no salvage was reported in 2008). The loss has been low since 1995 except 2002 and 2010 (Figure 99). Majority of the loss occurred at the SFPF.

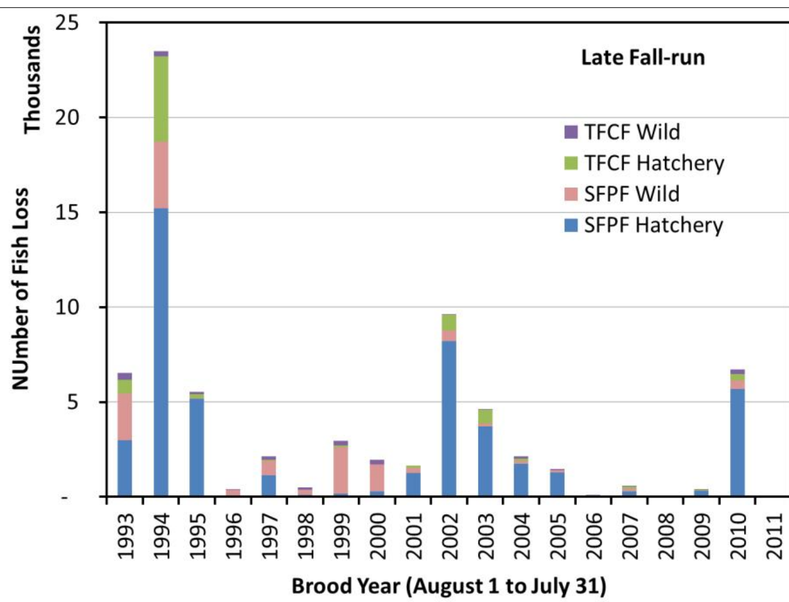


Figure 99. Juvenile late fall-run loss by brood year

Juvenile steelhead loss was highest in 2000 and lowest in 1997. The loss has decreased since 2000 (Figure 100). Majority of the loss were hatchery fish and occurred at the SFPF.

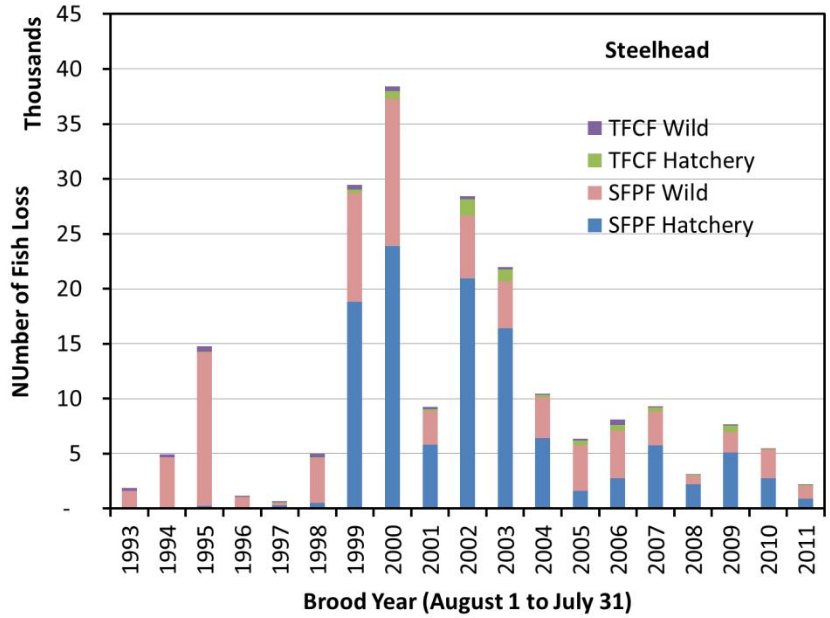


Figure 100. Juvenile steelhead loss by brood year. Note that 100% fin clipping started with brood year 1999.

Provided in Table 43 is a data summary for fish losses of juvenile Chinook salmon and steelhead at the SFPF and TFCF.

Table 43. Summary of juvenile Chinook salmon and steelhead losses at the SFPF and TFCF using the new equations in this report

Brood Year	Winter-run			Spring-run			Fall-run			Late Fall-run			Steelhead		
	Hatchery	Wild	Total	Hatchery	Wild	Total	Hatchery	Wild*	Total	Hatchery	Wild	Total	Hatchery	Wild	Total
1993	11,689	7,465	19,154	2,184	8,166	10,350	4,765	21,361	26,126	3,714	2,834	6,548	351	5,615	5,966
1994	27,364	12,613	39,977	21,550	68,319	89,869	36,400	153,444	189,845	19,699	3,791	23,490	419	14,224	14,643
1995	30,366	6,609	36,975	4,559	91,331	95,891	6,005	89,731	95,735	5,360	176	5,536	879	41,611	42,490
1996	13	1,661	1,674	885	146,653	147,538	10,763	56,189	66,952	75	342	417	13	3,731	3,744
1997	3,743	4,067	7,810	6,350	49,513	55,863	5,751	234,174	239,925	1,200	932	2,132	1,274	1,213	2,487
1998	1,254	10,026	11,279	61,749	286,609	348,358	61,109	410,462	471,571	118	371	489	1,575	13,388	14,963
1999	6,865	16,066	22,931	24,789	249,747	274,537	32,973	333,694	366,667	253	2,708	2,961	53,823	29,910	83,734
2000	9,142	54,892	64,033	1,984	113,110	115,095	8,759	211,899	220,658	301	1,650	1,951	70,301	39,422	109,724
2001	18,759	9,050	27,809	10,728	25,362	36,090	8,448	22,575	31,022	1,361	276	1,637	16,933	9,855	26,788
2002	62,311	19,060	81,371	7,139	110,210	117,350	918	31,264	32,182	9,034	600	9,634	66,784	17,186	83,971
2003	52,543	21,203	73,746	1,630	29,794	31,424	1,792	75,705	77,498	4,429	188	4,617	51,787	13,033	64,820
2004	10,772	3,777	14,550	8,651	69,007	77,658	18,759	83,320	102,079	1,873	258	2,132	18,887	11,079	29,967
2005	3,462	7,128	10,590	1,398	33,531	34,928	3,370	110,425	113,795	1,296	161	1,457	7,116	12,470	19,586
2006	5,207	8,167	13,374	111	13,700	13,811	86	7,167	7,253	74	31	104	10,998	14,602	25,600
2007	14,508	3,242	17,750	690	30,393	31,083	6	24,249	24,255	421	149	570	18,239	8,920	27,158
2008	1,127	3,964	5,091	23	22,150	22,173	-	9,304	9,304	-	-	-	6,819	2,438	9,257
2009	6,183	4,228	10,411	195	13,831	14,026	30	9,279	9,309	368	12	380	17,740	5,964	23,704
2010	3,883	11,624	15,507	1,933	132,018	133,951	12,380	87,495	99,875	6,012	691	6,703	8,032	7,403	15,435
2011	3,094	5,331	8,425	714	6,273	6,988	311	6,334	6,644	37	30	66	3,113	3,259	6,372
Mean	14,331	11,062	25,393	8,277	78,933	87,210	11,191	104,109	115,300	2,928	800	3,728	18,689	13,438	32,127
Median	6,865	7,465	15,507	1,984	49,513	55,863	5,751	75,705	77,498	1,200	276	1,951	8,032	11,079	23,704

* Some fall-run Chinook salmon juveniles counted as "wild" were hatchery fish without adipose fin clipped.

4 Juvenile Fish Flux and Abundance in the Delta

4.1 Juvenile Chinook and Steelhead Monitoring

4.1.1 Monitoring Locations and Methods

Chinook and steelhead juveniles entering the Delta are monitored at Sherwood Harbor in the Sacramento River and Mossdale in the San Joaquin River, while juveniles leaving the Delta are monitored at Chipps Island in the Delta outlet (Figure 101). USFWS and CDFW used boat trawls to catch, count, and measure Chinook and steelhead juveniles at those three locations. Monitoring data are used to estimate the flux and abundance of winter-run, spring-run, fall-run, late fall-run, and steelhead juveniles in the Delta.

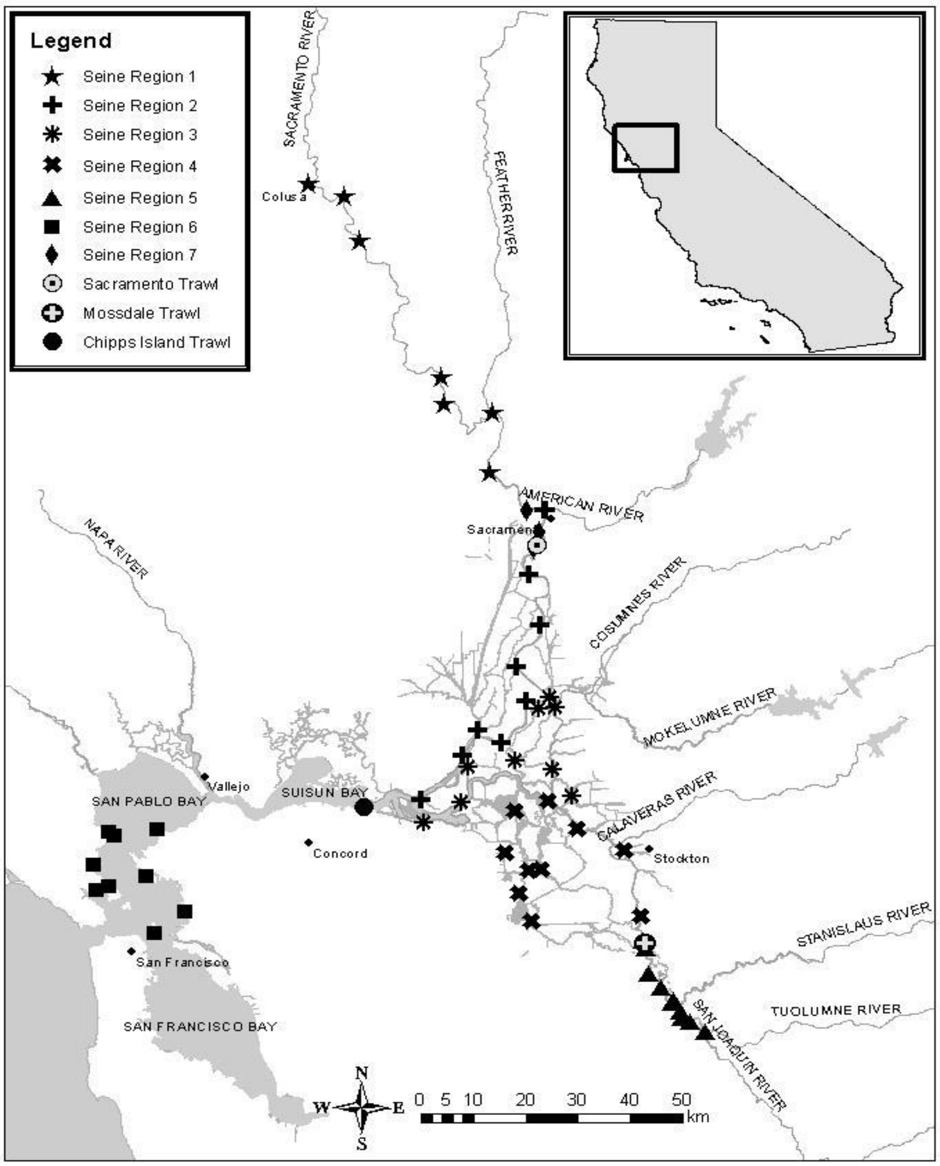


Figure 101. Juvenile fish trawl stations in the Delta. Courtesy of USFWS.

4.1.1.1 Sacramento River

A midwater trawl with the mouth opening of 8.36 m^2 (1.83 m by 4.57 m) was used in the Sacramento River at Sherwood Harbor since 1988. Because the trawl net does not open completely while under tow, the effective mouth area of the midwater trawl was estimated to be 5.08 m^2 (U.S. Fish and Wildlife Service 2007). The midwater trawl was replaced by a Kodiak trawl with the mouth opening of 13.94 m^2 (1.83 m by 7.62 m) for the months of October through March since December 1994. The effective mouth area of the Kodiak trawl was estimated to be 12.54 m^2 (U.S. Fish and Wildlife Service 2007). The midwater trawling has continued for the months of April through June.

Trawling in the Sacramento River was conducted for the months of April, May, and June between 1988 to1992, whereas the trawling has been conducted year round since 1994. The trawling has been conducted for 2 to 7 days per week since 1992 (Table 44).

In general, ten 20-minute tows are conducted per sampling day. Occasionally, inclement weather, mechanical problems, or excessive fish catches required reducing tow times or the number of tows. All tows were done in the middle of the channel facing upstream against the current within 1.5 km of the sample site (Brandes and McLain 2001).

Table 44. Trawling days per week in 2012

Sampling Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sherwood Harbor midwater trawl	0	0	0	3	2	2	3	3	3	0	0	0
Sherwood Harbor Kodiak trawl	3	3	3	0	0	0	0	0	0	3	3	3
Chipps Island midwater trawl	7	3	3	7	7	7	3	3	3	3	3	7
Mossdale Kodiak trawl	3	3	3	5	5	3/2	3	3	3	3	3	3

4.1.1.2 San Joaquin River

A Kodiak trawl (same as that used in the Sacramento River) has been used by CDFW in the San Joaquin River at Mossdale since 1988 (O'Brien 2011). Trawling is conducted two miles downstream of Mossdale Landing County Park (RM 56) to just upstream of the Old River confluence. Trawling was performed five days a week from March 29th to May 30th, three days a week from May 31st to June 20th, and two days a week from June 21st to June 30th. All trawling occurred during daylight hours, generally starting between 0800 and 0900 hours. Each sampling day consisted of 10 tows at 20 minutes per tow. Sampling days were extended on days when efficiency tests were conducted. Trawling was conducted three days per week from July to March by USFWS. Trawling was conducted year-round for 3 days per week since 1999 (Table 44). The trawling was conducted in the upstream direction in the center of the river (U.S. Fish and Wildlife Service 2012).

4.1.1.3 Chipps Island

A larger midwater trawl with the mouth opening of 27.88 m^2 (3.05 x 9.14 meter) has been used at Chipps Island since 1978. The effective mouth area of the midwater trawl was estimated to be 18.58 m^2 (U.S. Fish and Wildlife Service 2007)[4]. The midwater trawling at Chipps Island was initially conducted during the spring months of April, May, and June, and year-round sampling has been conducted since October 1994. The trawling is conducted for 3 to 7 days per week (Table 44).

In general, ten 20-minute tows were conducted for each sampling day. Trawls were conducted within a 3 km section of the river channel upstream of the western tip of Chipps Island (Brandes and McLain, 2001). Trawls were conducted in both directions (upstream and downstream) regardless of tide in three channel locations: north, south, and middle. Occasionally, inclement weather, mechanical problems, or excessive delta smelt or salmon catch reduced tow duration or number of tows per day. Tow duration was reduced or scheduled trawling was cancelled to stay within daily or annual delta smelt incidental take limits. For instance, between February 5 and March 10 of 2008, trawling at Chipps Island was cancelled due to concerns about high delta smelt incidental take. A similar curtailment period occurred between June and October of 2007. During some periods, tows were limited to as little as 5 minutes to assess delta smelt take prior to conducting tows of 15 or 20 minutes (Pyper *et al.* 2013b).

4.2 Fish Counting and Measurement

The bag of the net is collected and placed into a 10 gallon (38 L) tub with water from the river or bay. The net is thoroughly checked to ensure no fish are inadvertently left behind. Every organism found is placed in the tub. Fish are retrieved from the tub with a small hand net and are placed on a measuring board for identification to species and to obtain fork length measurements (in mm). The fish are then transferred to a 5 gallon (19 L) recovery bucket prior to being released.

Before August 1, 1977 all Chinook salmon captured were measured and fork lengths recorded. Between August 1, 1977 and July 31, 1992 only 50 Chinook salmon from each sample taken were measured and those not measured were recorded as a total sum, minus those measured. After August 1, 1992, 50 individuals from each race of Chinook salmon were measured and those not measured were assigned a count reference number to associate them with measured Chinook salmon. All Chinook salmon from all years are entered into the USFWS database as CHN. The salmon race (run) is classified using the length-at-date criteria. Fish that are not measured are designated with a fork length of “0” and a count of “1” or greater. Chinook salmon that were not measured between August 1, 1977 and July 31, 1992 cannot be raced nor can they be associated with any measured fish (U.S. Fish and Wildlife Service 2012).

Chinook salmon with a clipped adipose fin are brought back to the office to extract the embedded coded wire tags. A coded wire tag detector wand (Northwest Technologies) is used

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[4] Recent measurements conducted in 2009 determined that the trawl net fished at Chipps Island has a mean effective-fishing mouth size of 12.7 m^2 (Whitesel) or 13.0 m^2 (Confluence) depending on the vessel used (preliminary unpublished data) (Pyper *et al.* 2013a).

for adipose clipped steelhead to determine the presence of coded wire tags. Those with embedded coded wire tags are brought back to the office.

If there are too many fish recovered (>2000), a sub-sample is taken from the recovery tub and placed into six sub-samples, after first ensuring that a homogenous mix has been achieved. A graduated container, with holes in the bottom to allow for water drainage, is used to collect sub-samples. Sub-samples are then placed into flow through containers that are transferred to another tub for identification, measurement, and enumeration. Once a volume has been determined, remaining fish are then released to minimize handling stress and overcrowding. Measurements, numbers of individuals and the species composition of sub-samples are then extrapolated to the population previously in the tub. This new sub-sampling protocol was implemented in 2005. In the early 1980's sub-sampling was conducted at Chipps Island using a graduated cylinder and discarding the excess water. In addition, reducing sampling times or areas have also been employed to reduce catch if too many fish are caught or the catch rate is anticipated to be high (U.S. Fish and Wildlife Service 2012).

4.3 Juvenile Chinook and Steelhead Monitoring Data

Juvenile fish monitoring data in the Delta were obtained from USFWS' Stockton Fish and Wildlife Office (http://www.fws.gov/stockton/jfmp). The website was accessed and the data were downloaded on February 8, 2013. While three monitoring stations had different start dates, all the data downloaded ended on September 28, 2012 (Table 45). However, some of the monitoring data from earlier years were not used to estimate the juvenile flux or abundance because data for critical time periods were not collected.

Table 45. Time frame for available juvenile fish monitoring data

Station	Start Date	End Date
Sherwood Harbor in the Sacramento River	4/5/1988	9/28/2012
Mossdale in the San Joaquin River	4/25/1994	9/28/2012
Chipps Island in the Delta outlet	5/18/1976	9/28/2012

Juvenile monitoring started at Sherwood Harbor in the Sacramento River on April 5, 1988. However, juvenile data were not collected in the winter or spring from 1988 to 1992 (Table 46). Therefore, we did not use the monitoring data from April 5, 1988 to July 31, 1992 in this report. Note that the 1992 brood year starts 8/1/1992.

Table 46. Time periods when juvenile data were not collected at Sherwood Harbor

Start Date	End Date
7/1/1988	4/13/1989
7/1/1989	7/1/1990
7/1/1990	4/14/1991
6/13/1991	12/5/1991
3/26/1992	5/5/1992

Juvenile monitoring started at Mossdale in the San Joaquin River on April 25, 1994. However, juvenile data were not collected in the winter or spring from 1994 to 1998 (Table 47). Therefore, we did not use the monitoring data from April 25, 1994 to July 31, 1998 in this report. Note that the 1998 brood year starts August 1, 1998. We used the 1998-2011 average to substitute the 1992-1997 brood year data.

Table 47. Time periods when juvenile data were not collected at Mossdale

Start Date	End Date
6/9/1994	3/31/1996
6/29/1996	9/3/1996
12/28/1996	3/20/1997
6/28/1997	4/1/1998
7/1/1998	11/3/1998

Juvenile monitoring started at Chipps Island on May 18, 1976. However, juvenile data were not collected in the winter or spring from 1976 to 1993 (Table 48). Therefore, we did not use the monitoring data from May 8, 1988 to July 31, 1993 in this report. Note that the 1993 brood year starts 8/1/1993. We used the 1993-2011 average to substitute the 1992 brood year data.

Table 48. Time periods when juvenile data were not collected at Chipps Island

Start Date	End Date
7/10/1976	11/9/1976
11/17/1976	5/8/1977
6/29/1977	4/2/1978
6/27/1978	4/1/1979
6/21/1979	1/13/1980
1/14/1980	4/1/1980 (conducted once per week)
7/1/1980	9/30/1990
10/1/1980	12/13/1980 (conducted once per week)
14/14/80	4/4/1981
7/3/1981	4/5/1982
6/25/1982	4/7/1983
7/2/1983	4/1/1984
7/1/1984	3/31/1985
6/21/1985	4/6/1986
6/19/1986	4/5/1987
6/23/1987	4/4/1988
6/23/1988	4/4/1989
7/1/1989	4/4/1990
6/23/1990	4/4/1991
6/29/1991	4/2/1992
6/23/1992	4/4/1993
7/9/1993	11/1/1993

6/21/1994	10/2/1994

The juvenile monitoring database included those data from special studies (i.e., trawl efficiency studies, survival studies, etc.), which showed more tows than the regular monitoring. This type of data was excluded from analysis in this report. There were some data that were collected for comparing trawling methods (mid-water trawl vs. Kodiak trawl) side by side in the Sacramento River. In this case, the data from the Kodiak trawl were excluded from analysis. We used up to 10 tows per day of trawl data in this report.

Note that if too many fish were caught in a particular day, not all fish were measured or identified for races of Chinook salmon. These fish were classified as Chinook but no race was assigned before August 1, 1992. Therefore, the sum of spring-run, winter-run, fall-run, and late fall-run Chinook salmon will not add up to the total Chinook for the data collected before August 1, 1992.

4.4 Juvenile Fish Flux

Fish flux is defined as the number of fish passing a river (channel) cross-section within a certain time period, e.g., minute, day, month, or year. There are two methods to estimate the fish flux given the juvenile trawl data in the unit of catch per day (24 hours) (CPD) or catch per cubic meter (CPCM).

4.4.1 Use of Trawl Efficiency to Calculate Juvenile Fish Flux

Trawl efficiency (E) is defined as the ratio of the number of fish captured by the trawl (N_{Tr}) to the total number of fish (N_W) passing the cross-section of a river (channel) within a certain time period (e.g., 24 hours).

$$E = \frac{N_{Tr}}{f_d N_W} \qquad \text{Equation 16}$$

Because the sampling time length and sampling water volume are not always consistent over the past several decades of trawling, the number of fish captured by the trawl should be scaled to the 24-hour basis by multiplying the fish catch with the factor f_d – fraction of the trawling time in 24 hours. Given assumptions of randomness, this is equivalent to defining efficiency as the ratio of the number of fish that would be captured by the trawl if the trawl is operated continuously (24 hours a day) to the total number of fish in the water over the same time period (Pyper *et al.* 2013a).

When using fish catch data to calculate fish flux, we considered the diel movement behavior of outmigrating juvenile Chinook salmon. Chapman et al (Chapman *et al.* 2013) found that about 70% of Chinook salmon juveniles move at night from the lower Sacramento River through the Delta. As juvenile fish monitoring by trawl was conducted during the daytime, the fish catch data were adjusted using the 70% nocturnal movement with 14 h of darkness and the 30% diurnal movement with 10 h of light. The 24- hour juvenile Chinook salmon catch may be calculated using the following equations:

$$N_{24(CHN)} = N_{10(d)} + N_{14(n)}$$

$$N_{10(d)} = N_{Catch}\frac{24}{T_{tow}}\frac{10}{24} = N_{Catch}\frac{10}{T_{tow}}$$

$$N_{14(n)} = \frac{0.7}{0.3}N_{10(d)} = 2.333\ N_{Catch}\frac{10}{T_{tow}}$$

$$N_{24(CHN)} = N_{catch}\frac{33.33}{T_{tow}}$$ Equation 17

For juvenile steelhead, Chapman et al. (Chapman *et al.* 2013) found that their movements into the Delta are nearly equal during day and night times. The 24- hour juvenile steelhead catch may be calculated using the following equations:

$$N_{24(STH)} = N_{catch}\frac{24}{T_{tow}}$$ Equation 18

Given the 24-hour juvenile catch data, the daily (24 hours) fish flux (ϕ) can be calculated as

$$\emptyset = \frac{N_{24}}{E}$$ Equation 19

where E = 0.00375 for mid-water trawl and 0.00140 for Kodiak trawl, on average, at Sherwood Harbor in the Sacramento River; 0.0094 for the Chipps Island trawl; and 0.041 for the Mossdale trawl.

USFWS developed two types of experiments to estimate trawl efficiency as described below.

4.4.1.1 Trawl Efficiency Based on Ocean Recovery Rates of Paired Fish Release Groups

Trawl efficiency may be estimated from studies on paired fish release groups, i.e., one coded-wire tag (CWT) group released downstream of Chipps Island that is paired with one or more fish groups released upstream of Chipps island. The downstream release group provides the basis for estimating the survival rate of the upstream group from the point of release to passage at Chipps Island. The survival rate is then used to estimate the total number of juveniles passing Chipps Island, which is used to calculate the trawl efficiency given the number of juveniles captured by the Chipps Island trawl (Pyper *et al.* 2013a). One of the assumptions for this method is that upstream and downstream release groups have similar ocean survival rates. However, the ocean survival rates for downstream release groups were apparently lower than those for upstream release groups (Pyper *et al.* 2013a).

Chipps Island trawl efficiencies based on the paired-release studies, averaged by year, are presented in Table 49. Trawl efficiencies were estimated from two datasets: the dataset with all upstream releases (including those with upstream survival rates ≥ 1) and the dataset without those releases having upstream survival rates ≥ 1. Out of a total of 215 upstream releases, 45 releases showed upstream survival rates ≥ 1. Note that Pyper et al. (2013a) excluded only 11 such releases from their trawl efficiency analysis with the remaining 34 releases being assigned a survival rate of 1. By definition, the trawl efficiency should be calculated from the proportion of sampling time length (p-time) as presented in Table 49. However, Pyper *et al.* (2013a) used a "volume" based approach (p-vol) through an arbitrary scalar equal to 1000 m^3 per minute to "standardize" trawl efficiencies, which tend to be lower than those from the sampling time length approach.

The sampling time based mean trawl efficiency across all years increased slightly (from 0.0089 to 0.0094) while the median trawl efficiency remained the same (0.0071) when excluding the upstream releases with upstream survival rates ≥ 1. The trawl efficiency estimated from paired-release studies is limited to Chipps Island as there were no similar studies conducted for the Sacramento River or San Joaquin River. No such trawl efficiency studies have been conducted for steelhead juveniles.

Table 49. Chipps Island trawl efficiency averaged by year from paired-release studies

Year	All Data (n = 215)	Data with Upstream Survival Rate < 1 (n = 170)
1979	0.0409	0.0409
1980	0.0067	0.0067
1981	0.0071	0.0071
1982	0.0118	0.0114
1983	0.0100	0.0143
1984	0.0094	0.0094
1985	0.0015	0.0015
1986	0.0066	0.0066
1988	0.0076	0.0085
1989	0.0077	0.0077
1990	0.0046	0.0056
1991	0.0221	0.0221
1992	0.0277	0.0277
1994	0.0044	0.0044
1996	0.0074	0.0075
1997	0.0045	0.0045
1998	0.0078	0.0085
1999	0.0037	0.0040
2000	0.0016	0.0024
2001	0.0022	0.0026
2002	0.0080	0.0100
2003	0.0046	0.0046
2004	0.0054	0.0060
2005	0.0097	0.0097
2008	0.0002	0.0008
Minimum	0.0002	0.0008
Maximum	0.0409	0.0409
Median	0.0071	0.0071
Mean	0.0089	0.0094
Standard Deviation	0.0090	0.0089

4.4.1.2 Trawl Efficiency Based on Special Release Studies

In this approach, marked juveniles were released upstream of, but not far away from, the trawl station. The number of the marked fish captured by subsequent trawling is used to calculate the trawl efficiency. This type of study has been conducted at Chipps Island, Sherwood Harbor, and Mossdale on Chinook salmon juveniles, but no such studies were conducted for steelhead juveniles. A key assumption of this approach is that fish survival from the point of release to passage at a trawl station was 100%.

4.4.1.2.1 Chipps Island

To estimate the trawl efficiency at Chipps Island, CWT Chinook juveniles were released at Jersey Point (~19 km upstream of Chipps Island), Sherman Island (~13 km upstream), or Pittsburg (~4 km upstream). There were 34 releases from 1990 to 2010 at Jersey Point, 27 releases from 1999 to 2011 at Sherman Island, 3 releases in 2009 at Pittsburg. The number of fish released each time ranged from 23,000 to 150,000 at Jersey Point, 25,000 to 1,114,000 at Sherman Island, and 30,000 to 34,000 at Pittsburg. All Jersey Point releases were fall run. Of the 27 Sherman Island releases, 25 were fall-run and two were late-fall run (Pyper *et al.* 2013a). Note that the trawl efficiency estimates presented below were derived from the "volume" based approach (Pyper *et al.* 2013a), which tend to be lower than those from the time based approach.

Table 50. Chipps Island trawl efficiency averaged by year from three release sites

Release Year	Jersey Point	Sherman Island	Pittsburg
1990	0.0039	ND	ND
1991	0.0111	ND	ND
1994	0.0014	ND	ND
1995	0.0029	ND	ND
1996	0.0058	ND	ND
1997	0.0045	ND	ND
1998	0.0089	ND	ND
1999	0.0051	0.0040	ND
2000	0.0051	ND	ND
2001	0.0045	ND	ND
2002	0.0057	ND	ND
2003	0.0074	ND	ND
2004	0.0034	0.0050	ND
2005	ND	0.0067	ND
2009	0.0065	0.0055	0.0124
2010	0.0017	0.0079	ND
2011	ND	0.0018	ND
Mean (All data)	0.0052	0.0051	0.0124
Mean (Excluding 2011)	0.0052	0.0058	0.0124
Mean (99, 04, 09, and 10)	0.0041	0.0056	ND

Mean (Mortality adjusted and sampling time based)	0.0077	0.0080	0.0129

ND = No Data

The "volume" based mean trawl efficiency at Chipps Island was 0.0052 from the Jersey Point releases, 0.0058 from the Sherman Island releases, and 0.0124 from the Pittsburg releases, when the year 2011 was excluded (Table 50). These trawl efficiencies were derived based on the assumption that fish survival from the point of release (Jersey Point or Sherman Island) to passage at Chipps Island was 100%, which is invalid as juvenile mortality occurs in the channel section between the release site and Chipps Island. If we assume that mortality rates were proportional to the distance fish travel (e.g., 1% per km), the mortality rates from Jersey Point, Sherman Island, and Pittsburg to Chipps Island would be 19%, 13%, and 4%, respectively. The mortality "adjusted" trawl efficiency would be 0.0064 for the Jersey Point releases, 0.0067 for the Sherman Island releases, and 0.0129 for the Pittsburg releases using the following equation:

$$E_m = \frac{\bar{E}_{tr}}{1 - M_{cum}}$$

where E_m = Trawl efficiency adjusted for mortality; $\bar{E}_{tr}$ = Mean trawl efficiency over years sampled; M_{cum} = Cumulative mortality over river reach from release to Chipps Island.

As a general rule, the sampling time based trawl efficiency is about 20% higher than the "volume" based trawl efficiency. Therefore, the time based trawl efficiencies for the Chipps Island trawl are 0.0077 for the Jersey Point releases, 0.0080 for the Sherman Island releases, and 0.0129 for the Pittsburg releases. The Pittsburg releases occurred in 2009 when the time based efficiency is assumed to be similar to the "volume" based efficiency.

In summary, the mean trawl efficiency estimates were the highest from the Pittsburg special release studies and similar between the Jersey Point and the Sherman Island special release studies. The mean trawl efficiency at Chipps Island from the paired-release studies is similar to those from the Jersey Point or Sherman Island special release studies. Because the Pittsburg release study was based on three releases in one year, the trawl efficiencies from the Jersey Point or Sherman Island releases seemed more appropriate than that from the Pittsburg releases.

4.4.1.2.2 Sacramento River

Studies for estimating both midwater and Kodiak trawl efficiencies were conducted in the Sacramento River near Sherwood Harbor from 2002 through 2009. CWT juvenile Chinook salmon were released at the Broderick boat ramp in West Sacramento or Miller Park in Sacramento. The Broderick boat ramp is 8.5 river km and Miller Park is 4.5 km upstream of the trawling area near Sherwood Harbor. Trawling began near the time of each release and continued for approximately 24 hours. Released fish recovered after the first 24 hours were not used in calculating the trawl efficiency. The juvenile survival rate from release sites to the trawl site was considered 100% (Michel 2010, Michel *et al.* 2013). The mean trawl efficiency was 0.00140 for the Kodiak trawl[5] and 0.00375 for the midwater trawl (Table 51).

Table 51. Trawl efficiency studies in the Sacramento River at Sherwood Harbor

Release Year	# Juveniles Released	Catch by Trawl	Fraction of Trawling Time	Total Catch in 24 hours	Trawl Efficiency
Kodiak Trawl					
2002	69490	121	0.694	174	0.00251
2003	64547	29	0.774	37	0.00058
2004	48987	48	0.583	82	0.00168
2006	50460	35	0.817	43	0.00085
Number of Samples					4
Median					0.00126
Average					0.00140
Standard Deviation					0.00087
95% Confidence Interval					0.00085
Mid-water Trawl					
2003	50,284	169	0.666	254	0.00505
2005	101,563	184	0.743	248	0.00244
2007	144,138	476	0.652	730	0.00506
2009	129,272	221	0.703	314	0.00243
Number of Samples					4
Median					0.00374
Average					0.00375
Standard Deviation					0.00151
95% Confidence Interval					0.00148

[5] These trawl efficiency values are different from what Wilder and Ingram (2006) provided. This is caused by different definitions of the efficiency. We define "trawl efficiency" as the ratio of the number of fish captured by the trawl to the total number of fish in the water. Wilder and Ingram (2006) used "net efficiency" that is defined as the ratio of the number of fish captured by the net to the actual number of fish in the water at the size of the net. Neglecting effects such as herding that might increase the catch, it is equal to the probability that a fish will be caught in the net if the water the fish is in goes through the net. The reason is that the fish may be able to avoid or pass through the sampling net. From the definitions of trawl efficiency and net efficiency provided above, net efficiency is always greater than trawl efficiency. However, when the size (width) of the net is equal to the channel width and trawling is conducted continuously, then net efficiency = trawl efficiency.

4.4.1.2.3 San Joaquin River

Trawl efficiency studies have been conducted in the San Joaquin River since 1989. The results of these studies are provided in Table 52. It appeared that trawl efficiency decreases with increasing flow in the San Joaquin River at Vernalis (Figure 102).

Table 52. Kodiak trawl efficiency studies in the San Joaquin River at Mossdale

Release Date	#Juveniles Released	Catch by Trawl	Trawl time Fraction	Trawl Efficiency
1989	2550	40	0.282	0.056
1996	2549	27	0.658	0.043
1997	3967	37	0.667	0.014
1998	5010	78	0.704	0.022
1999	2981	6	0.714	0.014
2001	1520	77	0.639	0.056
2002	1974	16	0.822	0.011
2003	5056	205	0.662	0.051
2004	2027	114	0.751	0.033
2005	1948	28	0.820	0.026
2006	4998	142	0.722	0.012
2008	2830	110	0.864	0.045
2010	3123	416	0.754	0.062
2011	3162	153	0.727	0.067
2012	2000	125	0.839	0.111
Min				0.011
Max				0.111
Median				0.043
Mean				0.041
Standard Deviation				0.027
95%CI				±0.014

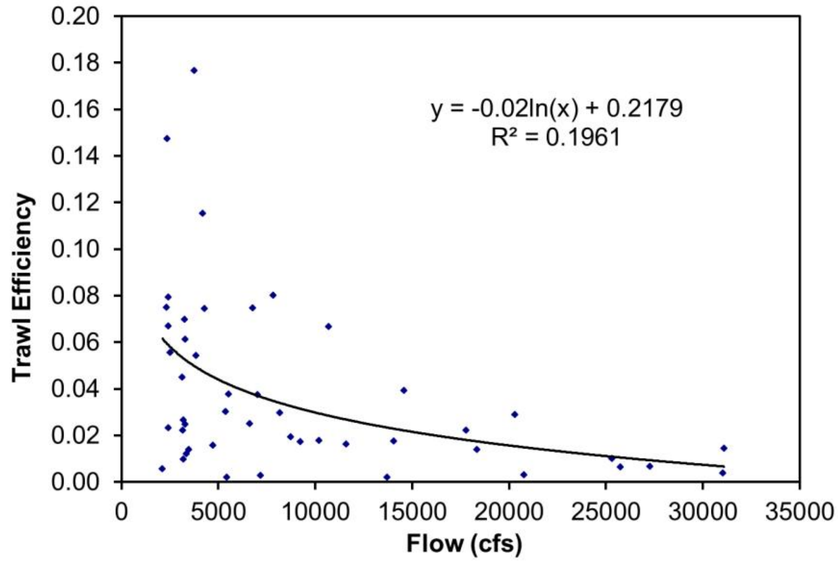

Figure 102. Kodiak trawl efficiency vs. San Joaquin River flow at Vernalis based on release studies from 1989 to 2012

4.4.2 Use of Fish Migration Speed or Flow Velocity to Calculate Juvenile Fish Flux

We describe this method below but have not analyzed trawl data with this method in this report. The daily fish flux may be directly calculated as follows, given fish density (fish/m^3), channel width, and the depth and speed of fish migration (Kimmerer 2008):

$$\phi = \zeta x z v \qquad \text{Equation 20}$$

where

ζ = Fish density (fish/m^3),
x = Channel width (m),
z = Water depth (m) to which juvenile fish distribute, and
v = Fish migration speed (m/d).

The fish density may be calculated based on the number of fish captured and the water volume sampled by trawling:

$$\zeta = \frac{N_{tr}}{V} \qquad \text{Equation 21}$$

where

N_{tr} = Number of fish captured by trawling, and
V = Water volume sampled by trawling (m^3).

Fish migration speed can be replaced by flow velocity if fish migrate downstream at a speed equal to the flow velocity.

The following assumptions are made for using this method:

- Fish are randomly distributed in space (across the channel and only to a certain depth).

- Fish are randomly distributed in time (during day and at night).
- Fish do not avoid the trawl net or are attracted to it and the net efficiency is 100%.
- Fish cannot pass through the trawl net, i.e., all fish trapped into the trawl net are kept inside the net.

This method may be applied to all trawling stations if channel width and the fish migration depth and speed are known. While channel width is readily available (Table 53), the distribution depth and migration speed of salmonid juveniles have been the subjects of many studies.

Table 53. Channel width (m) used in fish flux calculation

Sacramento River at Sherwood Harbor	San Joaquin River at Mossdale	Delta Outlet at Chipps Island
180	90	1000

4.4.2.1 Depth Distribution of Juvenile Salmonids

Both laboratory and field studies have shown that juvenile salmonids prefer to occupy surface waters but will move up or down in the water column in response to adverse condition changes such as temperature and oxygen levels (Carter *et al.* 2009). Kimmerer (2008) used the water depth of 4 m to calculate fish flux at Chipps Island. Klimley *et al*. (2010) observed a positive correlation between the frequency of smolt detections and depths ranging from 1-11.3 m. However, this relationship was not evident in waters deeper than 11.3 m. During 2007-2008, Chinook salmon and steelhead smolts were detected in water ranging from 6-8 m in depth along the eastern span of the San Francisco-Oakland Bay Bridge. Three dimensional positioning from mobile tracking JSATS fish in the Columbia River estuary indicated that Chinook salmon migrated through the lower Columbia River at 4.1–10.5 m for yearlings and 4.6–27.7 m subyearlings (Carter *et al.* 2009). A water depth of 6 m was used in this report to calculate juvenile flux at all three trawl stations.

4.4.2.2 Migration Speed of Juvenile Salmonids

Research results from the Columbia River system indicated that juvenile salmonids migrate at a fast rate in river channels, slow down when they reach the estuary, and finally substantially speed up while reaching the river mouth (Carter *et al.* 2009). Michel (2010) reported that the juvenile Chinook salmon migration speed from the I80/50 bridge to Freeport was 26.2 km/d. This result is based on acoustic tag studies with a relatively low number of tagged fish. Out of a total of 804 late-fall-run Chinook tagged and released in 2007, 2008, and 2009, only 30 tagged fish survived and reached the Golden Gate Bridge. In comparison, acoustic tag studies were conducted in the Columbia River basin with hundreds of thousands of tagged juveniles released in upstream locations and subsequently thousands of these released fish were detected at various locations downstream of the release sites. The migration speed of Chinook juveniles from Bonneville Dam (rkm225.2) to near Kalama, Washington (rkm86.2) in the lower Columbia River ranged from 64.3 to 89.3 km/d, with an average of 77.2 km/d (Carter *et al.* 2009). The migration speed of 77.2 km/d was used in this report to calculate Chinook flux at Sherwood Harbor in the Sacramento River.

Kimmerer (2008) applied the migration speed of 6 km/d for Chinook juveniles passing Chipps Island, which was based on the reports from Brandes and McLain (2001) and Newman (2003). Klimley *et al*. (2010) reported the migration speed of 7.1 km/d when smolts traveled from Rio Vista to Carquinez even though the sample size was small – a total of 48 tagged fish were detected at Carquinez. Michel (2010) reported the migrate rate of 15.3 km/d between Freeport and Chipps Island. The migration rate of 7.1 km/d was used in this report to calculate Chinook flux at Chipps Island because this rate would best represent the migration route passing Chipps Island.

There are no migration rate data available for steelhead in the lower Sacramento River although Sandstrom (2012) found the average migration speed of 32.7 km/d for steelhead smolts traveling about 500 river km from a release site in the Upper Sacramento River to the Golden Gate Bridge, implying that the actual migration rate passing Sherwood Harbor could be greater than 32.7 km/d. The migration rate of steelhead smolts from Bonneville Dam (rkm225.2) to near Kalama, Washington (rkm86.2) in the lower Columbia River ranged from 97 to 110.4 km/d (Carter *et al.* 2009), with an average of 103.7 km/d, which was used to calculate steelhead flux at Sherwood Harbor in the Sacramento River.

Klimley et al (2010) conducted steelhead migration studies in the Delta and the Estuary. In 2006-2007 they released 49 steelhead juveniles into the mainstem of the Sacramento River near Rio Vista. They detected 11 tagged steelhead at Carquinez, with the average migration time of 9.8 days. Given the distance (56.1 km) between Rio Vista and Carquinez, the estimated migration speed was 5.7 km/d. Although they did not specifically report the result of the 2007-2008 steelhead group (50 steelhead) released at Rio Vista, they provided the combined result of several studies concurred in 2007-2008, with the average migration time being 6 days and the migration speed being 9.4 km/d. The average speed of the two-year studies was 7.5 km/d, which was used to calculate the steelhead flux at Chipps Island.

Summarized in Table 54 are juvenile migration speeds (km/d) used in fish flux calculation. The same migration speeds for the Sacramento River were used for the San Joaquin River.

Table 54. Juvenile migration speeds (km/d) used in fish flux calculation

Species	Sacramento River	Chipps Island
Chinook	77.2	7.1
Steelhead	103.7	7.5

4.5 Daily Juvenile Fish Flux

We computed daily juvenile fish flux for winter-run, spring-run, fall-run, and late fall-run Chinook salmon and steelhead at Sherwood Harbor, Mossdale, and Chipps Island using the trawl efficiency method. The linear interpolation was used to fill data gaps for those days when juvenile monitoring was not conducted.

Since hatchery Chinook juveniles with adipose fin clipped were not identified for races in the trawl data at Sherwood Harbor in the Sacramento River, Mossdale in the San Joaquin River, and Chipps Island in the Delta outlet, it is not possible to estimate hatchery fish flux for individual races (i.e., winter-run, spring-run, fall-run, and late fall-run). Instead, we estimated the total hatchery Chinook and steelhead as these data were provided in the juvenile monitoring database.

There were only three events reported with each capturing one hatchery juvenile steelhead by trawl at Mossdale in the San Joaquin River.

We examined daily fish flux after interpolation of the data for those days that did not have juvenile monitoring. We corrected the interpolated data if they were found to be unrealistic. For example, wild steelhead juveniles at Mossdale were interpolated from mid-September of 2000 to early February 2001, resulting in unusually high monthly fish flux from October through January. This type of incorrect interpolation resulted from a large data gap expanding 4 months. By comparing with other years, we reasonably assumed that wild steelhead catch at Mossdale was zero from October through January, and corrected the daily steelhead flux data accordingly.

Presented below is the daily juvenile flux for winter-run, spring-run, and steelhead.

4.5.1 Winter-run Chinook Salmon

Winter-run juveniles entered from the Sacramento River to the Delta as early as in late November. There were two migration peaks. The first peak occurred in December and the second occurred in February and March (Figure 103 and Figure 104).

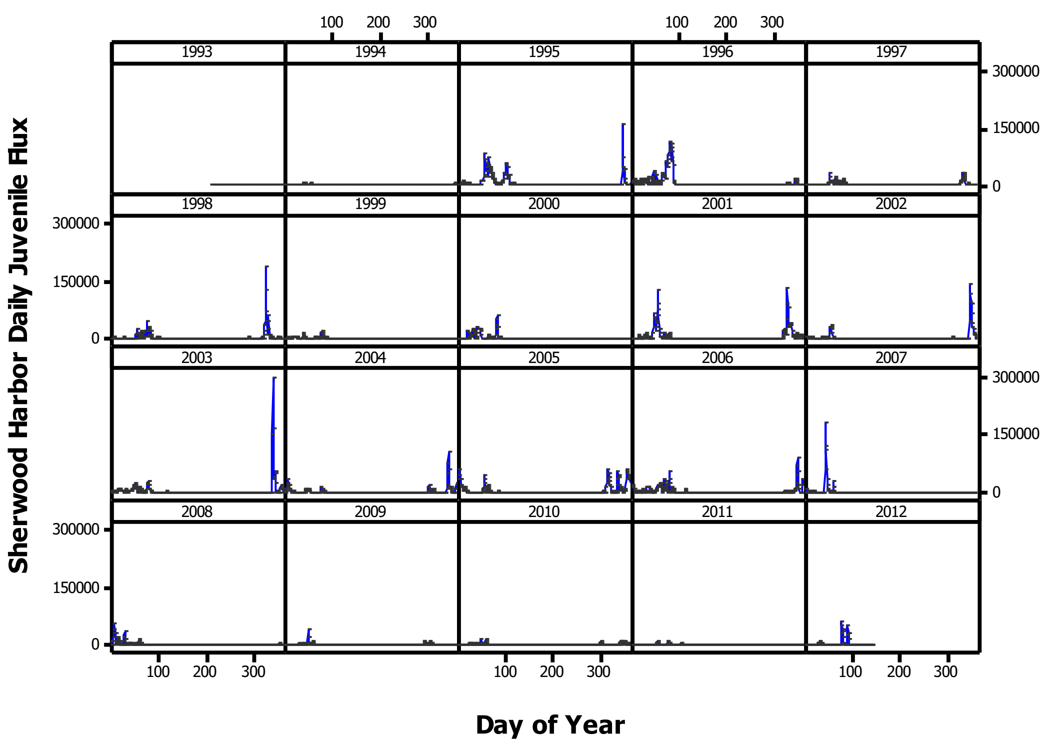

Figure 103. Daily juvenile flux of wild winter-run Chinook salmon in the Sacramento River at Sherwood Harbor from brood year 1993 to 2011

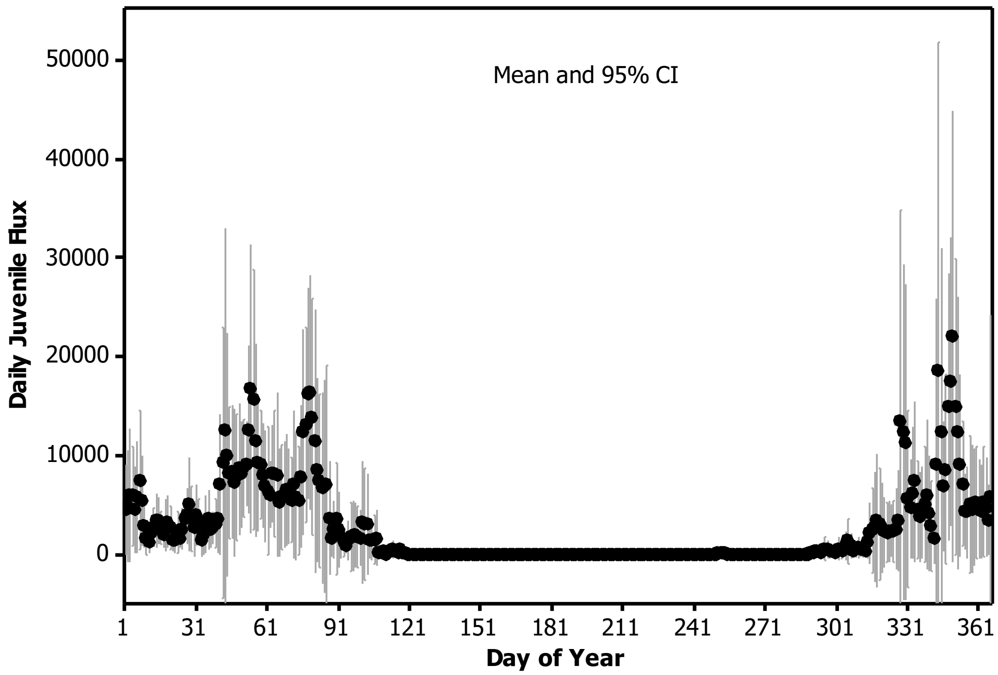

Figure 104. Mean daily juvenile flux of wild winter-run Chinook salmon in the Sacramento River at Sherwood Harbor (dots are the mean and bars are 95% CI)

Winter-run juveniles exited the Delta in mid-February, with the peak migration in March. Most juveniles passed Chipps Island at the end of April (Figure 105 and Figure 106).

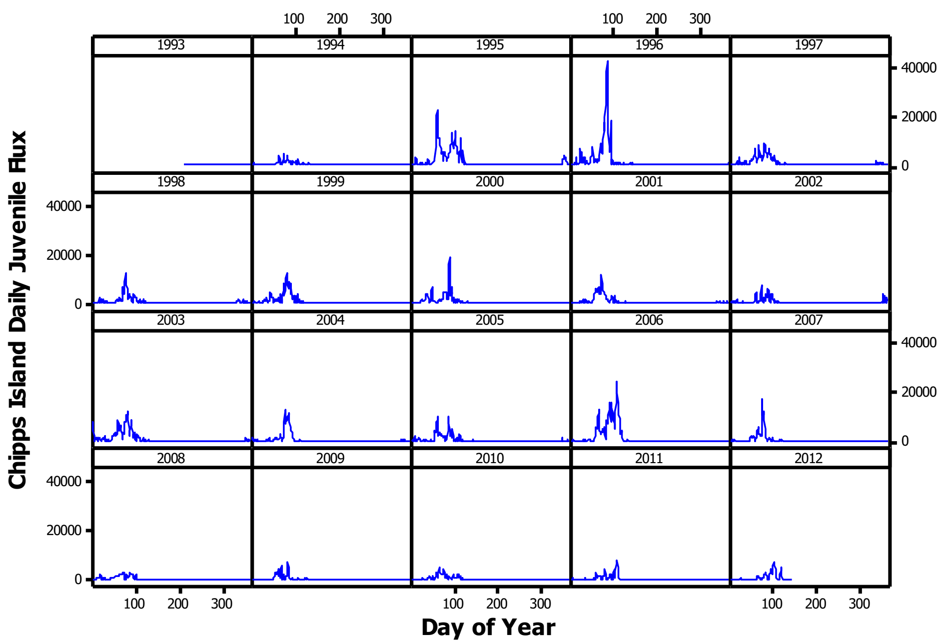

Figure 105. Daily juvenile flux of wild winter-run Chinook salmon at Chipps Island from brood year 1993 to 2011

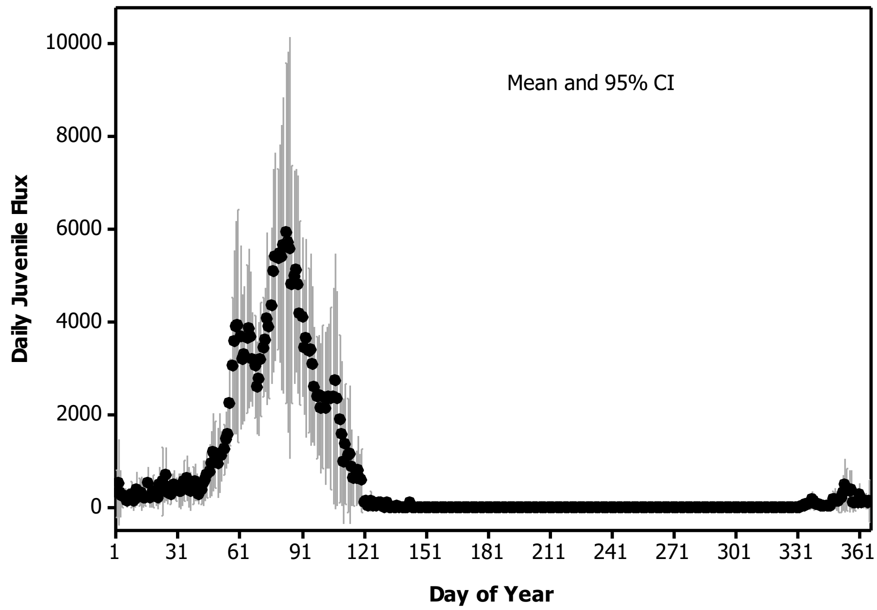

Figure 106. Mean daily juvenile flux of wild winter-run Chinook salmon at Chipps Island from brood year 1993 to 2011 (dots are the mean and bars are 95% CI)

4.5.2 Spring-run Chinook Salmon

Spring-run juveniles entered from the Sacramento River to the Delta as early as in December, with the peak migration from late March to late April (Figure 107 and Figure 108).

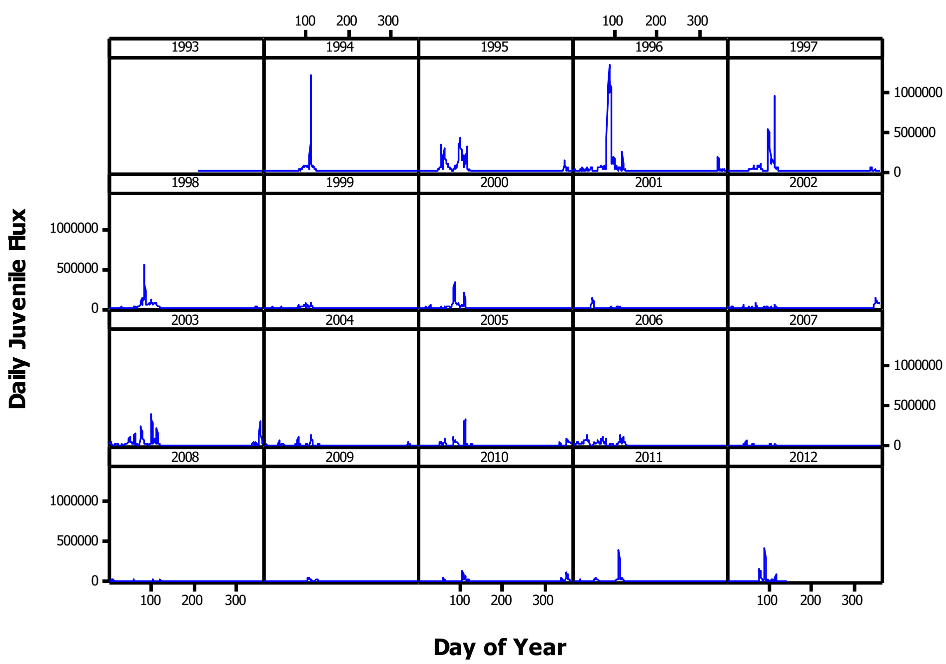

Figure 107. Daily juvenile flux of wild spring-run Chinook salmon in the Sacramento River at Sherwood Harbor from brood year 1993 to 2011

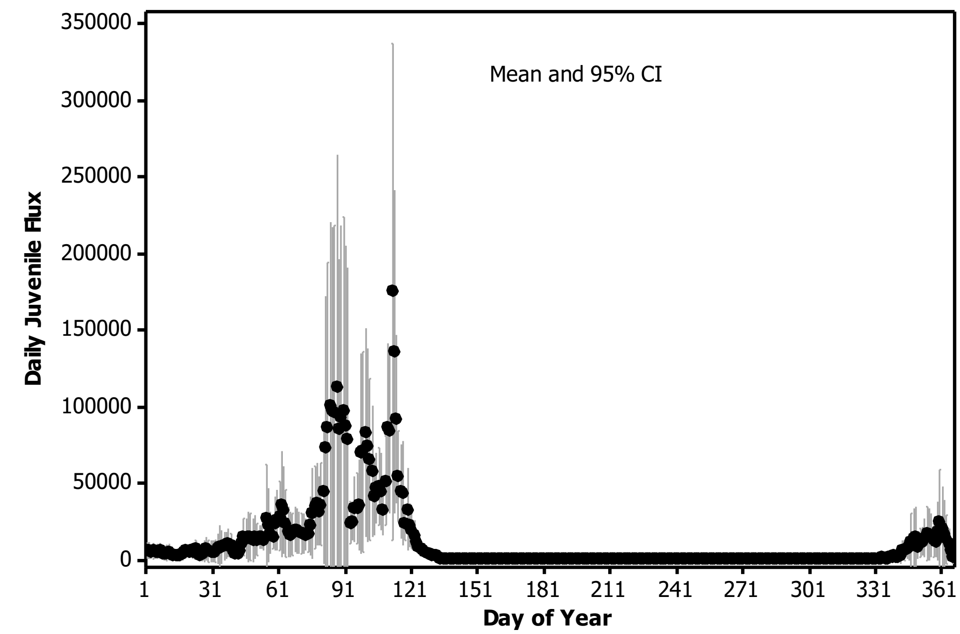

Figure 108. Mean daily juvenile flux of wild spring-run Chinook salmon in the Sacramento River at Sherwood Harbor (dots are the mean and bars are 95% CI)

Spring-run juveniles exited the Delta in mid-March, with the peak migration in April. Most juveniles passed Chipps Island at the end of May (Figure 109 and Figure 110).

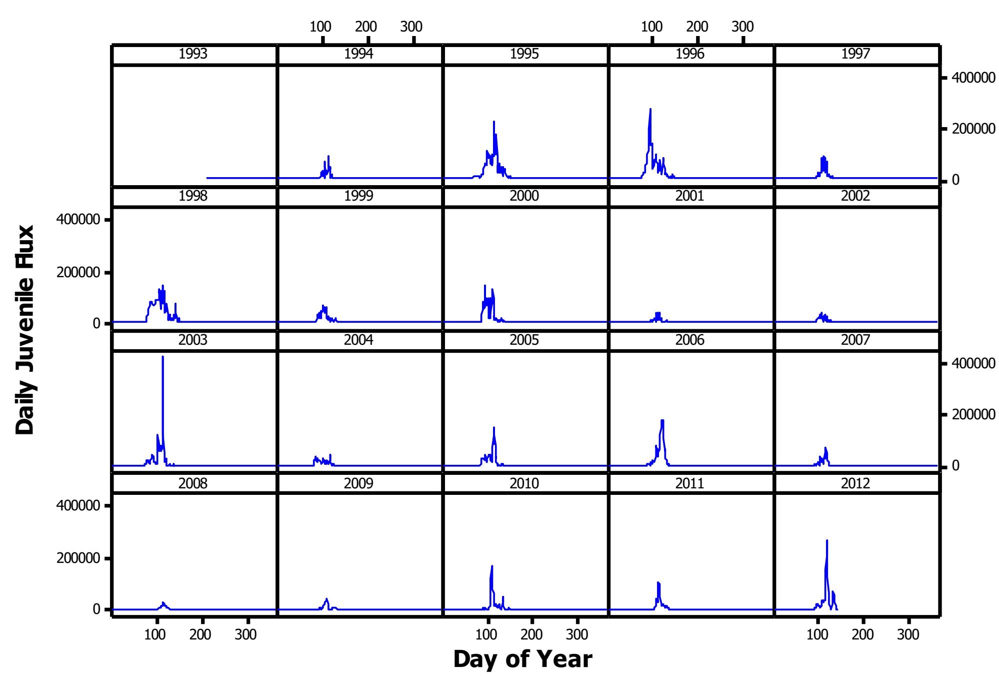

Figure 109. Daily juvenile flux of wild spring-run Chinook salmon at Chipps Island from brood year 1993 to 2011

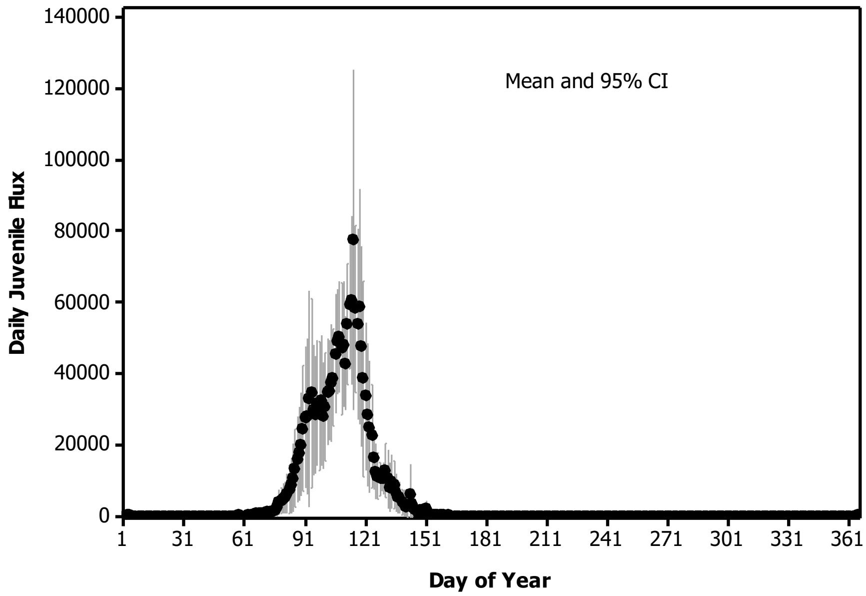

Figure 110. Mean daily juvenile flux of wild spring-run Chinook salmon at Chipps Island from brood year 1993 to 2011 (dots are the mean and bars are 95% CI)

4.5.3 Steelhead

Steelhead juveniles entered from the Sacramento River to the Delta in late January. There were two peaks of migration – one from mid-February to mid-March and the other in April (Figure 111 and Figure 112).

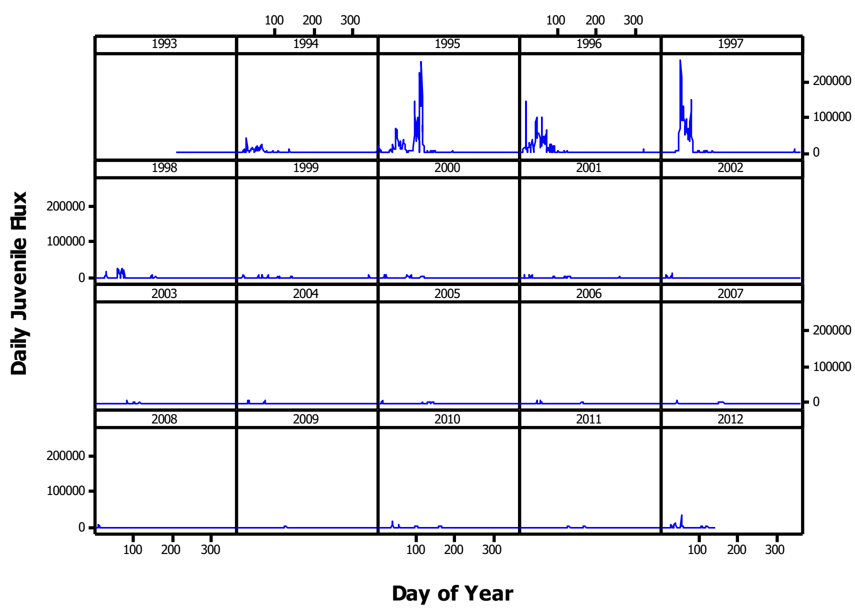

Figure 111. Daily juvenile flux of wild steelhead in the Sacramento River at Sherwood Harbor from brood year 1993 to 2011

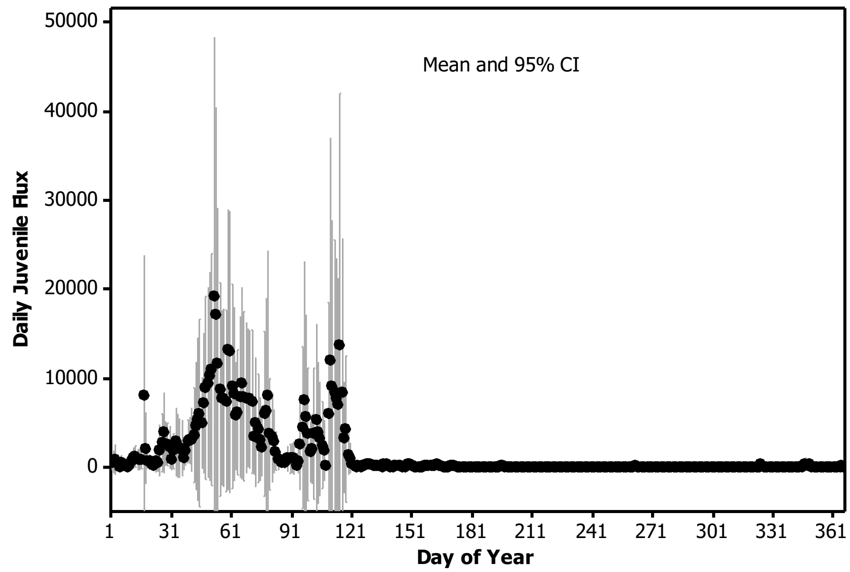

Figure 112. Mean daily juvenile flux of wild steelhead in the Sacramento River at Sherwood Harbor from brood year 1993 to 2011 (dots are the mean and bars are 95% CI)

Steelhead juveniles exited the Delta in late January. There were two peaks of migration – one from mid-February to mid-March and the other in late April. This migration pattern is coincident with the pattern of steelhead juveniles entering the Delta.

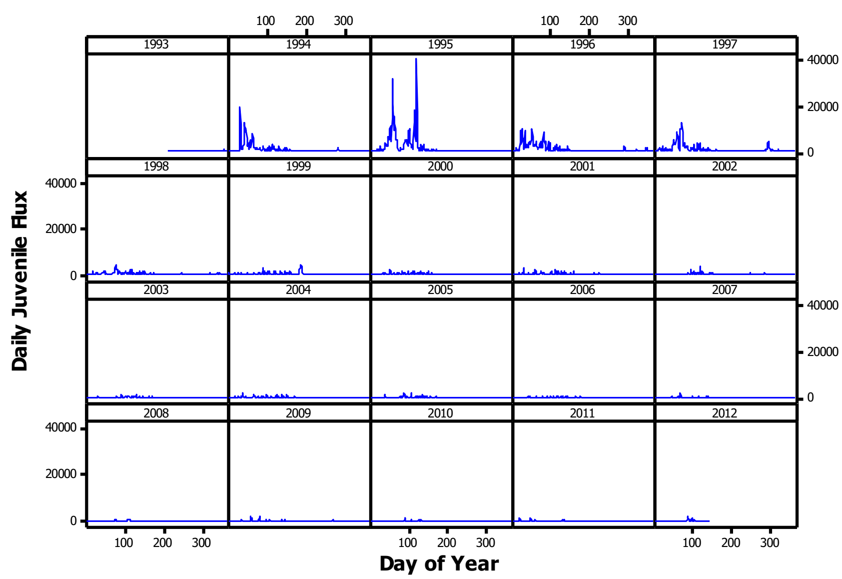

Figure 113. Daily juvenile flux of wild steelhead at Chipps Island from brood year 1993 to 2011

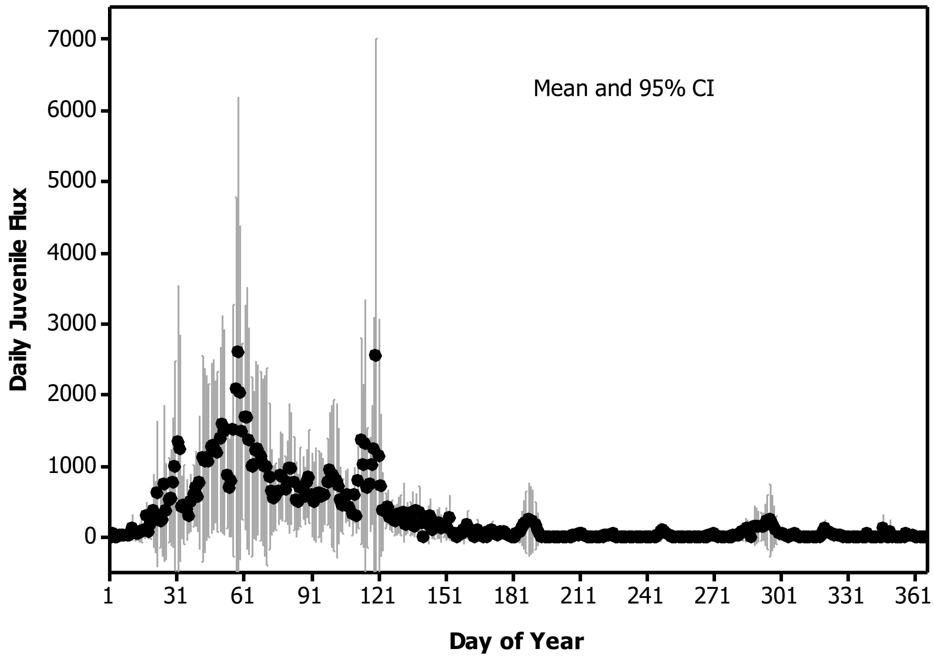

Figure 114. Mean daily juvenile flux of wild steelhead at Chipps Island from brood year 1993 to 2011 (dots are the mean and bars are 95% CI)

4.6 Monthly and Yearly Juvenile Fish Flux

The mean monthly flux of wild juvenile winter-run Chinook salmon at Sherwood Harbor was the highest in March, followed by February and December. The mean monthly flux of wild juvenile winter-run Chinook salmon at Chipps Island was the highest in March, followed by April and February (Figure 115 and Figure 116).

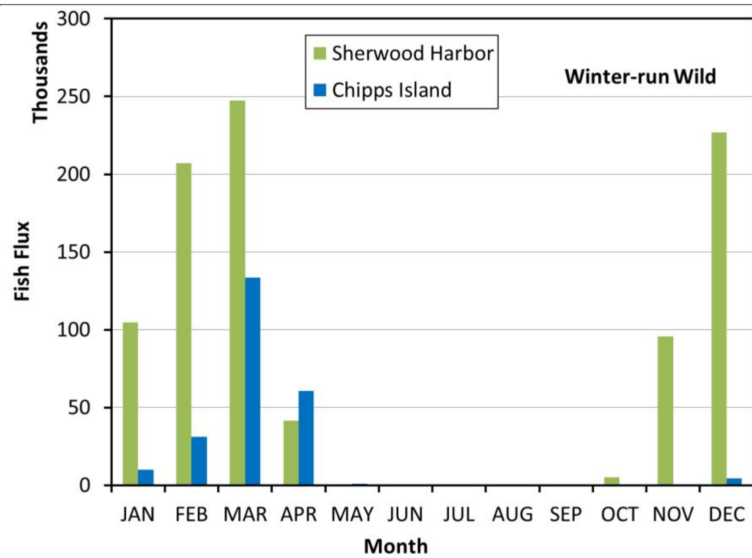

Figure 115. Mean monthly flux of wild juvenile winter-run Chinook salmon in the Sacramento River at Sherwood Harbor and at Chipps Island

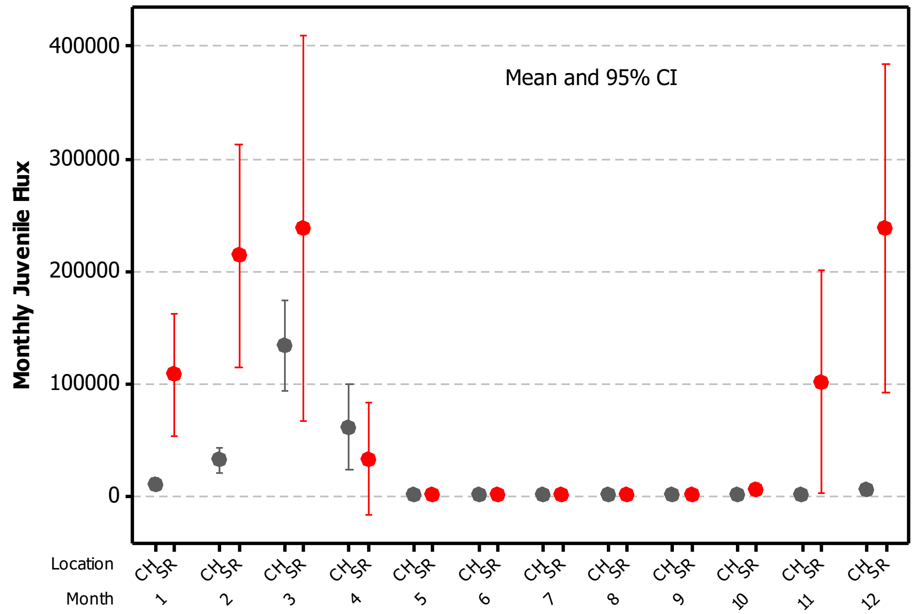

Figure 116. Monthly juvenile flux of wild winter-run Chinook salmon at Chipps Island (CH) and in the Sacramento River at Sherwood Harbor (SR)

The yearly flux of wild juvenile winter-run Chinook salmon at Sherwood Harbor was the highest in 1995 and the lowest in 1993. The yearly flux showed an increased trend from 1996 to 2005. The yearly flux decreased in 2007 and has remained low since then (Figure 117).

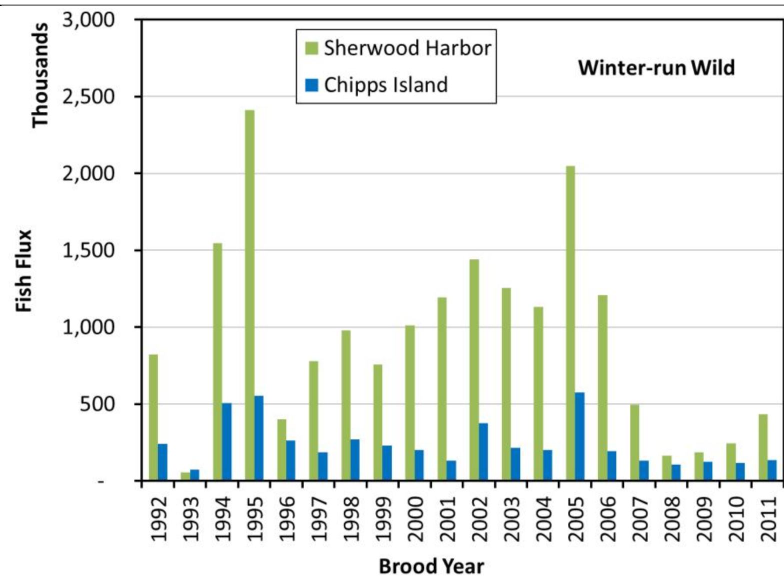

Figure 117. Yearly flux of wild juvenile winter-run Chinook salmon in the Sacramento River at Sherwood Harbor and at Chipps Island

The mean monthly flux of wild juvenile spring-run Chinook salmon at Sherwood Harbor in April was the highest, followed by March and May. The mean monthly flux of wild juvenile spring-run Chinook salmon at Chipps Island showed a similar pattern (Figure 118).

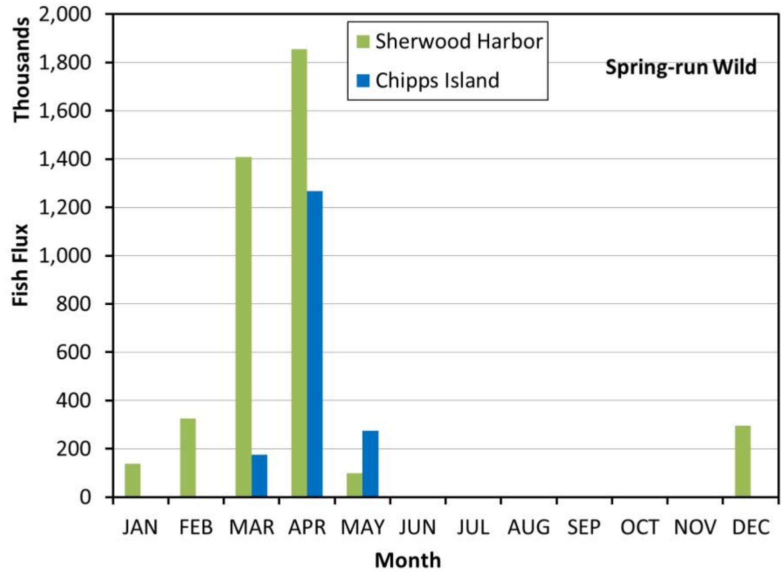

Figure 118. Mean monthly flux of wild juvenile spring-run Chinook salmon in the Sacramento River at Sherwood Harbor and at Chipps Island

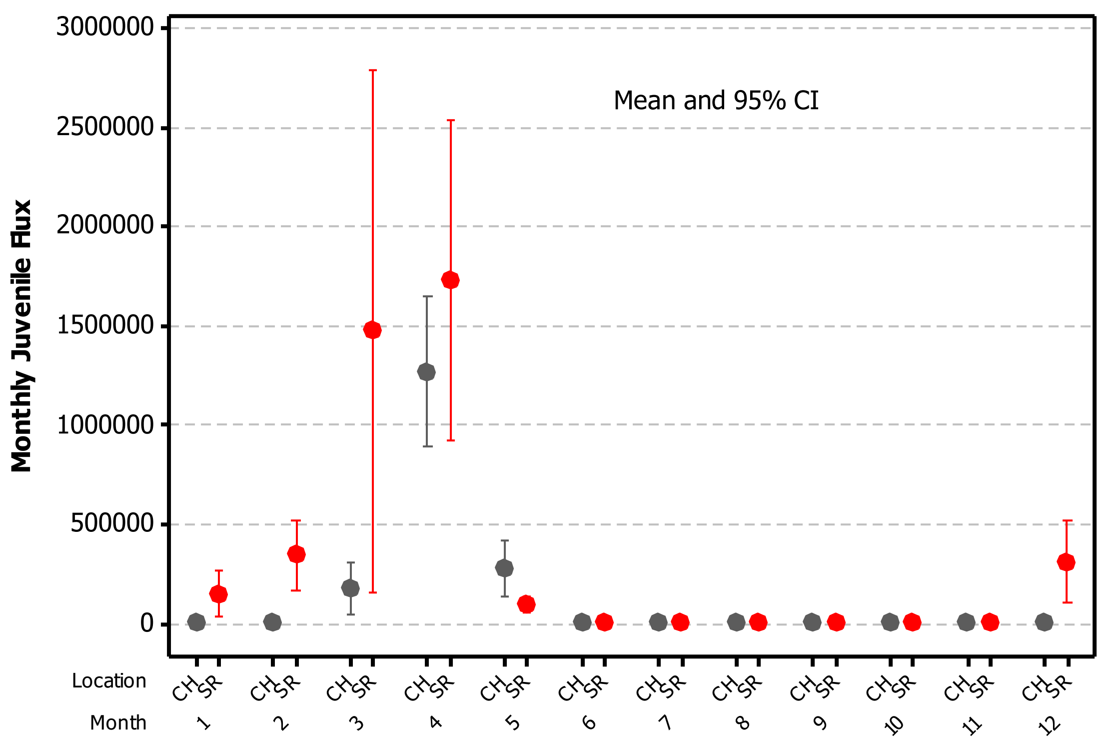

Figure 119. Monthly juvenile flux of wild spring-run Chinook salmon at Chipps Island (CH) and in the Sacramento River at Sherwood Harbor (SR)

The yearly flux of wild juvenile spring-run Chinook salmon at Sherwood Harbor was relatively high from 1992 to 1997 and from 2002 to 2005, and relatively low from 1998 to 2001 and from 2006 to 2011 (Figure 120).

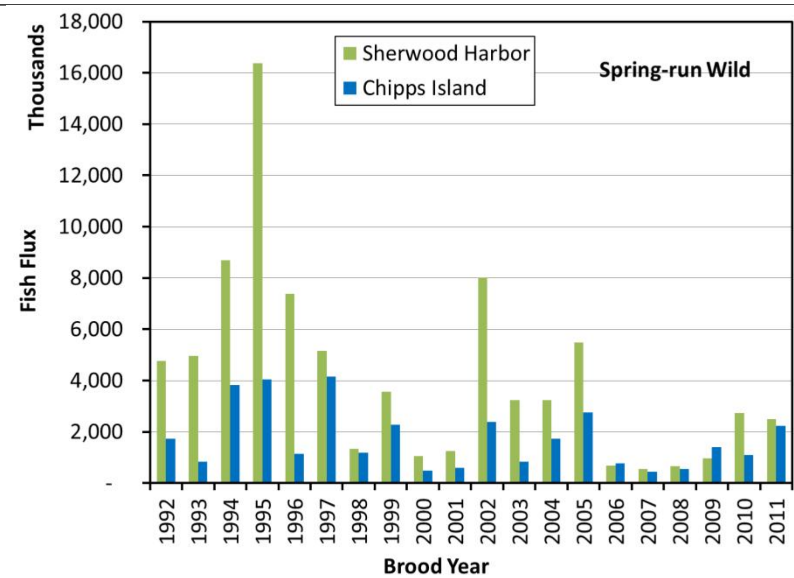

Figure 120. Yearly flux of wild juvenile spring-run Chinook salmon in the Sacramento River at Sherwood Harbor and at Chipps Island

The mean monthly flux of wild juvenile steelhead at Sherwood Harbor was the highest in February and March, followed by April (Figure 121).

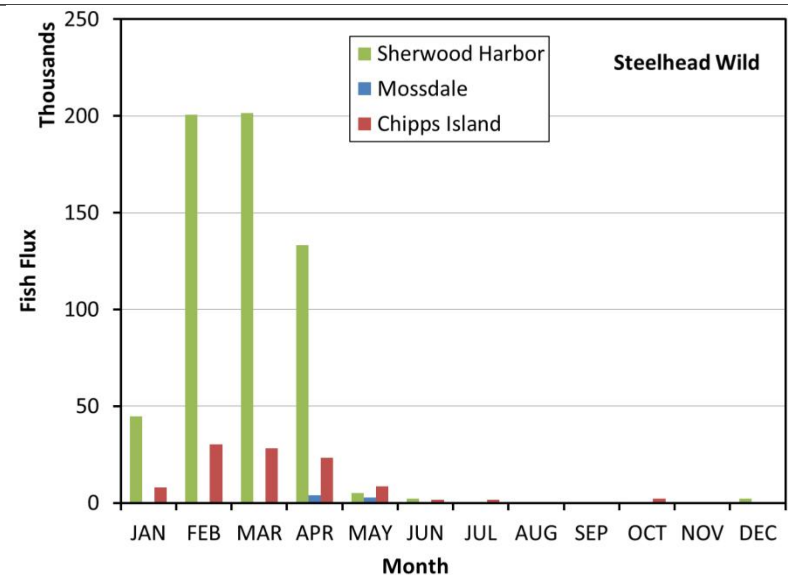

Figure 121. Mean monthly flux of wild juvenile steelhead in the Sacramento River at Sherwood Harbor, in the San Joaquin River at Mossdale, and at Chipps Island

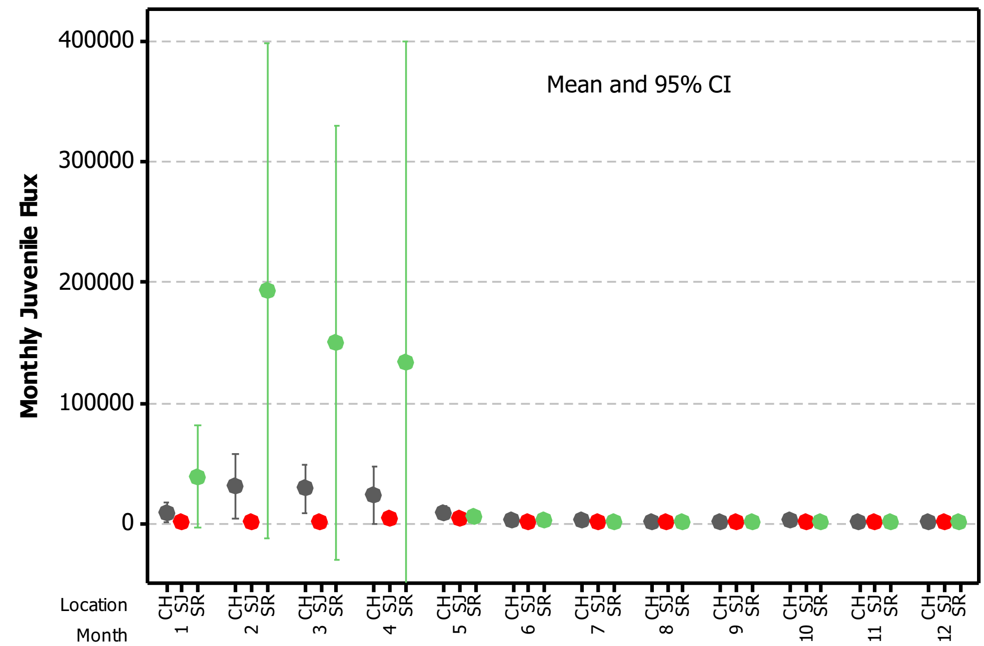

Figure 122. Monthly juvenile flux of wild steelhead at Chipps Island (CH), in the San Joaquin River at Mossdale (SJ), and in the Sacramento River at Sherwood Harbor (SR)

The yearly flux of wild juvenile steelhead at Sherwood Harbor was the highest in 1994. The yearly flux showed a sharp decrease from 1996 to 1997 and has remained very low since 1998 (Figure 123). This is probably related to the requirement to fin clip all hatchery produced steelhead juveniles starting in 1997. The juvenile steelhead flux from the San Joaquin River accounts for very small portion of the total flux.

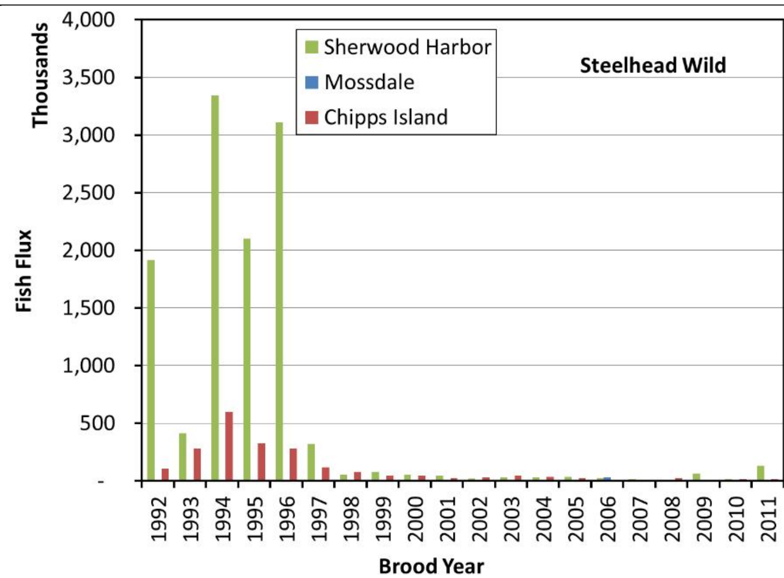

Figure 123. Yearly flux of wild juvenile steelhead.

The mean monthly flux of hatchery juvenile steelhead at Sherwood Harbor was the highest in February, followed by January and March (Figure 124).

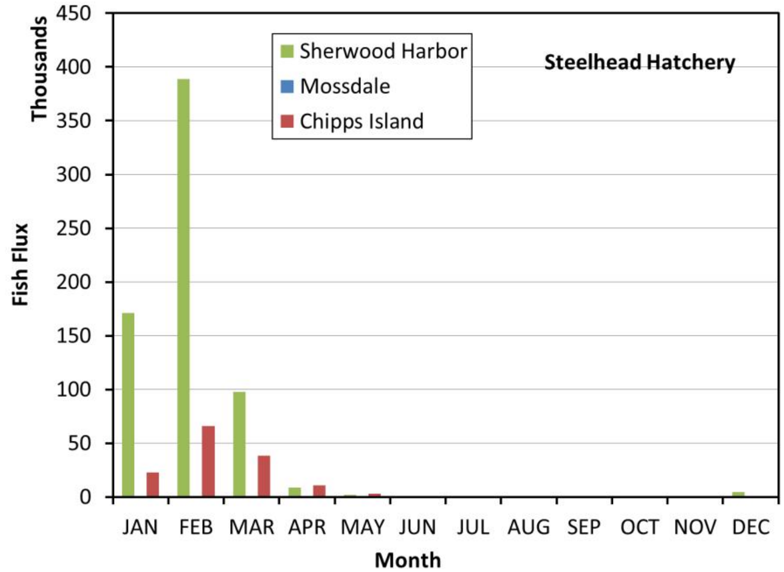

Figure 124. Mean monthly flux of hatchery juvenile steelhead

The yearly flux of hatchery juvenile steelhead at Sherwood Harbor was the highest in 2000. There was no juvenile steelhead flux in 1996 (Figure 125).

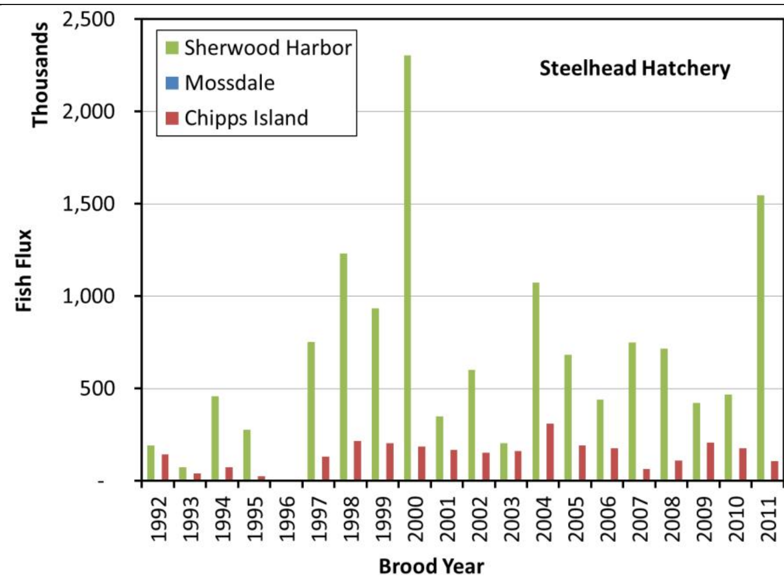

Figure 125. Yearly flux of hatchery juvenile steelhead

4.7 Fish Flux-Based Juvenile Survival Rates through the Delta

The juvenile survival rate through the Delta (from the Delta entrance to the Delta exit) may be estimated from the number of fish leaving the Delta divided by the number of fish entering the Delta—Fish influx, which is the total number of juveniles from the Sacramento River (SR flux), San Joaquin River (SJ flux), and other tributaries. In this report, we use the sum of fish from the Sacramento River and San Joaquin River as the yearly fish influx since the number of juvenile fish from other tributaries is unknown but expected to be smaller than that from the two major rivers.

Wild juvenile winter-run survival rates through the Delta ranged from 0.1 to 0.65 except for 1993 when the survival rate was greater than 1 (1.2) (Figure 126). This is likely caused by uncertainties associated with juvenile monitoring, fish flux computation, and low abundance in 1993. The median survival rate for wild juvenile winter-run Chinook salmon was 0.28, with a mean of 0.31 (excluding 1993). This Delta survival rate for winter-run is comparable to the findings from experimental studies in the Delta. Perry (2010) conducted juvenile survival studies in the Delta using acoustic tagged late fall-run juveniles (smolts). The results indicated that juvenile survival rates through the Delta ranged from 0.16 to 0.40, depending on which route fish took, and the overall survival was estimated to be 0.33. On the other hand, Michel *et al* (2015) found higher Delta survival rates for late fall-run smolts when released in the upper Sacramento River, ranging from 0.43 to 0.71 (2011 wet year).

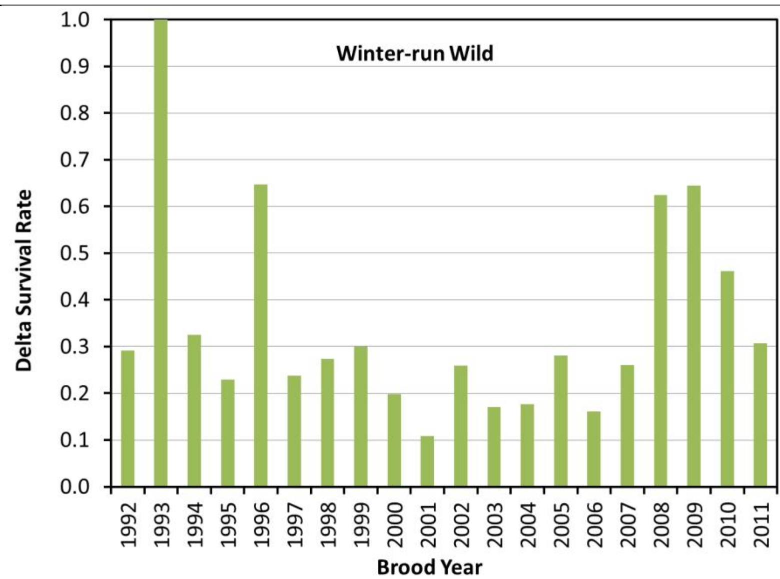

Figure 126. Wild juvenile winter-run survival rates through the Delta

The wild juvenile spring-run survival rates through the Delta ranged from 0.15 to 0.79 except for 2009 when the survival rate was > 1 (1.25) (Figure 127). The median survival rate was 0.43, with a mean of 0.42.

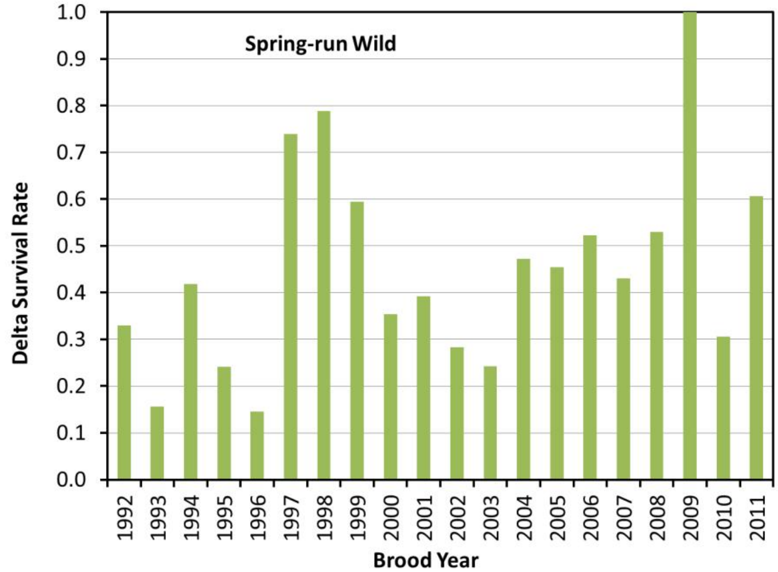

Figure 127. Wild juvenile spring-run survival rates through the Delta

The wild juvenile steelhead survival rates through the Delta ranged from 0.05 to 0.8 except 1998, 2002-2004, and 2008 when the survival rate was close to or greater than 1 (Figure 128). This is likely caused by uncertainties associated with juvenile monitoring and fish flux computation. The median survival rate for wild juvenile steelhead was 0.53, with a mean of 0.38 (excluding survival rates greater than 1).

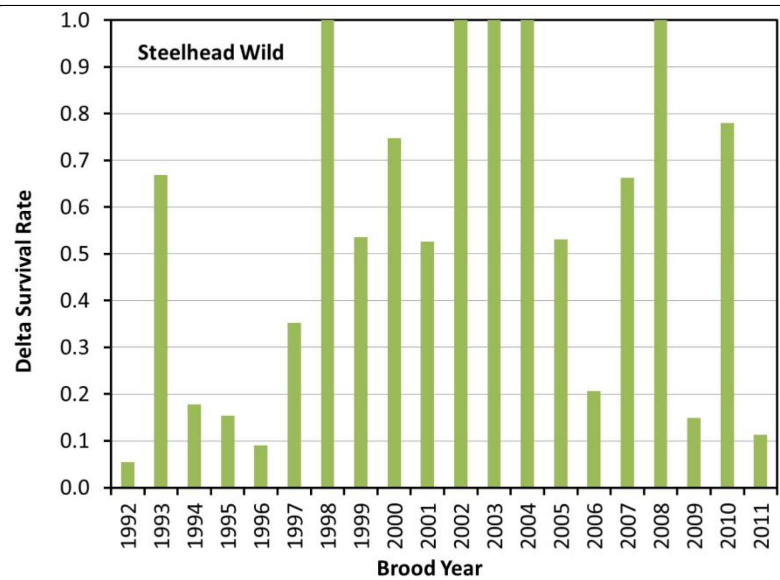

Figure 128. Wild juvenile steelhead survival rates through the Delta

The hatchery juvenile steelhead survival rates through the Delta ranged from 0.1 to 0.8 (Figure 129). The median survival rate for hatchery juvenile steelhead was 0.25, with a mean of 0.31, which is lower than that for wild juvenile steelhead.

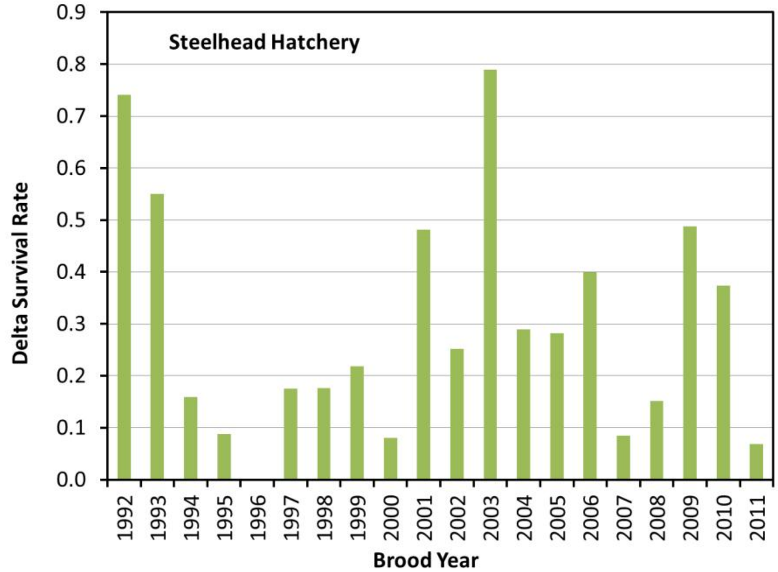

Figure 129. Hatchery juvenile steelhead survival rates through the Delta

4.8 Cumulative Percent Juvenile Flux

The cumulative percent juvenile flux for wild winter-run Chinook salmon is presented in **Error! eference source not found.**. From the cumulative flux, the time period of juvenile migration from Sherwood Harbor to Chipps Island may be estimated. Juveniles appeared to spend longer time in the Delta when they arrived early but shorter time when they arrived late. It was about 43 days for 50% of juveniles that entered the Delta to pass Chipps Island.

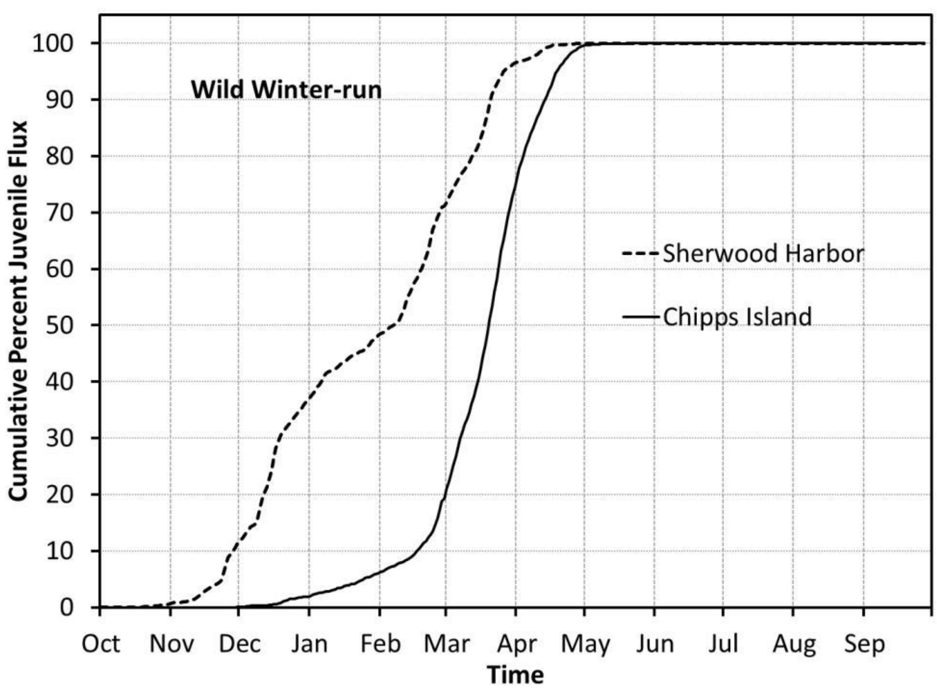

Figure 130. Cumulative percent flux for wild juvenile winter-run Chinook salmon

The cumulative percent juvenile flux for wild spring-run Chinook salmon is presented in Figure 131. Juveniles appeared to spend longer time in the Delta when they arrived early but shorter time when they arrived late. It was about 20 days for 50% of juveniles that entered the Delta to pass Chipps Island.

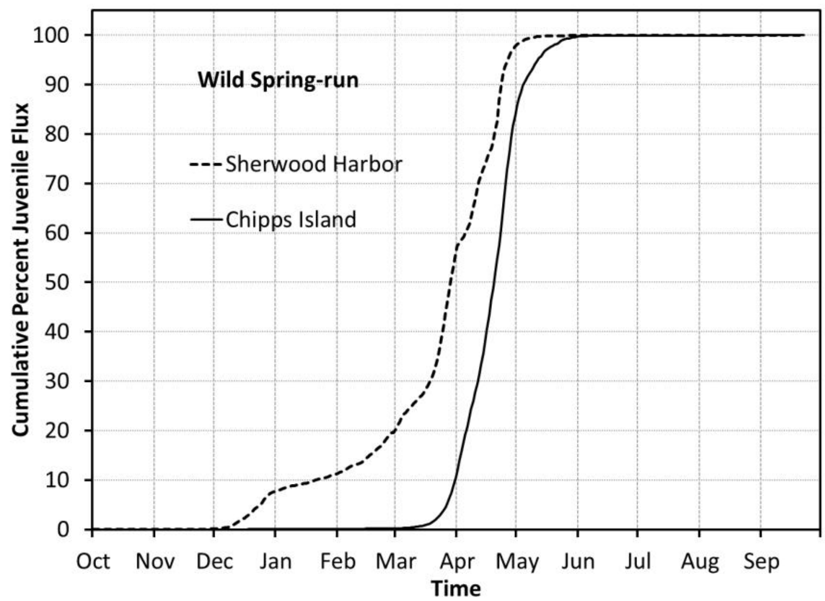

Figure 131. Cumulative percent flux for wild juvenile spring-run Chinook salmon

The cumulative percent juvenile flux for wild steelhead is presented in Figure 132. Steelhead juveniles appeared to spend much less time in the Delta than Chinook juveniles. It was about 7 days for 50% of juveniles that entered the Delta to pass Chipps Island.

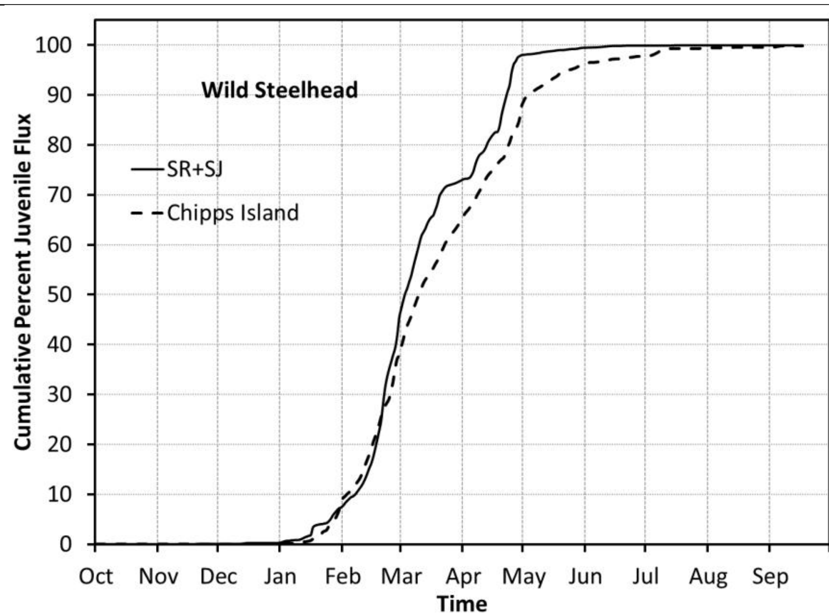

Figure 132. Cumulative percent flux for wild juvenile steelhead

4.9 Juvenile Fish Abundance in the Delta

When juvenile fish enter the Delta, mainly from the Sacramento and San Joaquin rivers, it takes some time before reaching either Chipps Island or water export facilities. This means that the daily total number of juvenile fish in the delta is not equal to the daily net fish flux, which equals the total influx minus the total outmigration. Rather, it is the cumulative number of juveniles for the time period residing in the Delta minus the total number of fish outmigration passing Chipps Island.

The daily total number of juvenile fish in the Delta (Φ) can be estimated as:

$$\Phi = \sum_1^t \{\phi_{in}(1-\gamma)^t\} - \phi_{0ut} \qquad \text{Equation 22}$$

Where

ϕ_{in} = Number of fish entering the Delta
ϕ_{0ut} = Number of fish leaving the Delta
γ = Fish daily mortality rate in the Delta
t = Fish residence time (day) in the Delta

And

$$\phi_{in} \approx \phi_{SJ} + \phi_{SR} \qquad \text{Equation 23}$$

$$\phi_{0ut} = \phi_{WE} + \phi_{CI} \qquad \text{Equation 24}$$

Where

ϕ_{SJ} = Number of fish entering the Delta from the San Joaquin River
ϕ_{SR} = Number of fish entering the Delta from the Sacramento River
ϕ_{WE} = Number of fish leaving the Delta through water export
ϕ_{CI} = Number of fish leaving the Delta at Chipps Island

Since the salvaged fish return to the river upstream of Chipps Island, they would be counted for by the Chipps Island trawl. So Equation 22 becomes

$$\phi_{0ut} = \phi_{CI} \qquad \text{Equation 25}$$

If the average fish residence time in the Delta is 15 days, Equation 20 becomes

$$\boldsymbol{\Phi} = \sum_{\mathbf{1}}^{\mathbf{15}} \{(\boldsymbol{\phi_{SJ}} + \boldsymbol{\phi_{SR}})(\mathbf{1}-\boldsymbol{\gamma})^{15}\} - \boldsymbol{\phi_{CI}} \qquad \text{Equation 26}$$

In theory, all juvenile winter-run or spring-run should come from the Sacramento River. In reality, however, some of the juvenile Chinook originating from the San Joaquin River may be counted as winter-run or spring-run if their sizes fall within the length-at-date of winter-run or spring-run. Since we found that this type of counting was very low for the San Joaquin River Chinook, we reasonably assume that almost all juvenile winter-run or spring-run originate from the Sacramento River. Similarly, most of the juvenile steelhead come from the Sacramento River (about 90% on average).

The daily survival rates (γ) for Chinook salmon or steelhead can be calculated from the overall survival rate and residence time in the Delta. Juveniles may go through four different channels when they migrate from the Sacramento River to pass Chipps Island. Their survival rates depend on what channel they take. In general, survival rates of juveniles staying in the mainstem channel and Sutter and Steamboat sloughs are higher than those traveling through Delta Cross Channel and Georgiana Slough. The overall Delta survival rates for late fall-run Chinook salmon juveniles ranged from 0.16 to 0.40 based on acoustic tag studies conducted from 2006 to 2009, with the average of 0.33 (Perry *et al.* 2010, Perry *et al.* 2013). As provided in section 4.4, the median Delta survival rate was 0.28 for wild winter-run juveniles and 0.43 for wild spring-run juveniles.

Sandstrom (Sandstrom 2013) conducted multiyear acoustic tag studies on steelhead smolts released at sites in the Upper Sacramento River from 2007 to 2011. He found that the average survival rate for steelhead smolts traveling through the Delta was 0.921. As provided in section 4.4, we found that the median Delta survival rate was 0.53 for wild steelhead juveniles.

The residence time or travel time varies with the routes juveniles take. The travel time for the December 2006 (Perry *et al.* 2010, Perry *et al.* 2013) release from the release point (near Sacramento) to the lower delta (Chipps Island) was quickest for fish migrating through Sutter and Steamboat sloughs (median = 7 d), followed by the Sacramento River (median =10.7 d) and the interior delta via the Delta Cross Channel and Georgiana Slough (median =13.8 d). For the January 2007 release, the travel time was similar for fish migrating through the Sacramento River (median=18.1 d) and Sutter and Steamboat sloughs (median=17.8 d). Only one fish traveled through the interior delta, which took 33.9 d to travel from release to Chipps Island. We used the average residence time of 15 d for juvenile Chinook salmon.

Klimley *et al*.(2010) found that it took 8 days on average for steelhead to migrate from Rio Vista to Carquinez. The time would be longer if they went through channels in the interior Delta. We used the residence time of 10 d for juvenile steelhead.

The percent daily fish salvage was calculated by dividing the number of daily fish salvage by the daily fish abundance in the Delta.

Percent daily fish salvage = $\frac{Daily\ Fish\ Salvage}{Daily\ Fish\ Abundance}$

The daily juvenile abundance of wild winter-run is presented in Figure 133 and Figure 134. The abundance was high in December and March.

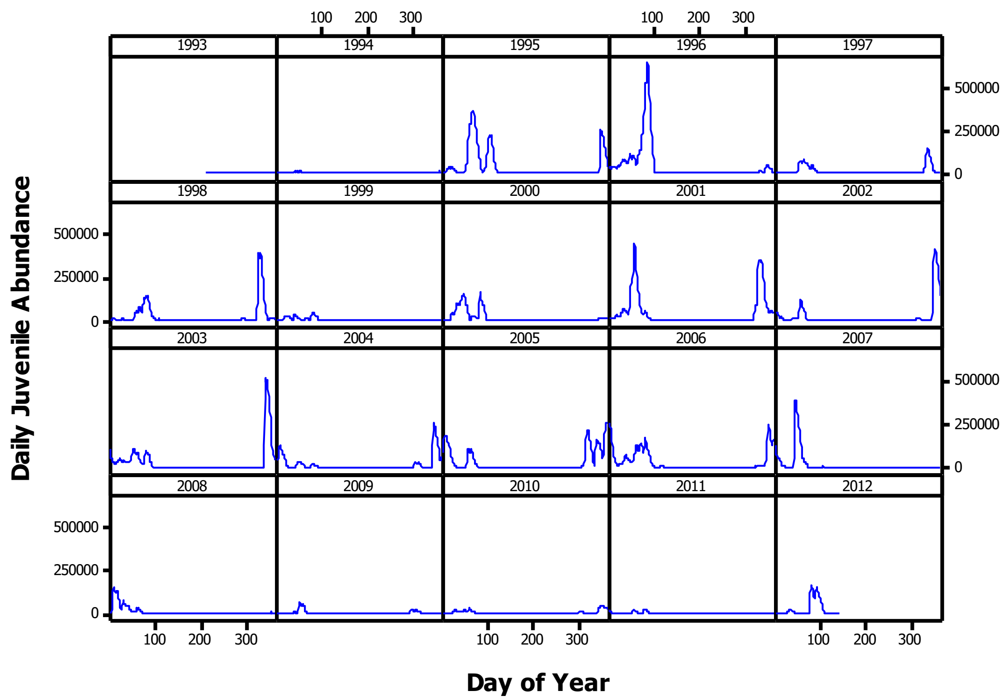

Figure 133. Daily juvenile abundance of wild winter-run Chinook salmon in the Delta from 1993 to 2011

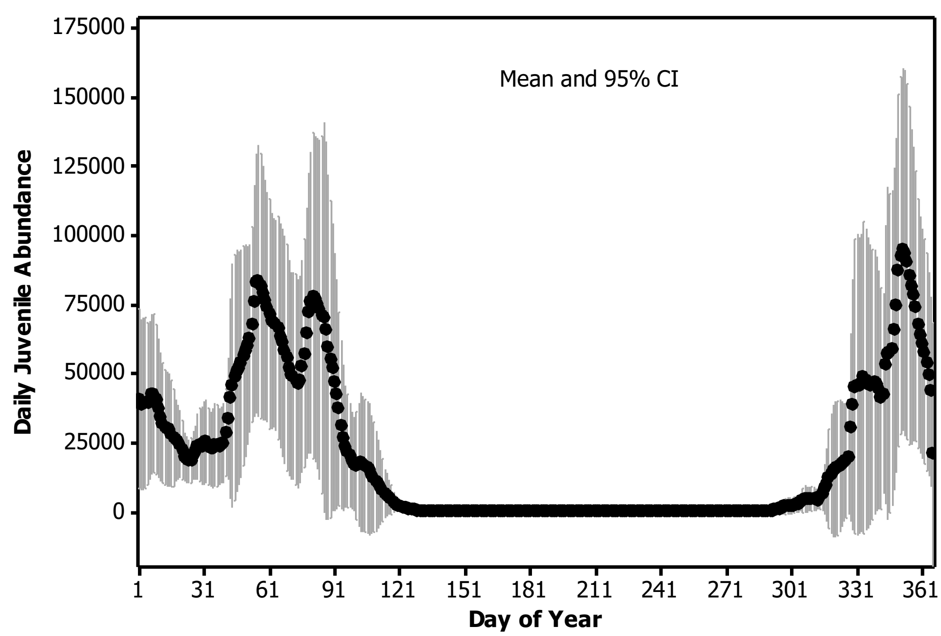

Figure 134. Mean daily juvenile abundance of wild winter-run Chinook salmon in the Delta from 1993 to 2011

The daily juvenile abundance of wild spring-run is presented in Figure 135 and Figure 136. The abundance was high in April.

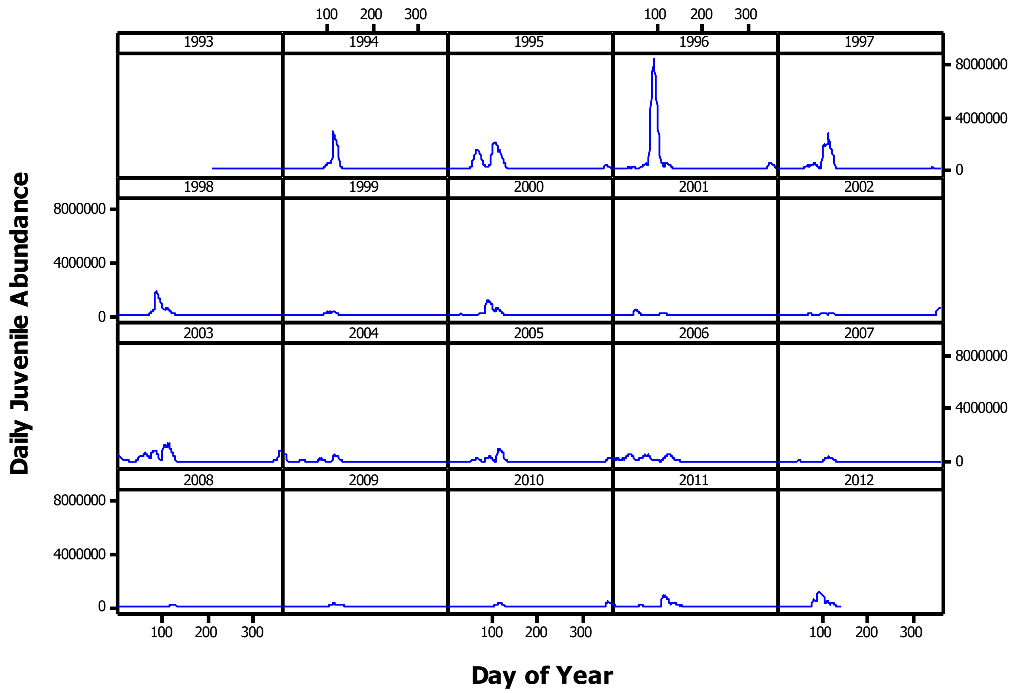

Figure 135. Daily juvenile abundance of wild spring-run Chinook salmon in the Delta from 1993 to 2011

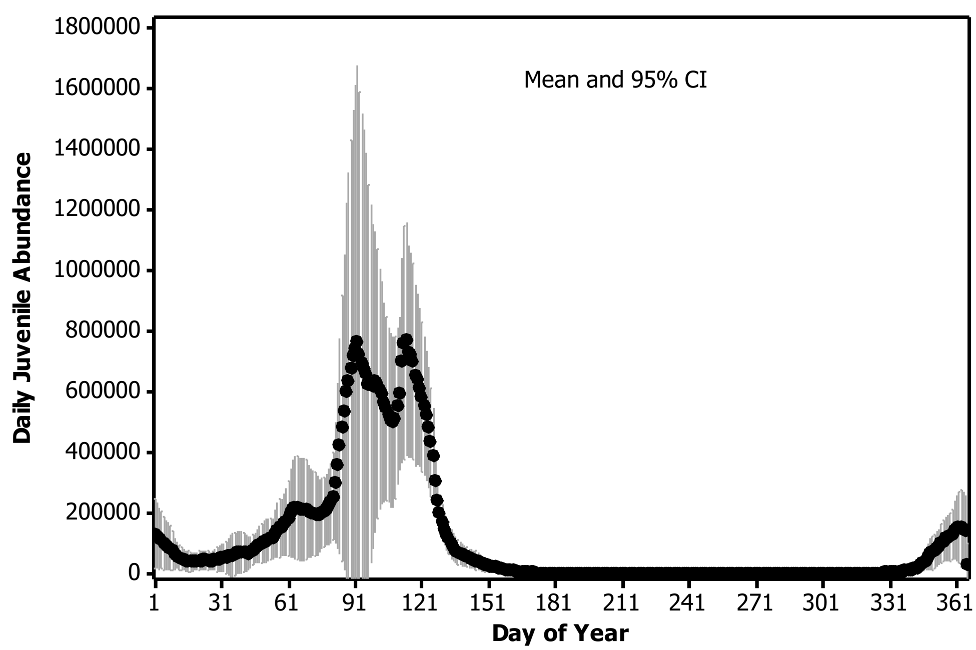

Figure 136. Mean daily juvenile abundance of wild spring-run Chinook salmon in the Delta from 1993 to 2011

The daily juvenile abundance of wild steelhead is presented in Figure 137 and Figure 138. The abundance was high from Mid-February to mid-March and in late April.

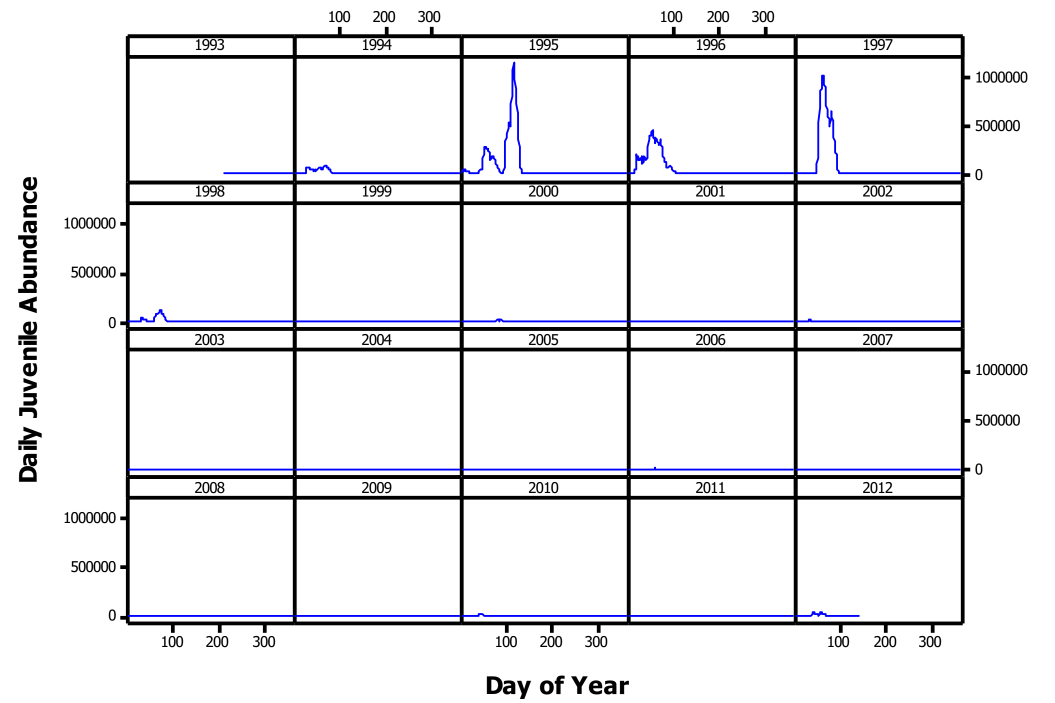

Figure 137. Daily juvenile abundance of wild steelhead in the Delta from 1993 to 2011

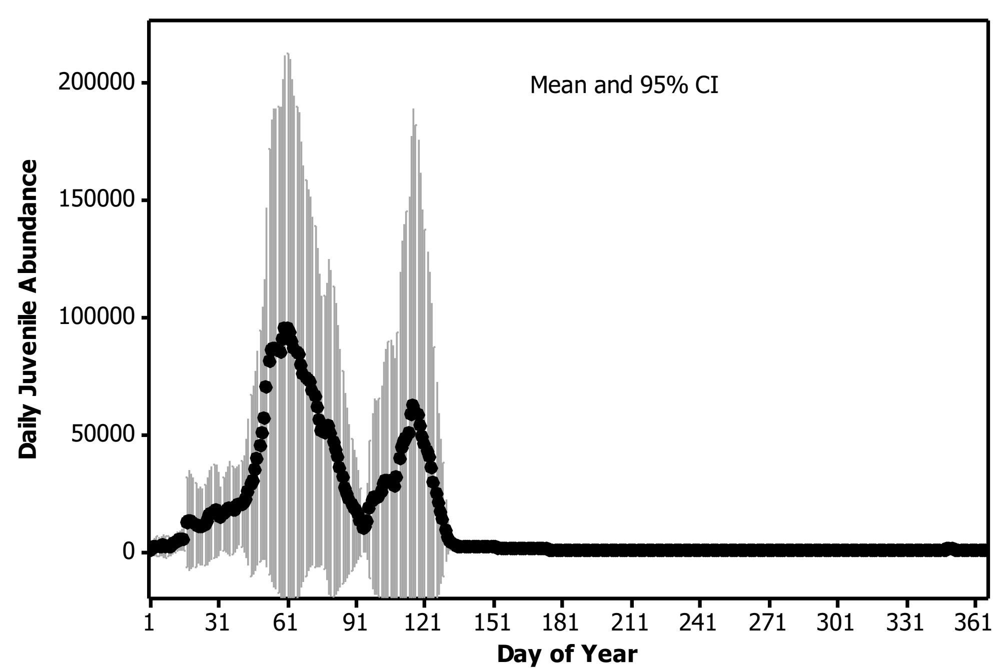

Figure 138. Mean daily juvenile abundance of wild steelhead in the Delta from 1993 to 2011

5 Factors Affecting Juvenile Fish Salvage or Loss in the Delta

Juvenile fish salvage (Γ) or loss (Ψ) at the water export facilities may be affected by a number of factors (i.e., variables), including

- water export (θ),
- fish abundance (ϕ),
- Flow (ζ),
- tide height (ω), and
- predation

There are daily data available for the above variables except for predation, which was not considered in this report due to lack of available data. Juvenile fish salvage or loss may be expressed as the following function:

$$\Gamma \text{ } or \text{ } \Psi = f(\theta, \phi, \zeta, \omega) \qquad \text{Equation 27}$$

Water export includes water exported by the Banks and Jones Pumping Plants. Flow includes Delta inflow, Delta outflow, and OMR flow. Tide height includes maximum, mean, and minimum tide heights. The total number of juvenile fish in the Delta may be expressed as daily fish influx, moving total influx, or daily abundance.

As juvenile fish loss at the water export facilities is an extension of juvenile fish salvage, we assume that correlations between the fish salvage and the factors ($\theta, \phi, \zeta, \omega$) are applicable to those between the fish loss and these factors. We therefore focus on and report fish salvage correlations in this report, which by extension, will also describe fish loss relationships.

We used two methods to evaluate how these factors influence the quantity of juvenile fish salvaged at the SFPF and TFCF. The first method is Pearson's correlation coefficient, which measures the strength of association between two continuous variables. Of interest is whether one variable generally increases as the second increases, whether it decreases as the second increases, or whether their patterns of variation are totally unrelated. This method is very efficient for looking at many correlations when there is a large set of variables for comparison.

The second method is multiple linear regression (MLR) that was used with an attempt to select the "most important" variables affecting juvenile fish salvage. A stepwise regression procedure was used for the MLR. The procedure combines the ideas of the forward and backward methods. It alternates between adding and removing variables, checking significance of individual variables within and outside the model. Variables significant when entering the model will be eliminated if later they test as insignificant.

To evaluate which of the selected variables by a MLR model has a greater effect on the fish salvage, we used standardized coefficients or β coefficients. Standardized coefficients refer to how many standard deviations a dependent variable (fish salvage or loss in our case) will change, per standard deviation increase in the predictor variable (e.g., water export, juvenile abundance, flow, or tide height).

The biggest issue in MLR is multi-collinearity that is the condition where at least one explanatory variable is closely related to one or more other explanatory variables. It can result in coefficients that may be unrealistic in sign (e.g., a negative correlation between fish salvage and water export). Usually this occurs when two variables describing approximately the same thing are counter-balancing each other in the equation, having opposite signs. Concern over multi-collinearity should be strongest when the purpose is to make inferences about coefficients. Concern can be somewhat less when only predictions are of interest, provided that these predictions are for cases within the observed data range of variables (Helsel and Hirsch 2002).

An excellent diagnostic for measuring multi-collinearity is the variance inflation factor (VIF). Serious problems are indicated when VIF > 10 (Helsel and Hirsch 2002). We will eliminate one of the two variables when the VIF indicates a strong correlation between them.

While it is important to point out that correlation does not necessarily imply causation, our scientific knowledge, based on studies on physical processes and fish behavior in the Delta, indicates that water export, fish abundance, flow, and tide height do affect the quantity of juveniles salvaged at the water export facilities. If there were no water export or no fish entering the Delta, there would be no fish salvage or loss. High inflows from the Sacramento River or San Joaquin River might carry a large quantity of juveniles into the Delta and may lead to high salvage. On the other hand, if high inflows result in high outflow, more juveniles might migrate more quickly through the Delta. Higher tides are expected to slow down outflow and push water inward and may lead to more juveniles going to the pumping facilities.

All salvage data were logarithmically transformed prior to analysis. Statistical analyses for the data were performed using SPSS (PASW Statistics 17.0) and Minitab (Minitab 15).

5.1 Wild Winter-run Chinook Salmon

5.1.1 Pearson's Correlation Coefficient

The wild juvenile winter-run salvage or loss at the SFPF, TFCF, or when combined, showed positive correlations with water export (SWP, CVP, or combined), Sacramento River flow, and fish influx or abundance; but negative correlations with OMR flow and SJR I:E ratio. The combined SFPF and TFCF juvenile salvage for winter-run is negatively correlated to the SJR flow at Vernalis (Table 55).

Table 55. Pearson's correlation coefficient for the salvage and loss of wild winter-run Chinook salmon

Variables	Statistic	LN(SWP Salvage)	LN(CVP Salvage)	LN(Combined Salvage)	LN(SWP Loss)	LN(CVP Loss)	LN(Combined Loss)
SWP Export	Pearson r	.407**	.084*	.200**	.393**	.016	.382**
	Sig. (2-tailed)	.000	.023	.000	.000	.668	.000
	N	857	732	1186	836	727	1168
CVP Export	Pearson r	.073*	.247**	.153**	.057	.114**	.062*
	Sig. (2-tailed)	.031	.000	.000	.095	.002	.032
	N	870	744	1204	849	739	1186

Combined Export	Pearson r	.338**	.152**	.214**	.321**	.052	.324**
	Sig. (2-tailed)	.000	.000	.000	.000	.163	.000
	N	857	732	1186	836	727	1168
OMR Flow	Pearson r	-.215**	-.019	-.171**	-.202**	.038	-.189**
	Sig. (2-tailed)	.000	.668	.000	.000	.400	.000
	N	561	500	790	543	495	775
I:E Ratio	Pearson r	-.140**	-.023	-.150**	-.125**	.019	-.121**
	Sig. (2-tailed)	.000	.537	.000	.000	.610	.000
	N	855	729	1183	834	724	1165
SJR Flow	Pearson r	-.049	.001	-.086**	-.042	.003	-.031
	Sig. (2-tailed)	.152	.969	.003	.220	.931	.291
	N	868	741	1201	847	736	1183
SR Flow	Pearson r	.204**	.133**	.111**	.211**	.116**	.184**
	Sig. (2-tailed)	.000	.000	.000	.000	.002	.000
	N	870	744	1204	849	739	1186
Minimum Tide Height	Pearson r	.065	.016	.018	.053	.015	.066*
	Sig. (2-tailed)	.056	.667	.528	.124	.684	.024
	N	870	744	1204	849	739	1186
Mean Tide Height	Pearson r	.139**	.017	.015	.132**	-.011	.070*
	Sig. (2-tailed)	.000	.647	.597	.000	.762	.016
	N	870	744	1204	849	739	1186
Maximum Tide Height	Pearson r	.084*	.034	.023	.085*	-.003	.038
	Sig. (2-tailed)	.013	.361	.423	.013	.925	.193
	N	870	744	1204	849	739	1186
Fish Flux at Sherwood Harbor	Pearson r	.122**	.151**	.076**	.110**	.163**	.072*
	Sig. (2-tailed)	.000	.000	.008	.001	.000	.013
	N	870	744	1204	849	739	1186
Fish Influx	Pearson r	.126**	.154**	.080**	.114**	.167**	.075**
	Sig. (2-tailed)	.000	.000	.006	.001	.000	.010
	N	870	744	1204	849	739	1186
15d Total Influx	Pearson r	.202**	.263**	.166**	.196**	.260**	.149**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	870	744	1204	849	739	1186
Daily Abundance	Pearson r	.176**	.268**	.159**	.169**	.268**	.128**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	801	672	1101	782	667	1085
LN(DA)	Pearson r	.207**	.227**	.187**	.193**	.224**	.162**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	737	630	1017	721	625	1001

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

5.1.2 Multiple Linear Regression

Presented below are regression results for juvenile winter-run when the HORB was not installed. There were only 25 samples for winter-run salvage when the HORB was installed, preventing them from a meaningful regression analysis.

5.1.2.1 SFPF Juvenile Winter-run Salvage

We developed a total of four regression models for juvenile winter-run salvage at the SFPF (Table 56). One model was based on all the available data and the other three models were derived from the data within each month of January through March. We were unable to develop a regression model for the data within December or April as no variables were entered into the model.

Overall, the juvenile wild winter-run salvage at the SFPF increased with increasing SWP water export and juvenile abundance, based on the ALL model. All four selected SWP water export and juvenile abundance, and two models selected tide height. For the four models with water export and juvenile abundance selected, the standardized coefficients for water export were greater than those for juvenile abundance, indicating water export would have larger influence than abundance on wild winter-run salvage at the SFPF. Fish salvage showed a positive correlation with mean tide height for the JAN model whereas a negative correlation with minimum tide height for the MAR model.

Table 56. Summary of multiple regression for wild juvenile winter-run salvage at the SFPF and standardized coefficients for each selected variable when HORB was not installed

Dataset		ALL	DEC	JAN	FEB	MAR	APR	# Models
Number of Samples		469	46	101	117	163	41	**4**
R^2		0.234	NV	0.527	0.501	0.259	NV	
Adjusted R^2		0.231		0.513	0.493	0.245		
p		0.000		0.000	0.000	0.000		
Water Export	SWP	0.387		0.644	0.510	0.432		**4**
	CVP	Not Applicable						
	Combined							
OMR			NV				NV	**0**
Inflow	SR							**0**
	SJR							
	Combined							
Delta Outflow								**0**
I/E Ratio								**0**
Tide Height	Minimum					-0.220		**2**
	Mean			0.265				

	Maximum							
Daily Abundance		0.300			0.451	0.288		**4**
Ln(Daily Abundance)				0.338				

NV = No variables were entered into the equation.
Blanks indicate that a variable was not selected by a model.

5.1.2.2 TFCF Juvenile Winter-run Salvage

We developed a total of six regression models for juvenile winter-run salvage at the TFCF (Table 57). One was based on all the data available and the other five models were derived from the data within each month of December through April.

Overall, juvenile fish salvage at the TFCF increased with increasing CVP water export and juvenile abundance and decreasing mean tide height, based on the ALL model. Four out of the six models selected CVP water export, three models selected abundance, and three models each selected inflow, outflow, or tide height. Fish salvage showed a positive correlation with outflow and negative correlation with the San Joaquin River flow for the JAN model.

Table 57. Summary of multiple regression for wild winter-run salvage at the TFCF and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	DEC	JAN	FEB	MAR	APR	# Models
Number of Samples		416	41	65	130	138	41	**6**
R^2		0.145	0.155	0.408	0.383	0.041	0.360	
Adjusted R^2		0.139	0.134	0.378	0.379	0.033	0.343	
p		0.000	0.011	0.000	0.000	0.018	0.000	
Water Export	SWP	Not Applicable						**4**
	CVP	0.192		0.534		0.201	0.600	
	Combined	Not Applicable						
OMR								**0**
Inflow	SR							**1**
	SJR			-0.350				
	Combined							
Delta Outflow				0.362				**1**
I/E Ratio								**0**
Tide Height	Minimum							**1**
	Mean	-0.102						
	Maximum							
Daily Abundance		0.305	0.394					**3**

Ln(Daily Abundance)				0.619			

Blanks indicate that a variable was not selected by a model.

5.1.2.3 Combined Juvenile Winter-run Salvage

We developed a total of six regression models for combined juvenile winter-run salvage (Table 58). One was based on all the available data and the other five models were derived from the data within each month of December through April.

Overall, the combined juvenile winter-run salvage increased with increasing combined water export and juvenile abundance and decreasing mean tide height, based on the ALL model. Four out of the six models selected water export (SWP, CVP, or combined) and abundance, while two models selected I/E ratio and tide height. Three models each selected OMR flow, inflow, or mean tide height.

Fish salvage showed a positive correlation with the Sacramento River flow and negative correlation with the San Joaquin River flow for the JAN model, negative correlation with OMR flow for the MAR model, and negative correlation with the I/E ratio for the DEC and APR models. The original JAN model selected both the combined export and the SWP export that had a negative sign to the coefficient. This was caused by collinearity between the SWP export and the combined export, with the VIF being 12.2. After the SWP export was deselected, the JAN model selected the CVP export and the combined export, with no collinearity between them. The DEC model indicated a negative correlation with the CVP export and there was no collinearity among the selected variables. When the CVP export was deselected, only the I:E ratio variable was entered into the DEC model.

Table 58. Summary of multiple regression for combined wild juvenile winter-run salvage and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	DEC	JAN	FEB	MAR	APR	# Models
Number of Samples		663	77	134	177	205	68	**6**
R^2		0.131	0.207	0.359	0.359	0.144	0.281	
Adjusted R^2		0.127	0.174	0.352	0.352	0.140	0.259	
p		0.000	0.001	0.000	0.000	0.000	0.000	
Water Export	SWP				0.248			**4**
	CVP		-0.287	0.214				
	Combined	0.204		0.277				
OMR						-0.379		**1**
Inflow	SR			0.439				**1**
	SJR			-0.210				
	Combined							
Delta Outflow								**0**

I/E Ratio			-0.341				-0.420	**2**
Tide Height	Minimum							**1**
	Mean	-0.076						
	Maximum							
Daily Abundance		0.301			0.519			**4**
Ln(Daily Abundance)			0.232				0.451	

Blanks indicate that a variable was not selected by a model.

In summary, both water export and juvenile abundance strongly affected juvenile wild winter-run salvage at the SFPF and TFCF. To a lesser degree, inflow, tide height, and I:E ratio played a role in controlling fish salvage.

5.2 Wild Spring-run Chinook Salmon

5.2.1 Pearson's Correlation Coefficient

The wild juvenile spring-run salvage or loss at the SFPF, TFCF, or when combined, showed positive correlations with water export (SWP, CVP, or combined) and fish influx or abundance; but negative correlations with OMR flow, I:E ratio, and Delta outflow. The combined SFPF and TFCF juvenile salvage for spring-run is negatively correlated to the SJR flow at Vernalis (data not shown).

5.2.2 Multiple Linear Regression

Presented below are regression results for juvenile spring-run when the HORB was not installed.

5.2.2.1 SFPF Juvenile Spring-run Salvage

We developed a total of four regression models for juvenile spring-run salvage at the SFPF (Table 59). One model was based on all the available data and the other three models were derived from the data within each month of March through May.

Overall, the juvenile wild spring-run salvage at the SFPF increased with increasing SWP water export and juvenile abundance (all four models), but decreased with increasing mean tide height (three models). Three models each selected OMR flow, SJR flow, or Delta outflow. Fish salvage showed a positive correlation with the Delta outflow for the APR model whereas a negative correlation with the OMR flow and SJR flow.

Table 59. Summary of multiple regression for wild juvenile spring-run salvage at the SFPF and standardized coefficients for each selected variable when HORB was not installed

Dataset	All	MAR	APR	MAY	# Models
Number of Samples	441	122	172	101	**4**
R2	0.247	0.216	0.484	0.177	

Adjusted R2		0.242	0.196	0.469	0.152	
p		0.000	0.000	0.000	0.000	
Water Export	SWP	0.140	0.387	0.331	0.308	**4**
	CVP	Not Applicable				
	Combined					
OMR Flow				-0.714		**1**
Inflow	SR					**1**
	SJR		-0.197			
	Combined					
Delta Outflow				0.768		**1**
I/E Ratio						**0**
Tide Height	Minimum					**3**
	Mean	-0.217		-0.260	-0.248	
	Maximum					
Ln(Daily Abundance)		0.418	0.162	0.337	0.238	**4**

Blanks indicate that a variable was not selected by a model.

5.2.2.2 TFCF Juvenile Spring-run Salvage

We developed a total of four regression models for juvenile spring-run salvage at the TFCF (Table 60). One model was based on all the available data and the other three models were derived from the data within each month of March through May.

Overall, the wild juvenile spring-run salvage at the TFCF increased with increasing CVP water export and juvenile abundance (all four models), but decreased with increasing mean tide height (two models) and increasing Delta outflow (two models). Two models selected inflow and I:E ratio. Fish salvage showed a positive correlation with the maximum tide height for the MAR model and the combined inflow for the May model, whereas a negative correlation with the SJR flow. For the I:E ratio, one model showed a positive correlation and the other showed a negative correlation with fish salvage.

Table 60. Summary of multiple regression for wild juvenile spring-run salvage at the TFCF and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	MAR	APR	MAY	# Models
Number of Samples		589	157	221	139	**4**
R2		0.322	0.254	0.567	0.537	
Adjusted R2		0.317	0.234	0.559	0.519	
p		0.000	0.000		0.000	
	SWP	Not Applicable				**4**

Water Export	CVP	0.212	0.185	0.433	0.407	
	Combined	Not Applicable				
OMR Flow						**0**
Inflow	SR					**2**
	SJR			-0.513		
	Combined				0.423	
Delta Outflow		-0.186	-0.337			**2**
I/E Ratio				0.168	-0.377	**2**
Tide Height	Minimum					**3**
	Mean	-0.104			-0.235	
	Maximum		0.169			
Ln(Daily Abundance)		0.533	0.492	0.376	0.368	**4**

Blanks indicate that a variable was not selected by a model.

5.2.2.3 Combined Juvenile Spring-run Salvage

We developed a total of four regression models for combined juvenile spring-run salvage at the SFPF and TFCF (Table 61). One model was based on all the available data and the other three models were derived from the data within each month of March through May.

The combined wild juvenile spring-run salvage increased with increasing juvenile abundance (all four models), combined inflow (two models), and CVP export (one model); increased with decreasing mean tide height (two models), I:E ratio (two models), Delta outflow (two models), and OMR flow (one model).

Table 61. Summary of multiple regression for combined wild juvenile spring-run salvage and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	MAR	APR	MAY	# Models
Number of Samples		673	199	239	145	**4**
R2		0.332	0.157	0.505	0.563	
Adjusted R2		0.328	0.148	0.499	0.548	
p		0.000	0.000	0.000	0.000	
Water Export	SWP					**1**
	CVP				0.213	
	Combined					
OMR Flow				-0.994		**1**
Inflow	SR					**2**
	SJR					

	Combined			0.462	0.503	
Delta Outflow		-0.128	-0.282			**2**
I/E Ratio		-0.134			-0.614	**2**
Tide Height	Minimum					**2**
	Mean	-0.149			-0.306	
	Maximum					
Ln(Daily Abundance)		0.553	0.377	0.423	0.407	**4**

Blanks indicate that a variable was not selected by a model.

In summary, both water export and juvenile abundance strongly affected wild juvenile spring-run salvage at the SFPF and TFCF. To a lesser degree, tide height, inflow, Delta outflow, and I:E ratio played a role in controlling juvenile spring-run salvage.

5.3 Wild Steelhead

5.3.1 Pearson's Correlation Coefficient

The wild juvenile steelhead salvage or loss at the SFPF, TFCF, or when combined, showed positive correlations with water export (SWP, CVP, or combined), Sacramento River flow, and fish abundance; but negative correlations with OMR flow and I:E ratio. The combined SFPF and TFCF juvenile salvage for steelhead is negatively correlated to the SJR flow at Vernalis. The daily juvenile steelhead flux from the San Joaquin River at Mossdale is positively correlated to the San Joaquin River flow at Vernalis (data not shown).

5.3.2 Multiple Linear Regression

Presented below are regression results for steelhead when the HORB was not installed.

5.3.2.1 SFPF Juvenile Steelhead Salvage

We developed a total of five regression models for juvenile steelhead salvage at the SFPF (Table 62). One model was based on all the available data and the other four models were derived from the data within each month of January through April. We were unable to develop a regression model for the data within May as no variables were entered into the model.

The wild juvenile steelhead salvage at the SFPF increased with increasing SWP water export (four models) and juvenile abundance (two models), but decreased with increasing OMR flow (one model) and mean tide height (one model). Wild steelhead salvage showed a negative correlation with juvenile abundance for the MAR model.

Table 62. Summary of multiple regression for wild juvenile steelhead salvage at the SFPF and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	JAN	FEB	MAR	APR	MAY	# Models
Number of Samples		410	62	94	87	109	38	**5**
R2		0.126	0.458	0.206	0.443	0.088	NV	
Adjusted R2		0.124	0.440	0.179	0.346	0.080		
p		0.000	0.000	0.000	0.000	0.002		
Water Export	SWP	0.355		0.183	0.307	0.297		**4**
	CVP	Not Applicable						
	Combined							
OMR Flow				-0.335			NV	**1**
Inflow	SR							**0**
	SJR							
	Combined							
Delta Outflow								**0**
I/E Ratio								**0**
Tide Height	Minimum							**1**
	Mean		-0.242					
	Maximum							
Ln(Daily Abundance)			0.637	0.391	-0.402			**3**

Blanks indicate that a variable was not selected by a model.
NV = No variables were entered into the equation.

5.3.2.2 TFCF Juvenile Steelhead Salvage

We developed a total of four regression models for juvenile steelhead salvage at the TFCF (Table 63). One model was based on all the available data and the other three models were derived from the data within each month of January, February, and April. We were unable to develop a regression model for the data within March or May as no variables were entered into the model.

The wild juvenile steelhead salvage at the TFCF increased with increasing CVP water export (three models), juvenile abundance (one model), and SR flow (one model), but decreased with increasing mean tide height (one model).

Table 63. Summary of multiple regression for wild juvenile steelhead salvage at the TFCF and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	JAN	FEB	MAR	APR	MAY	# Models
Number of Samples		292	33	66	67	78	27	
R2		0.133	0.325	0.308		0.455		**4**
Adjusted R2		0.130	0.303	0.286	NV	0.440	NV	
p		0.000	0.001	0.000		0.000		
Water Export	SWP	Not Applicable						
	CVP	0.365		0.461	NV	0.490	NV	**3**
	Combined	Not Applicable						
OMR Flow								**0**
Inflow	SR		0.570					
	SJR							**1**
	Combined							
Delta Outflow					NV		NV	**0**
I/E Ratio								**0**
Tide Height	Minimum							
	Mean					-0.318		**1**
	Maximum							
Ln(Daily Abundance)				0.346				**1**

Blanks indicate that a variable was not selected by a model.

NV = No variables were entered into the equation.

5.3.2.3 Combined Juvenile Steelhead Salvage

We developed a total of six regression models for combined juvenile steelhead salvage at the SFPF and TFCF (Table 64). One model was based on all the available data and the other five models were derived from the data within each month of January through May.

The combined wild juvenile steelhead salvage increased with increasing CVP water export (four models), juvenile abundance (two models), Delta outflow (one model), and SR flow (one model); but decreased with increasing SJR flow (two models), OMR flow (one model), and mean tide height (one model).

Table 64. Summary of multiple regression for combined wild steelhead salvage and standardized coefficients for each selected variable when HORB was not installed

Dataset		All	JAN	FEB	MAR	APR	MAY	# Models
Number of Samples		519	69	112	115	134	55	**6**
R2		0.127	0.290	0.221	0.279	0.280	0.081	
Adjusted R2		0.122	0.279	0.200	0.266	0.269	0.064	
p		0.000	0.000	0.000	0.000	0.000	0.035	
Water Export	SWP							**4**
	CVP	0.123		0.320		0.305		
	Combined						0.285	
OMR Flow		-0.292						**1**
Inflow	SR	0.123						**3**
	SJR			-0.252	-0.785			
	Combined							
Delta Outflow					0.436			**1**
I/E Ratio								**0**
Tide Height	Minimum							**1**
	Mean					-0.292		
	Maximum							
Ln(Daily Abundance)			0.538	0.403				**2**

Blanks indicate that a variable was not selected by a model.

In summary, both water export and juvenile abundance strongly affected wild juvenile steelhead salvage at the SFPF and TFCF. To a lesser degree, inflow, tide height, and OMR flow played a role in controlling steelhead salvage.

The I:E ratio was not selected by any of the 15 MLR models we developed for wild juvenile steelhead, although it was selected by two of the 16 models for wild juvenile winter-run and four of the 12 models for spring-run, one of which is positively correlated to the SFPF salvage. This seems contradictory to the result from the Pearson's correlation coefficient, but actually it is not. The Pearson's correlation coefficient looks at variables individually, while the MLR considers all variables holistically. Even though the combined salvage increases with decreasing I:E ratio, based on the Pearson's correlation coefficient, the I:E ratio was not as a strong variable as water export, juvenile abundance, or inflow affecting the fish salvage. In addition, as it is strongly correlated to water export and inflow, the I:E ratio will not be selected by an MLR model if water export, inflow, or both has been selected by the model.

5.4 Yearly Fish Flux Is Not Significantly Correlated to Yearly Fish Salvage

There is no significant correlation between yearly fish flux and yearly fish salvage for wild winter-run, spring-run, and steelhead and hatchery steelhead, although yearly juvenile savage shows a somewhat increasing trend with increasing yearly juvenile flux (Figure 139, Figure 140, Figure 141, and Figure 142). This implies that the yearly juvenile salvage is also affected by other factors besides the juvenile flux.

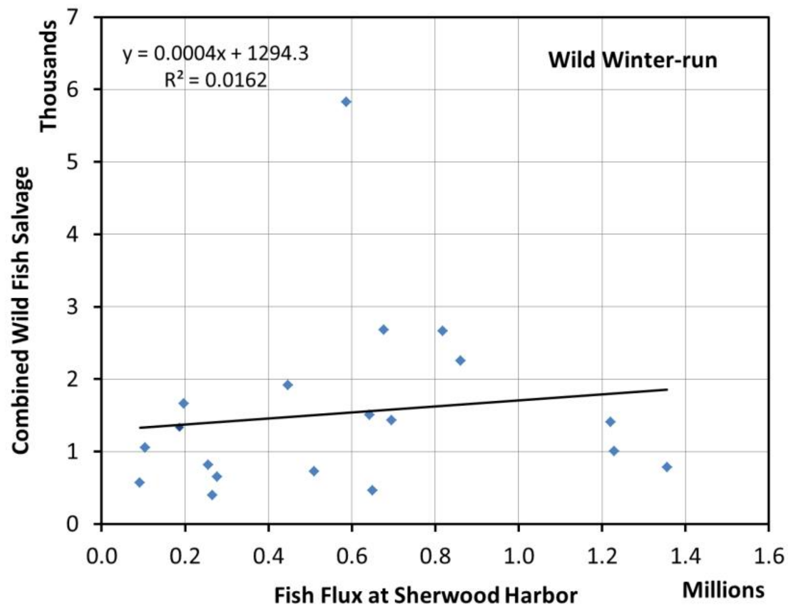

Figure 139. Scatter plot of yearly wild winter-run flux against salvage

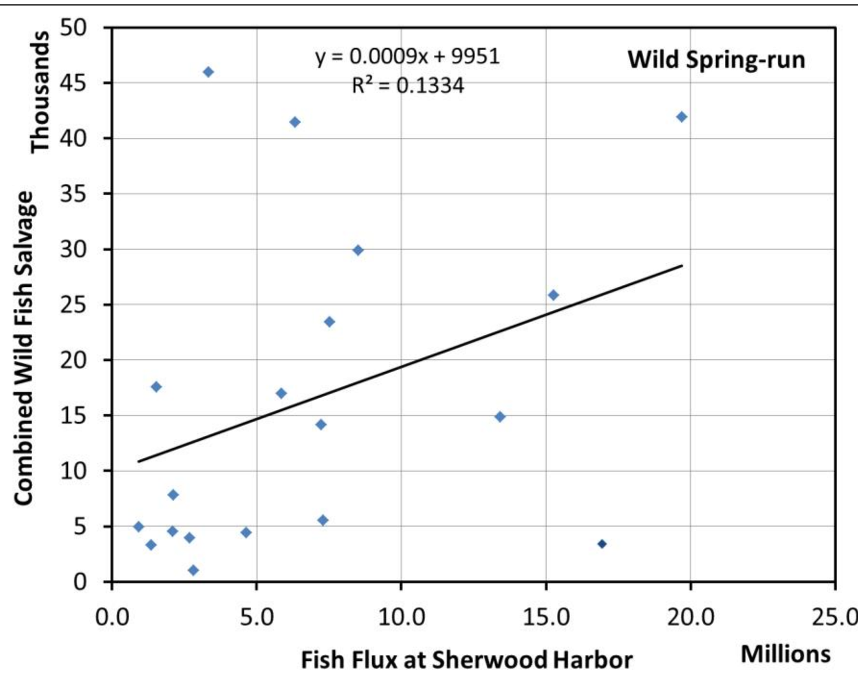

Figure 140. Scatter plot of yearly wild spring-run flux against salvage

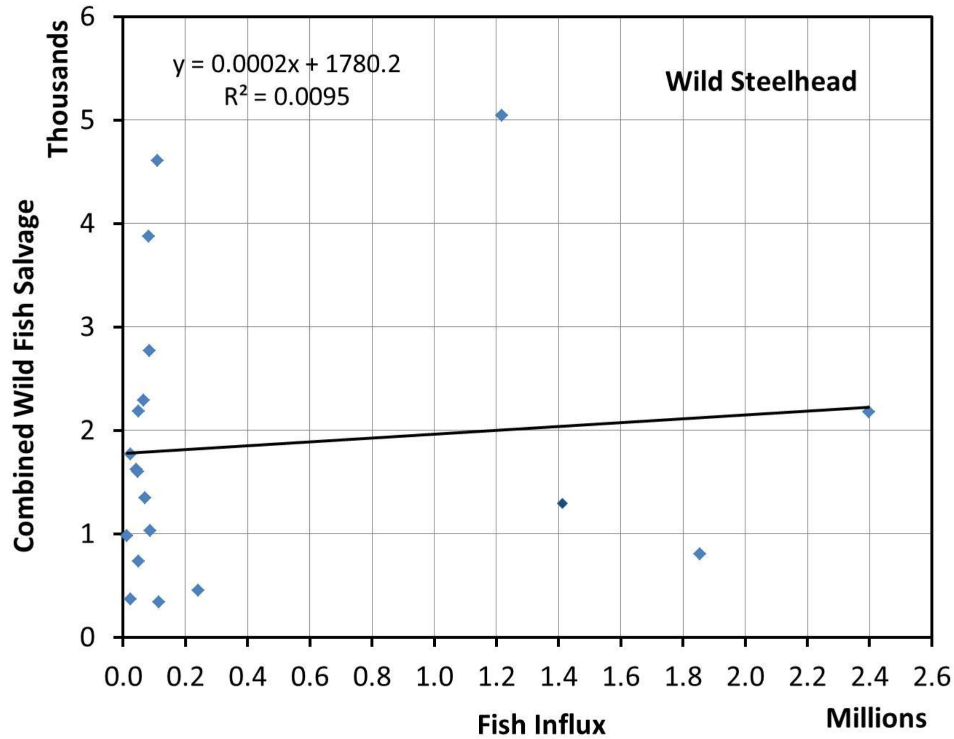

Figure 141. Scatter plot of yearly wild steelhead flux against salvage

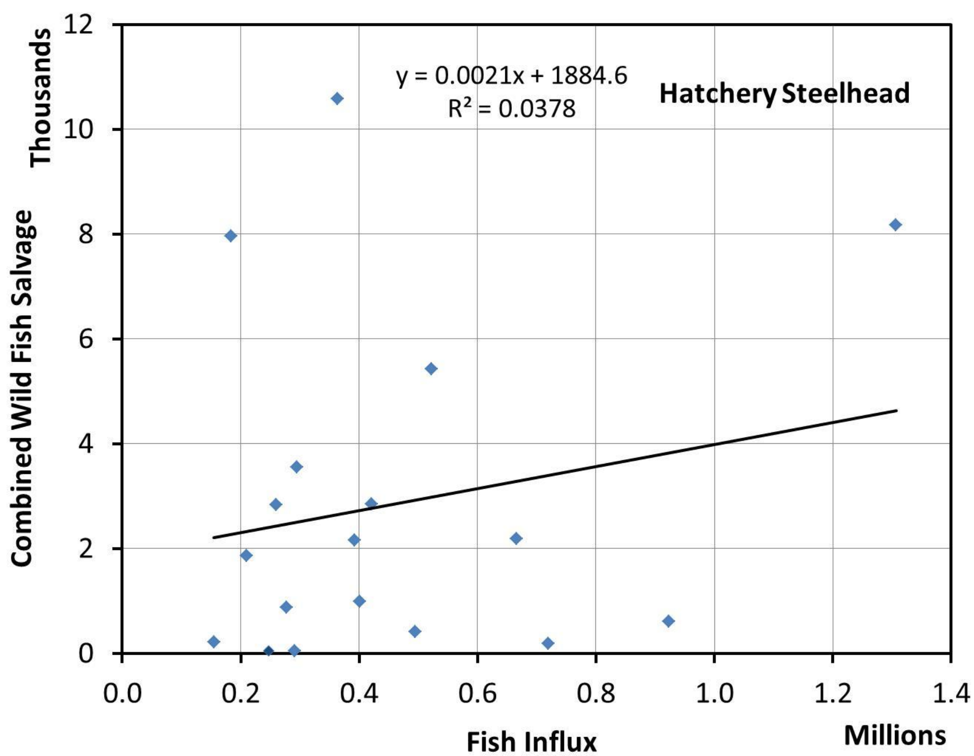

Figure 142. Scatter plot of yearly hatchery steelhead flux against salvage

6 Conclusions

From water year 1956 to 2011, flows from the Sacramento (including Yolo Bypass) and San Joaquin rivers contributed to 93% of the total yearly inflows to the Delta (Figure 6). The yearly Sacramento River flow accounted for about 90% of the combined flow from the Sacramento and San Joaquin rivers. The average monthly inflow to the Delta was highest in February and lowest in October. Flows from the Sacramento (including Yolo Bypass) and San Joaquin rivers contributed to 94-97% of the total monthly inflows to the Delta (Figure 7).

The combined water export through the JPP and BPP showed a linear increase from about 1,000 cfs in late1950s to 6,000 cfs in early 1980s. The increasing trend slowed down since then. The combined water export reached the highest (9,000 cfs) in 2011 (Figure 11). The combined water export was highest in the months of July, August, and September, whereas they were lowest in the months of April and May (Figure 12). Since 1980s, the combined water exports decreased during the months of April and May, while it remained relatively stable for the months of January, February, March, and June. However, the combined water export has steadily increased for the months of July to December (Figure 13). The percent water export over the total inflow was > 40% for the months of July through November since 1990 (Figure 16).

Three OMR flows showed a similar pattern to water exports in seasonal variability—highest (positive or less negative) in April and May and lowest (more negative) in July, August, and September (Figure 18). OMR flows with the spring HORB installed were lower (more negative) than those with no spring HORB installed. The daily OMR flow (OMR2) can be reliably estimated with the following equations (Table 65):

Table 65. Equations for estimating the OMR flow based on the SJR flow and combined water export

HORB	Regression Equation	N	R^2
Installed	$Q_{OMR} = -555 - 0.897\ Q_{EXP} + 0.552\ Q_{SJR}$	5815	0.971
Not Installed	$Q_{OMR} = -1109 - 0.669\ Q_{EXP} + 0.0923\ Q_{SJR}$	230	0.766

The median fish sampling duration at the SFPF was between 20 and 30 minutes except for 1998 when the median duration was 10 minutes (Figure 30 B). The median sampling duration at the TFCF was 10 minutes from 1993 to 2009 and increased to 30 minutes since 2010 (Figure 32 A).

The median primary channel velocity at the SFPF was about 2.6 ft/s since 2000 (Figure 34). There were 2,292 records (3% of the total records) that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the SFPF. The median velocity at the TFCF was 3 ft/s for most years except for 1994, 2008, 2009, and 2012 that showed a velocity of about 1.5 ft/s (Figure 35 B). There were 14,013 records (15% of the total records) that showed that velocities were less than 1 ft/s, which would have resulted in low louver efficiency at the TFCF.

The median size of salvaged salmonid juveniles at the SFPF and TFCF is in the following decreasing order: Steelhead >> Late fall-run > Winter-run > Spring-run ≈ Fall-run. Hatchery fish seemed larger than wild fish for winter-run, fall-run, and late fall-run; smaller for steelhead; and similar for spring-run. The median size of salvaged striped bass was smaller than juvenile Chinook salmon or steelhead. The size distribution of salvaged fall-run juveniles showed two peaks – one around 37 mm and the other around 90 mm. The size distribution of salvaged striped bass also showed two peaks – one around 30 mm and the other around 90 mm.

The diel juvenile salvage patterns for Chinook salmon, steelhead, and striped bass at the SFPF are similar to those at the TFCF. The salvage rates for Chinook salmon were 2-4 times higher at night than in the day. The salvage rates for steelhead were somewhat lower at night than in the day, although the difference is much smaller compared to Chinook salmon. The salvage rate for striped bass was the highest at 2 AM.

The combined mean yearly salvage of salmonid juveniles was about 57,000. The magnitude of juvenile salvage at the SFPF and TFCF varies with species and month. Listed below are three months with the highest juvenile salvage (Table 66).

Table 66. Months with the highest salvage of juveniles

Species	Highest Month	2nd Month	3rd Month
Wild winter-run Chinook salmon	March	February	January
Wild spring-run Chinook salmon	April	May	March
Wild fall-run Chinook salmon	May	June	April
Wild late fall-run Chinook salmon	December	January	November
Wild steelhead	March	February	April
Striped bass	July	June	August

After systematically examining the process of using juvenile salvage data to calculate juvenile losses, we found serious flaws in the current calculation method that underestimates the juvenile loss. We developed new formulas for quantifying juvenile losses at the water export facilities. The loss (Ψ_T) of juvenile Chinook salmon and steelhead should be quantified using the following equation:

$$\Psi_T = N_4 K$$

where N_4 is the number of juveniles salvaged and K is a coefficient varying with facility and species (Table 67). The estimated mean yearly juvenile loss was about 11,000 for wild winter-run, 79,000 for wild spring-run, and 13,000 for wild steelhead.

Table 67. K values for quantifying the fish losses of juvenile Chinook salmon and steelhead

Facility	Fish Density or Primary Channel Velocity	Chinook	Steelhead
SFPF	Low	No Data	9.48
	High	12.53	4.54
TFCF	Low	19.27	1.97
	Median	2.98	No Data
	High	1.50	0.25

We used two methods to compute juvenile flux or abundance in the Delta. The first method is based on trawl efficiency and the second method is based on the depth distribution and migration speed of juveniles. We provide the results from the first method. The mean monthly flux of wild juveniles varies with month and species. The highest monthly flux is in March for wild winter-run Chinook salmon and wild steelhead, and in April for wild spring-run Chinook salmon (Table 68), which correspond to the highest juvenile salvages at the SFPF and TFCF.

Table 68. Months with the highest juvenile flux

Species	Location	Highest Month	2nd Month	3rd Month
Wild winter-run Chinook salmon	Sherwood Harbor	March	February	December
	Chipps Island	March	April	February
Wild spring-run Chinook salmon	Sherwood Harbor	April	March	May
	Chipps Island	April	May	March
Wild steelhead	Sherwood Harbor	March	February	April
	Chipps Island	February	March	April

The median yearly juvenile flux from 1992 to 2011 brood year is summarized in the following table (Table 69). Using the juvenile influx from the Sacramento River at Sherwood Harbor and the San Joaquin River (Mossdale) and outflux at Chipps Island, we calculated the overall Delta survival rates. The median Delta survival rate was 0.41 for wild juvenile winter-run Chinook salmon, 0.26 for wild juvenile spring-run Chinook salmon, and 0.47 for wild juvenile steelhead.

Table 69. Median yearly juvenile flux at three monitoring stations

Species	Sherwood Harbor	Mossdale	Chipps Island
Wild winter-run Chinook salmon	614,513	Not Applicable	201,067
Wild spring-run Chinook salmon	6,093,530	Not Applicable	1,288,216
Wild steelhead	70,931	7,051	38,872

In order to understand how fish abundance influences salvage, we need to estimate the number of juveniles available for entrainment, i.e., the daily juvenile abundance. We developed a method to estimate the daily juvenile abundance in the Delta based on the influx, outflux, daily survival rate, and residence time of juveniles in the Delta.

We finally evaluated how each of the important variables (water export, flow, tide height, and juvenile abundance) affects the juvenile salvage at the SFPF and TFCF using Pearson's correlation and multiple linear regression methods. The fish salvage of wild juvenile winter-run and spring-run Chinook salmon and wild juvenile steelhead was positively correlated to water export (SWP, CVP, or combined), juvenile abundance, Sacramento River flow, or tide height; but negatively correlated to the SJR flow, the OMR flow, the I:E ratio, or Delta outflow. The multiple linear regression results indicate that water export and juvenile abundance are the most important variables impacting the number of juveniles salvaged at the SFPF and TFCF. To a lesser degree, inflow, tide height, the I:E ratio, or the OMR flow played a role in controlling fish salvage.

7 References

Bates, D. W., O. Logan, and E. A. Pesonen. 1960. Efficiency Evaluation Tracy Fish Collecting Facility Central Valley Project California. Department of the Interior.

Bowen, M. D., B. B. Baskerville-Bridges, K. W. Frizell, L. Hess, C. A. Karp, S. M. Siegfried, and S. L. Wynn. 2004. Tracy Fish Facility Studies, California, Volume 11, Empirical and Experimental Analyses of Secondary Louver Efficiency at the Tracy Fish Collection Facility: March 1996 to November 1997.

Brandes, P. L. and J. S. McLain. 2001. Juvenile Chinook Salmon Abundance, Distribution, and Survival in the Sacramento-San Joaquin Estuary. Fish Bulletin **179**:39-138.

Bridges, B., R. C. Bark, and M. D. Bowen. 2013. Predator Impacts on Fish Salvage at the Tracy Fish Collection Facility for Adult Delta Smelt and Juvenile Chinook Salmon. Bureau of Reclamation, Tracy Fish Collection Facility. 16650 Kelso Road, Byron, CA 94514.

Brown, R., S. Greene, P. Coulston, and S. Barrow. 1995. An evaluation of the effectiveness of fish salvage operations at the intake to the California Aqueduct, 1979-1993. in J.T. Hollibaugh editor. San Francisco Bay: The Ecosystem, San Francisco: American Association for the Advancement of Science.

Carter, J. A., G. A. McMichael, I. D. Welch, R. A. Harnish, and B. J. Bellgraph. 2009. Seasonal Juvenile Salmonid Presence and Migratory Behavior in the Lower Columbia River. PNNL-18246, Pacific Northwest National Laboratory, Richland, Washington. 76 p.

Chapman, E. D., A. R. Hearn, C. J. Michel, A. J. Ammann, S. T. Lindley, M. J. Thomas, P. T. Sandstrom, G. P. Singer, M. L. Peterson, R. B. MacFarlane, and A. P. Klimley. 2013. Diel movements of out-migrating Chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss) smolts in the Sacramento/San Joaquin watershed. Environmental Biology of Fishes **96**:273-286.

Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of Pre-Screen Loss of Juvenile Steelhead in Clifton Court Forebay.*in* California Department of Water Resources, editor.

Department of Water Resources and Department of Fish and Game. 1973. Evaluation testing program report for Delta Fish Protective Facility, State Water Facilities, California Aqueduct, North San Joaquin Division. 194 p.

Gingras, M. 1997. Mark/Recapture Experiments at Clifton Court Forebay to Estimate Pre-screening Loss to Juvenile Fishes: 1976-1993. Page 26 *in* C. D. o. F. a. Game, editor. Interagency Ecological Program for the San Francisco Bay/Delta Estuary.

Helsel, D. R. and R. M. Hirsch. 2002. Statistical Methods in Water Resources, Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 p.

Jahn, A. 2011. An Alternative Technique to Quantify the Incidental Take of Listed Anadromous Fishes at the Federal and State Water Export Facilities in the San Francisco Bay-Delta Estuary. Kier Associates. Prepared for National Marine Fisheries Service, Central Valley Office, July, 2011. 64 p.

Karp, C. A., L. Hess, and C. Liston. 1995. Re-evaluation of louver efficiencies for juvenile chinook salmon and striped bass at the Tracy Fish Collection Facility, Tracy, California, 1993. Tracy Fish Collection Facility Studies, California. Volume 3. U. S. Dept. of the Interior Bureau of Reclamation, April 1995. 37 p.

Kimmerer, W. J. 2008. Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science **6**.

Klimley, P., D. Tu, A. Hearn, W. Brostoff, P. LaCivita, and A. Bremner. 2010. Outmigration and Distribution in the San Francisco Estuary: 2006-2008. Interim Draft Report. 68 p.

Michel, C. J. 2010. River And Estuarine Survival And Migration Of Yearling Sacramento River Chinook Salmon (Oncorhynchus tshawytscha) Smolts And The Influence Of Environment. Master's Thesis. University of California, Santa Cruz, Santa Cruz.

Michel, C. J., A. J. Ammann, E. D. Chapman, P. T. Sandstrom, H. E. Fish, M. J. Thomas, G. P. Singer, S. T. Lindley, A. P. Klimley, and R. B. MacFarlane. 2013. The effects of environmental factors on the migratory movement patterns of Sacramento River yearling late-fall run Chinook salmon (Oncorhynchus tshawytscha). Environmental Biology of Fishes **96**:257-271.

Michel, C. J., A. J. Ammann, S. T. Lindley, P. T. Sandstrom, E. D. Chapman, M. J. Thomas, G. P. Singer, A. P. Klimley, and R. B. MacFarlane. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences.

Morinaka, J. 2011. A History of the Operational and Structural Changes to the State Fish Salvage Facility from 1968 – 2010. Draft Report. November 3, 2011. California Department of Fish and Game, Bay Delta Region, 4001 N. Wilson Way, Stockton, CA 95205. 61 p.

O’Brien, J. 2011. 2010 Mossdale trawl summary. Pages 99-106 *in* San Joaquin River Group Authority, editor. On implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). 2010 annual technical report.

Perry, R. W. 2010. Survival and Migration Dynamics of Juvenile Chinook Salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin River Delta. Ph.D. Dissertation. University of Washington.

Perry, R. W., P. L. Brandes, J. R. Burau, A. P. Klimley, B. MacFarlane, C. Michel, and J. R. Skalski. 2013. Sensitivity of survival to migration routes used by juvenile Chinook salmon to negotiate the Sacramento-San Joaquin River Delta. Environmental Biology of Fishes **96**:381-392.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating Survival and Migration Route Probabilities of Juvenile Chinook Salmon in the Sacramento-San Joaquin River Delta. North American Journal of Fisheries Management **30**:142-156.

Pyper, B., T. Garrison, and S. Cramer. 2013a. Analysis of trawl efficiency at Chipps Island using coded-wire-tagged releases of juvenile Chinook salmon. 97 p.

Pyper, B., T. Garrison, S. Cramer, P. Brandes, D. Jacobson, and M. Banks. 2013b. Absolute abundance estimates of juvenile spring-run and winter-run Chinook salmon at Chipps Island. 89 p.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Canada.

Sandstrom, P. 2013. Survival of Juvenile Steelhead Trout Using Acoustic Telemetry: A Field and Laboratory Study. UC Davis Dissertation.

Sanstrom, P. 2012. Sacramento River Steelhead: Hatchery vs. Natural Smolt Outmigration. A 2-page document published by the Delta Science Program of the Caliofrnia Delta Stewardship Council and California Sea Grant.

Skinner, J. E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. Proceedings of the Second Entrainment and Intake Screening Workshop. L.D. Jensen (ed.). The John Hopkins University Cooling Water Research Project, Report No. 15.

U.S. Fish and Wildlife Service. 2007. Abundance and survival of juvenile Chinook salmon in the Sacramento-San Joaquin estuary. 2001-2005 annual progress report. August 2007., U.S. Fish and Wildlife Service, Stockton, California.

U.S. Fish and Wildlife Service. 2012. Metadata for the Stockton Fish and Wildlife Office's San Francisco Bay/San Joaquin Delta Juvenile Fish Monitoring Program. Stockton Fish and Wildlife Office. October 2012. 19 p.