CHAPTER 5

SALMON SMOLT SURVIVAL INVESTIGATIONS

The 2011 VAMP is the 6th year that acoustic technology was used to estimate juvenile salmon survival in the southern Sacramento-San Joaquin Delta (2006-2011), and the third year where survival was estimated through the Delta to Chipps Island (2008, 2010 and 2011). Prior to 2007, coded wire tag studies were used to estimate survival through the Delta. As part of the background for reporting the results of the 2011 study, the previous coded wire tag studies conducted in the south Delta and through the Delta prior to the VAMP (1994-1999), during the VAMP (2000-2006) and results of the previous acoustic studies (2006-2010) are summarized below. More detail on each annual study is provided in previous reports and specific references are shown in Table 5-1.

Table 5-1
Reference Citations for Past Reports that Have Reported on Annual South Delta Salmon Smolt Survival Since 1994. Full Reference Citations are Found in the Reference List at the End of this Report

Study Type	Study Year	Reference List Citation
Pre-VAMP	1982-1995	USFWS, 1987
		Brandes and McLain, 2001
Pre-VAMP	1996	Brandes and McLain, 2001
		IEP 1996
Pre-VAMP	1997	Brandes and McLain, 2001
		IEP 1998
		DWR, 1998
Pre-VAMP	1998	IEP, 1999c
Pre-VAMP	1999	Brandes, 2000
		DWR, 2001
VAMP	2000	SJRGA, 2001
VAMP	2001	SJRGA, 2002
VAMP	2002	SJRGA, 2003
		DWR, 2003
	2003	SJRGA, 2004
VAMP	2004	SJRGA, 2005
VAMP	2005	SJRGA, 2006
VAMP	2006	SJRGA, 2007
VAMP	2007	SJRGA, 2008
VAMP	2008	SJRGA, 2009
		Holbrook et al, 2009
		Holbrook et al., 2013
VAMP	2009	SJRGA, 2010
		Buchanan et al., 2013
VAMP	2010	SJRGA, 2011
		Buchanan et al., 2013

Conceptual Model

The main objective of the VAMP was to better understand the relationship between Chinook salmon smolt survival through the Delta and San Joaquin River flows, combined Central Valley Project (CVP) and State Water Project (SWP) exports and installation of the head of Old River barrier (HORB). Survival during the smolt life-stage was assumed to be the mechanism associated with two statistically significant linear regressions between escapement and 1) San Joaquin River flow at Vernalis and 2) the ratio of San Joaquin River flow to CVP and SWP exports, 2 ½ years earlier (Figures 5-20 and 5-21 in SJRGA, 2007). It is these relationships between flow and flow/exports and escapement that are the basis for the hypothesis that increasing flow and decreasing exports during the smolt outmigration would increase adult escapement and production in the San Joaquin River basin.

Pre-VAMP and VAMP CWT studies

Between 1985 and 2006, juvenile salmon from Feather River Hatchery (FRH) or Merced River Hatchery (MRH) were marked and released to estimate survival in, or through, the Delta. The marked salmon were released at various locations in the Delta and reflect the evolution of different hypotheses and study designs. Coded wire tagged (CWT) fish used in the pre-VAMP studies were from FRH in study years 1989-1998 and from MRH in 1986-1989 and 1996-1999. Between 1996 and 1998, hatchery fish from MRH were paired with those from FRH and after 1999 only MRH stock were used in the experiments. Pre-VAMP studies were also conducted in 1985 using fish from MRH, but were marked using spray-dye.

The first pre-VAMP studies compared survival between marked FRH smolts released into upper Old River to FRH smolts released on the mainstem San Joaquin River at Dos Reis. These studies were conducted between 1985 and 1990 and suggested that survival was higher for fish released on the mainstem San Joaquin River at Dos Reis than for fish released into Old River (Brandes and McLain, 2001). The results of these studies were the basis for recommending a rock barrier at the head of Old River (HOR) to prevent juvenile salmon from migrating down Old River where survival appeared to be less.

Starting in 1994, survival was estimated through the Delta by pairing upstream releases to control releases at Jersey Point. This allowed absolute survival to be estimated between the upstream release location and Jersey Point using the relative recovery rate of marked fish from the upstream group relative to the control/downstream group. Recoveries were made at Chipps Island and in the ocean fishery and later, as part of the VAMP, at Antioch. Survival was estimated as part of the pre-VAMP studies between 1994 and 1999, with two of those years (1994 and 1997) measuring survival when the physical rock barrier was installed at the head Old River. The VAMP studies began in 2000 and continued until 2006 using juvenile salmon from MRH marked with CWTs. Marked fish were released both upstream (Mossdale and/or Durham Ferry) and downstream (Jersey Point) to estimate survival through the Delta. In 2006, acoustic tags were also used in the south Delta, as part of a pilot study. Between 2007 and 2011, acoustic tags were used to estimate survival in the south Delta (2007, 2009) or through the Delta to Chipps Island (2008, 2010 and 2011).

Between 1994 and 1999 marked fish were released on the San Joaquin River at Mossdale and Jersey Point. Starting in 2000, releases were also, or alternatively, made at Durham Ferry to allow the fish more distance to distribute naturally in the river channel prior to reaching the junction with Old River. To assess the mortality between Durham Ferry and Mossdale, releases were made at both locations in most years between 2000 and 2005. In 2006, releases were made only at Mossdale because San Joaquin River flows were so high that part of the flow was diverted into Paradise Cut (a flood bypass), which is upstream of Mossdale, but downstream of Durham Ferry. To better compare results to other VAMP years, when San Joaquin River flow was not diverted into Paradise Cut, the release site was changed from Durham Ferry to Mossdale in 2006. The releases at Jersey Point were generally made on a flood tide to increase fish dispersion throughout the channel before the tagged fish migrated downstream and encountered the recovery trawls at Antioch and Chipps Island. Releases at other locations generally did not incorporate the tides for determining release times.

In some years CWT releases were also made at Dos Reis which is located on the San Joaquin River downstream of the head of Old River and was used to help assess the mortality of marked salmon on the San Joaquin River downstream of Old River. Although it is assumed that fish released at Dos Reis migrated downstream via the mainstem San Joaquin River, there is the potential for fish released at Dos Reis to have moved upstream into Old River on flood tides, especially during periods of low San Joaquin River flows and high exports or into the interior Delta via Turner or Columbia Cuts or other downstream connections to the interior Delta.

For the releases of CWT fish, the water temperature in the hatchery truck was usually about 10 degrees lower than at the release site. This differential in water temperature between the hatchery truck and release sites potentially could have affected the survival of the study fish. To assess how these differences in water temperature might affect the short term survival of the study fish, a subset of the study fish were held for 48 hours and evaluated for health and physiological state starting in 1996 and has continued throughout the VAMP. The holding of fish for 48 hours also was used to determine if the handling, transport, and release processes affected the immediate and short-term (48 hour) survival and general condition of the experimental fish used in the VAMP and pre-VAMP experiments.

The purpose of the physiological and health assessments was to rule out survival differences due to differential health between release groups and between years. Sub-samples of fish held in net pens for all years were generally in good condition. In years where CWT fish were released, between 0 and 19 total mortalities were observed in the subsets of approximately 1,200 fish per year, after the 48-hour holding period. Mortality in 1998 was higher and was estimated to be as great as 9.2% for the Jersey Point release made on April 28, 1998, (IEP 1999a), which may have biased survival high in that year. In contrast, the health assessments conducted in 1998 concluded that the overall health of the fish examined as part of the pre-VAMP study appeared good (IEP, 1999b).

Table 5-2
Prevalence of *Tetracapsuloides bryosalmonae* (Tb) Detected in Merced River Hatchery Smolts 1996 – 2011. All Samples Were Taken from VAMP (and Precursor Project) Release Groups [1].

Year	Sample Dates	Tb Prevalence	Additional Information
1996	1 May	63% (5/8)	38% of Merced River Hatchery fish with kidney inflammation.
1997	1 May	0% (0/10)	
1998	17 Apr	0% (0/6)	No histopathology this study. No swollen or hemorrhaging organs reported
1999	20 Apr	0% (0/6)	Histopathology from only 1 release group
2000	18 Apr - 2 May	4% (2/45)	No kidney inflammation observed
2001	1 - 12 May	100% (34/34)	Increased kidney inflammation in second set of releases
2002	19 Apr - 1 May	46% (93/201)	Kidney inflammation observed in 2/201 fish examined
2003	21 Apr - 2 May	63% (30/48)	Increased gross clinical signs of PKD in later release groups
2004	22 - 26 Apr	50% (33/66)	Kidney inflammation in 5-14% of fish
2005	2 - 20 May	38% (6/16)	Overall mild PKD observed
2006	4 - 22 May	0% (0/20)	
2007	3 - 11 May	100% (30/30)	All early infections. No kidney inflammation observed.
2008	29 Apr - 8 May	79% (86/109)	Less than 30% with kidney inflammation
2009	23 Apr - 14 May	13% (10/76)	No kidney inflammation observed
2010	28 Apr - 20 May	100% (89/89)	31%-87% of fish with kidney inflammation
2011	19 May - 16 Jun	4% (3/78)	No kidney inflammation observed

[1] Fish were Assessed by Histopathological Examination of Posterior Kidney by the USFWS CA-NV Fish Health Center to Determine if Tetracapsuloides bryosalmonae Infections were Severe Enough to Influence Survival of the Study Groups During the Out-migration (2 – 3 Weeks Post Release). A Difference in Kidney Inflammation Between Upstream and Jersey Point Groups Could Help Explain Reduced Survival During Out-migration, but There was No Evidence There was Differential Infection Rates Within Paired Releases. Starting in 2007, Acoustic-tagged Fish were Used for the Studies and a High Prevalence of PKD Could Affect the Survival Rates of Acoustic-Tagged Fish Used in These Studies, as the Acoustic Tag Methodology Does Not Pair Upstream and Downstream Groups for Estimating Survival but There was no Evidence There was an Effect.

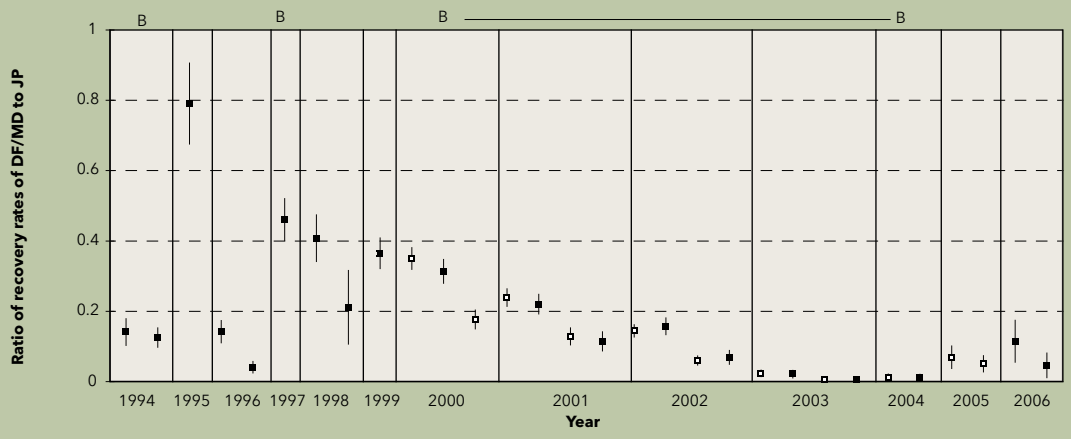
The USFWS California-Nevada Fish Health Center looked at health (bacterial, viral, and parasitic infections), smolt development, and stress response to determine if there were significant differences between CWT groups within a year that might affect survival estimates. While differences in smolt development and stress response were noted in some years, the most significant factor affecting survival for the fish used in the VAMP and pre-VAMP studies was infection with *Tetracapsuloides bryosalmonae* (the myxosporean parasite which causes Proliferative Kidney Disease (PKD))(Table 5-2). PKD is a progressive disease at water temperatures greater than 15° C and at water temperatures of 9° C the parasite can infect fish but it cannot multiply. The primary host for the parasite is bryozoan (Okamura and Wood, 2002). *T. bryosalmonae* infection can reduce a fish's performance due to associated kidney dysfunction and anemia. However, infection with the parasite does not necessarily kill the fish. *T. bryosalmonae* has been reported at MRH since the 1980's (Hedrick et al., 1986, as cited in Nichols and Foott, 2002) and in California since at least 1966 (Hedrick et al., 1985 as cited in Nichols and Foott, 2002). In 2001, *T. bryosalmonae* was found in over 90% of the samples tested from naturally spawned Chinook salmon on the Merced River (Nichols and Foott, 2002). T. bryosalmonae was present in fish used for the VAMP (Table 5-2).

To estimate survival through the Delta for CWT smolts released at Durham Ferry or Mossdale, recoveries from upstream groups were compared to releases made at Jersey Point to obtain a differential recovery rate between the two groups. The survival between the upstream and downstream location, estimated by dividing the recovery rate of the upstream group by the recovery rate of the downstream group, theoretically standardizes for differences in catch efficiency of recovery locations within and between years. Tagged fish were recovered at Chipps Island and as adults in the ocean fishery. Tagged fish were also recovered at Antioch starting in 2000.

Smolt survival between Durham Ferry or Mossdale and Jersey Point has varied considerably between 1994 and 2006 with differential recovery rates ranging from 0.01 to 0.79 (Figure 5-1). The year with the highest survival was 1995 and the years with the lowest survival were 2003 and 2004. Since 1997, there has been a general decline in survival (Figure 5-1). Survival rebounded slightly in 2005 and 2006 (Figure 5-1).

A statistically significant relationship between survival in the reach between Mossdale or Durham Ferry and Jersey Point and San Joaquin River flow at Vernalis has been observed with the HORB in place (1994, 1997, 2000-2004) ($r^2 = 0.73$, $p<0.01$; Figure 5-11 in SJRGA,

Figure 5-1
Estimates of Smolt Survival (+/- two Standard Errors) from Mossdale (Closed Squares) or Durham Ferry (Open Squares) to Jersey Point Between 1994 and 2006 Using Coded-wire-tagged Fish. Years with the Physical Head of Old River Barrier Installed are Denoted with B and are in 1994, 1997 and 2000 – 2004



2007). In addition, survival between Dos Reis and Jersey Point, between 1989 -1991 and 1995-1999 appeared to be related to San Joaquin River flow downstream of the HOR ($r^2 = 0.54$, $p<0.01$; Figure 5-14 in SJRGA, 2007) but the relationship no longer remained statistically significant ($p<0.05$) when results from 2005 and 2006 were added ($r^2 = 0.22$, $p<0.10$; Figure 5-13 in SJRGA, 2007).

In addition, the relationship between flow at Vernalis and the recovery rates of the Durham Ferry and Mossdale releases relative to those at Jersey Point without the HORB was much more variable with no apparent trend (Figure 5-12 in SJRGA, 2007). The 2005 and 2006 estimates were much lower than previous estimates at similar flow levels. Tagged fish released at Mossdale or Durham Ferry without a HORB could migrate either down upper Old River or via the mainstem San Joaquin River. It is not surprising that there is more variability associated with smolt survival at any given flow at Vernalis without the HORB since the flow and proportion of marked fish moving into HOR would vary more without the HORB. The proportion of juvenile salmon that migrated down HOR relative to the number that stayed in the mainstem San Joaquin River was a critical uncertainty for many years when CWT fish were used. However, based on the relationships above, fish that remained in the San Joaquin River at the HOR, when there was no HORB in place, were thought to experience higher survival at higher flows.

Another goal of the VAMP program was to identify the role of exports on juvenile salmon survival through the Delta. The relationship between San Joaquin River flow relative to exports and survival between Durham Ferry or Mossdale and Jersey Point, with the HORB in place, while statistically significant ($p<0.05$, Figure 5-15 in SJRGA, 2007), does not appear to explain the variability in CWT smolt survival as well as flow alone with the HORB in place. One potential explanation for these results is the low levels of exports and lack of variation in exports during these CWT experiments. During the studies, exports ranged between 1,450 and 2,350 cfs which were much lower than those incorporated into the adult escapement and flow relationship. Another complication is that exports and San Joaquin River flows were correlated during the VAMP studies with the HORB installed; higher exports were observed during times of higher flows (Figure 5-16 in SJRGA, 2007). As conditions did not provide a 7,000 cfs flow to test a

1,500 and 3,000 cfs export with a HORB, identifying the role of exports on survival was limited.

However, in 2006, an experiment was conducted to isolate the role of exports on survival during the VAMP. In 2006, flows were high and two levels of exports were tested (1,500 and 6,000 cfs) to determine if differences in survival could be detected at the two different export levels. Such an experiment was feasible in 2006 because flows were deemed high enough to provide adequate protection for delta smelt even with the 6,000 cfs exports. Results indicated that point estimates of survival were higher for the lower export period, but standard errors were large and lower temperatures during the low export period may have confounded the results (SJRGA, 2007). The 2006 data were limited in its precision because it relied primarily on recoveries at Chipps Island and Antioch as the ocean fishery south of Cape Falcon, Oregon was closed in 2008 and 2009 due to anticipated low Sacramento River fall-run adult returns (NOAA, 2008, 2009). Three and four year old adult salmon would have been recovered in the ocean fishery in 2008 and 2009 from the 2006 releases if the fishery had not been closed.

Bayesian hierarchical models were used to fit the VAMP and pre-VAMP CWT data (Newman, 2008). For the various models fitted, two robust conclusions were identified: 1) flow is positively related to survival between Dos Reis and Jersey Point; and 2) survival is higher from Dos Reis to Jersey Point relative to that from upper Old River to Jersey Point. However, the most recent "best model" does not incorporate flow or exports for either of the routes but survival was higher in the San Joaquin River than in Old River (K. B. Newman, U.S. Fish and Wildlife Service, personal communication).

In 2007, it was determined that not enough fish were available at MRH to conduct a CWT study for VAMP. In addition, there was the possibility that the trawling at Antioch and Chipps Island could be interrupted due to high incidental catches of delta smelt and reduce the effort for recovering CWT fish. These two circumstances prompted the transition away from CWT studies to acoustic telemetry. Acoustic telemetry provides a greater temporal and spatial coverage of the outmigration process than CWT studies. Furthermore, continuous, simultaneous monitoring at several locations allows estimation of distribution probabilities at junctions and reach-specific survival throughout the study region. In addition, acoustic telemetry data are amenable to a suite of robust and well developed statistical approaches that allow quantification of the uncertainty associated with estimates of survival, detection, and distribution probabilities.

Past acoustic studies

Acoustic tag studies between 2006 and 2010 used Hydroacoustic Technology, Incorporated (HTI) tags. Tag models and battery life of the tags varied across years.

During the 2006 VAMP, a pilot study was initiated to test whether acoustic tags could be used to monitor the migration of juvenile Chinook salmon smolts in the south Delta. A total of 100 acoustically tagged MRH fish were released at Mossdale (67) and Dos Reis (33), with the installation of five stationary receivers (see Table 1 and Figure 1 in Appendix D) (SJRGA, 2007). Receivers were not installed at Jersey Point or Chipps Island in 2006; thus survival through the Delta could not be estimated using the acoustic tags. The HORB was not in place during the 2006 VAMP studies as Vernalis flows were substantially greater than 5,000 to 7,000 cfs necessary for HORB installation (see Table 1 in Appendix D). During the 2006 study, it was estimated that 83% and 56% of the acoustically tagged smolts released at Mossdale and surviving to the HOR junction were diverted into Old River during the two releases, respectively. (Those fish assumed to be lost due to predation were subtracted from the total prior to estimating the proportion splitting at the junction) At the times when the tagged fish approached the flow split, it was estimated that approximately 53 and 51% of the mainstem San Joaquin River flow was diverted into Old River during the first and second release, respectively (SJRGA, 2007). In addition, limited mobile tracking found five of the 61 tags released at Mossdale in the scour hole near the junction with Old River, suggesting tagged fish had been preyed upon at that location.

In 2007, MRH smolts implanted with acoustic transmitters were released at five locations and movement of tagged smolts was monitored at 10 stationary receiver locations in the south and central Delta (see Table 1 and Figure 2 in Appendix D) (SJRGA, 2008). Due to logistical challenges, stationary receivers could not be installed at Chipps Island and Jersey Point which precluded estimation of survival through the Delta. Detections at the stationary receiver locations during 2007 indicated an average loss of 45% between Durham Ferry and Bowman Road (just north of Lathrop). The largest area of mortality was identified in an area adjacent to a railroad bridge (Navy Drive Bridge) near the Stockton Waste Water Treatment Plant (WWTP). Mobile tracking found fifteen percent (n=116) of 776 tags released, from four upstream sites, motionless at this location indicating that the tags were either in dead fish or had been defecated by a predator (SJRGA, 2008).

In 2008, the acoustic study design was revised and expanded to provide estimates of survival through the Delta and route selection probabilities at several junctions. The HORB was not installed in 2008. MRH smolts with surgically implanted acoustic transmitters were released at Durham Ferry and Stockton and movement of tagged smolts was monitored at 16 stationary receiver locations (see Table 1 and Figure 3 in Appendix D) (SJRGA, 2009). Unfortunately, tag life tests indicated that only 55-78% of tags used in the study were still functioning after 15 days which precluded generating unbiased estimates of survival (Holbrook et al., 2009, 2013). Estimates of survival in 2008 included both the probability that the tag was working and that the fish survived and estimates were potentially biased low. Joint fish and tag survival was estimated to be 0.06 ± 0.01 ($\widehat{SE}$) and 0.07 ± 0.02 ($\widehat{SE}$) from Mossdale to Chipps Island for the two weeks of releases made in 2008. Fish remaining in the San Joaquin River had a higher relative fish tag survival rate (0.07± 0.02 ($\widehat{SE}$) and 0.10± 0.02 ($\widehat{SE}$) for the first and second releases, respectively (C. M. Holbrook, U.S. Geological Survey, personal communication), but only about a 1/3 of the tagged fish (0.22 and 0.33) used this route (Holbrook et al., 2009). Most of the tagged fish (63-68%) released at Durham Ferry migrated through Old River where fish tag survival was less. Survival from Mossdale to Chipps Island using the Old River route was 0.05 ±0.02 ($\widehat{SE}$) and 0.06±0.02 ($\widehat{SE}$) for the first and second releases, respectively (C. M. Holbrook, U.S. Geological Survey, personal communication). In addition, none of the tagged fish that entered Turner Cut (49) were detected at Chipps Island (Holbrook et al., 2009).

Water quality monitoring near the Stockton WWTP was conducted in 2008 and found that all measured nitrogen compounds (total Ammonia Nitrogen, unionized ammonia, nitrate and nitrite) showed a significant increase in concentration downstream of the WWTP discharges into the San Joaquin River, although levels were below the chronic concentration established by EPA (SJRGA, 2009).

The VAMP study in 2009 was a scaled-back version of the 2008 VAMP study, due to the inability to install receivers at Chipps Island and Jersey Point (see Figure 4 in Appendix D). Study fish were fall/spring hybrids from FRH and all were released at Durham Ferry. In recognition of the potential bias associated with predators ingesting a tagged smolt, survival in the south Delta was estimated in two ways in 2009; one with all the detections and one by removing detections thought to be from a tagged smolt eaten by a predator and the predator moving by a downstream receiver with the tag inside its digestive track. For the survival estimates in 2009, detected tags that had a wavy or flat signal in the Raw Acoustic Tag (RAT) files were considered to be in predators (SJRGA, 2010). Typical "smolt" like behavior was assumed to be a signal with a distinct or muted peak past the receiver (SJRGA, 2010). While these behaviors are not able to truly determine if a tag was in a predator or not, it gives information on how survival may be different, given that these detection characteristics are able to differentiate between a real smolt and one that has been preyed upon.

Survival was estimated to be 0.06 ($\widehat{SE}$ = 0.01) in 2009, without predator-type detections, from Mossdale to six end points in the south Delta ($S_{Total\ (SD)}$) and based on release groups 3 -7 (see Table 1 in Appendix D) (SJRGA, 2010). Survival from Mossdale through the San Joaquin River to Turner Cut or the Channel Marker receivers (partial San Joaquin route ($S_{A(SD)}$) was 0.05 ($\widehat{SE}$ = 0.02), removing predator-type detections (see Table 1 in Appendix D) (SJRGA, 2010). Survival from Mossdale to the entrances of the water export facilities (CVP, RGU) or the northern Old River receivers at Highway 4 (ORN) (partial Old River route ($S_{B(SD)}$) was 0.08 ($\widehat{SE}$ = 0.02) without predator-type detections (see Table 1 in Appendix D) (SJRGA, 2010). Route specific survival was only calculated for release groups 3-6, because of missing data, due to receiver malfunction. Estimates of survival were 0.34 ($\widehat{SE}$ = 0.03) from Mossdale to the six end points, 0.10 ($\widehat{SE}$ =0.02) for $S_{A(SD)}$ and 0.58 ($\widehat{SE}$ = 0.06) for $S_{B(SD)}$(SJRGA, 2010) using all detections (see Table 1 in Appendix D).

The effect of water quality on juvenile salmon near the Stockton WWTP was also investigated in 2009 using paired sets of dummy tagged fish. No detectable differences in mortality between the Stockton and Durham Ferry groups were observed in 2009 (Nichols and Foott, 2009 and SJRGA, 2010).

The VAMP study in 2010 incorporated receivers at Chipps Island, but did not include receivers at Jersey Point due to budgetary constraints (see Figure 5 in Appendix D). During the 2010 study, MRH Chinook salmon smolts were acoustically tagged and released into the San Joaquin River at Durham Ferry and near Stockton and in Old River just downstream of the mainstem San Joaquin River (see Table 1 and Figure 5 in Appendix D). The releases at Old River and near Stockton were made to augment the number of fish that survived to those two locations from releases made at Durham Ferry and to assure some fish would be recovered at Chipps Island. A non-physical barrier was tested at the HOR by the Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) using fish from the VAMP.

Survival was low at 0.05 ($\widehat{SE}$ =0.01) between Mossdale and Chipps Island in 2010 with predator-type detections

removed, relative to past CWT estimates (Figure 5-1); (see also Table 1 in Appendix D); (SJRGA, 2011). Average population-level survival between Mossdale and Chipps Island was somewhat higher in 2010 when using all detections (0.11, $\widehat{SE}$ = 0.01) (see Table 1 in Appendix D) (SJRGA, 2011). Estimates of the probability of remaining in the San Joaquin River at the junction with Old River (ψ_A) averaged 0.47 ($\widehat{SE}$ =0.02) with predator-type detections removed (SJRGA, 2011). Survival from Mossdale to Chipps Island through the San Joaquin River route (S_A) was estimated to be 0.04 ($\widehat{SE}$ =0.01) and through the Old River route (S_B) was estimated to be 0.07 ($\widehat{SE}$ =0.01) when removing predator-type detections (see Table 1 in Appendix D) (SJRGA, 2011). Survival was slightly higher when all detections were used with survival through S_A estimated at 0.11 ($\widehat{SE}$ =0.01) and survival through S_B estimated at 0.12 ($\widehat{SE}$ = 0.01) (see Table 1 in Appendix D) (SJRGA, 2011). Only Release 1 showed a significant (α=0.05) difference in survival to Chipps Island through the two routes, with a significantly higher estimated probability of surviving to Chipps Island through the mainstem San Joaquin River route (P=0.0100) (SJRGA, 2011). Lack of significance for other releases may have been a result of low statistical power. However, when survival was pooled over all release groups, survival to Chipps Island was estimated to be significantly higher through the Old River route than through the San Joaquin River route (P=0.0133, one-sided Z-test on the lognormal scale) (SJRGA, 2011).

Survival was also estimated through the portion of the study area in 2010 that matched the 2009 study area. Average survival in the San Joaquin River route through the 2009 study area ($S_{A(SD)}$) without predator-type detections was estimated to be 0.32 ($\widehat{SE}$ =0.02) in 2010 (see Table 1 in Appendix D) (SJRGA, 2011). Average survival in the Old River route through this region ($S_{B(SD)}$), without predator-type detections, was estimated to be 0.77 ($\widehat{SE}$ =0.05) (SJRGA, 2011) in 2010. $S_{Total\ (SD)}$ in 2010 was estimated at 0.56 ($\widehat{SE}$ =0.03) (SJRGA, 2011) without predator-type detections. These survival estimates in 2010 were considerably higher than comparable estimates from 2009, when $S_{A(SD)}$ was estimated at 0.05 ($\widehat{SE}$ = 0.02), $S_{B(SD)}$ was estimated at 0.08 ($\widehat{SE}$ = 0.02) and $S_{Total(SD)}$ was estimated to be 0.06 ($\widehat{SE}$ =0.01) (SJRGA, 2010 and 2011) without predator-type detections (see Table 1 in Appendix D).

2011 Acoustic study

For the 2011 study, Chinook salmon smolts from MRH were acoustically tagged with Hydroacoustic Technology, Incorporated (HTI) tags and released into the San Joaquin River at Durham Ferry on the mainstem San Joaquin River about 21 rkm (13 miles) upstream of the Delta (Mossdale Bridge). This study design in 2011 was changed from that used in 2010 to allow all tagged fish in 2011 to express any potential handling mortality before they entered the Delta at Mossdale. In 2010, supplemental releases were made in Old River and at Stockton, for each of the seven releases made at Durham Ferry, thus the Stockton and Old River groups expressed the potential handling mortality in a river reach within the Delta. Because survival through the Delta is estimated starting at the Mossdale receiver location, tagged fish released at Durham Ferry have the distance between Durham Ferry and the Mossdale receiver location (21 rkm or 13 miles) to express any potential handling mortality that occurs, reducing its effect on survival through the Delta. Releasing all groups at Durham Ferry in 2011 reduced any impact of handling mortality on survival through the Delta and standardized the reach where it was expressed. The number of fish released at Durham Ferry was increased from 2010 samples sizes to accommodate the study design change in 2011. A sample size analysis was completed to determine appropriate samples size (Appendix E).

The VAMP releases in 2011 were also used to meet the study needs of four other studies: 1) a South Delta Temporary Barrier Project (TBP) study, to assess the survival of Chinook salmon and steelhead with the South Delta temporary barriers installed; 2) a 6-year steelhead study as part of the NMFS OCAP Biological Opinion to determine if salmon could be used as surrogates for estimating steelhead survival in the San Joaquin River basin; 3) a HOR study to evaluate fish routing and predation at the HOR without a physical or non-physical barrier installed; and 4) a pre-screen loss study at the CVP using a 2-D acoustic array. Additional Chinook salmon and steelhead releases were made as part of these four studies and are either summarized here, reported in other sections of this report (Chapter 6) or will be forthcoming in independent reports. Of the four releases groups of acoustic-tagged Chinook salmon discussed in this chapter, the first two groups were released during the 2011 VAMP and the last two were released after the end of the 2011 VAMP.

[1]*The name of the California Department of Fish and Game was changed on January 1, 2013 to California Department of Fish and Wildlife (CDFW)*

Each tagged fish released, as part of all of these acoustic studies, was detected and uniquely identified as it passed acoustic receivers placed at various locations throughout the Delta. Detection data from receiver sites were analyzed within a release-recapture model to simultaneously estimate survival, route distribution, and detection probabilities throughout the Delta. Detection data from mobile tracking were analyzed to help interpret survival estimates.

Study Design and Methods

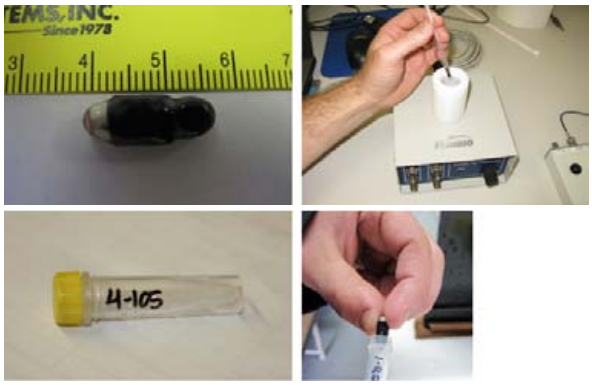
Study Fish

Study fish were obtained from the Merced River Hatchery. A total of 3,178 juvenile fall run Chinook salmon were transferred by California Department of Fish and Game[1] (DFG) from MRH to the CVP Tracy Fish Collection Facility (TFCF) on April 25th (n=1,139), May 9th (n=778), May 18th (n=610), June 3rd (n=568), and June 16th (83). Approximately half of the salmon delivered on April 25th were used for training, and the remaining fish were to be tagged on May 2nd and 3rd. However, due to cool water temperatures, fish growth at MRH during 2011 was relatively slow and fish did not meet minimum weight criteria by the target date. Tagging was postponed to May 16th and 17th to allow fish additional time to grow to adequate size.

Fish were generally held at TFCF for one week prior to tagging to allow for acclimation to Delta water quality and temperature prior to release; however, fish delivered on April 25th were held for three weeks due to the delay in tagging. Water temperatures in the holding tanks at TFCF were held at approximately 14-15° C until 3-4 days prior to tagging when water temperatures in the holding tanks were adjusted to ambient Delta condition. Fish were not held at ambient temperatures for the duration of holding at TCFC because PKD is progressive at temperatures greater than 15° C, and ambient Delta temperatures often exceed 15° C.

Transmitter Programming

Transmitters were programmed according to modified guidelines developed during the 2008 VAMP. Programming occurred the day prior to tagging which was two days prior to the start of each release. Transmitters were soaked for approximately 24 hours prior to programming. After programming, tags were sniffed in a cup of water using an HTI sniffer and monitored through at least three transmission cycles. At least 5 attempts were made to program each tag. Following successful programming, each tag was placed in a uniquely coded vial. Since the tags have no external identifiers, the codes on the vials were used to track the specifications (e.g., manufacturing lot, tag weight, period, sub-code, and pulse width) of individual tags.



During 2008 some tags passed activation and sniffing, but then failed shortly thereafter. To address this potential issue, a hydrophone was used during 2011 to listen to all activated tags immediately after each group of tags was programmed. This practice allowed for removal of any dead tags prior to surgical implantation in study fish.

Transmitter Implantation and Validation

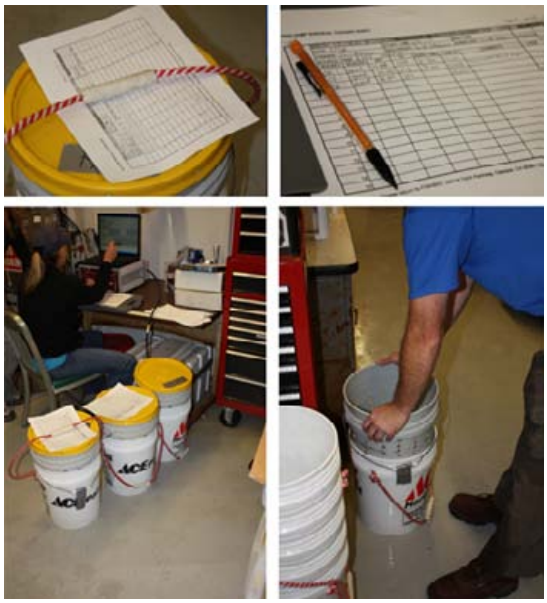
During 2011, training and tagging operations continued at the TFCF which was selected in 2009 as a preferred alternative to MRH for tagging (SJRGA, 2011). Tagging operations occurred at TFCF between May 16th and May 24th for VAMP and between June 6th and June 17th for the South Delta TBP study. Study fish were withheld food for 24 hours prior to transmitter implantation. During each tagging session fish were surgically implanted with

HTI acoustic transmitters following procedures based on a standard operating procedure (SOP) developed by the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS). The SOP (Appendix F) directed all aspects of the tagging operation, and several quality assurance checks were made during each tagging session to ensure compliance with the SOP guidance.

Prior to transmitter implantation, fish were anesthetized in 70 mg/L tricane methanesulfonate buffered with an equal concentration of sodium bicarbonate until they lost equilibrium. Fish were removed from anesthesia, and were measured (fork length (FL) to nearest mm) and weighed (to nearest 0.1 g). The HTI Model 795 Lm micro acoustic tag used for this study weighed 0.65 g in air (range: 0.58 g to 0.73 g), was 16.4 mm long, with a diameter of 6.7 mm. A minimum fish weight criterion of 12.1 g was used to ensure a maximum tag weight to body weight ratio of 5.4%.

Following implantation procedures outlined in Adams et al., 1998 and Martinelli et al., 1998, fish were surgically implanted with acoustic transmitters. Typical surgery times were less than 3 minutes. Fish were then placed into perforated 19 L (5 gal) buckets with high dissolved oxygen concentrations (110-130%) to recover from anesthesia effects. Each bucket was labeled with a unique

code. Buckets were perforated, starting 15 cm from the bottom, to allow water exchange. The non-perforated section of the bucket held 7 L of water to allow transfer without complete dewatering. Each bucket was stocked with three tagged fish, and was covered with a snap-on lid. Buckets were held in a flume at the TFCF facility until loaded for transport to the release site. Water levels were adjusted in the flume to ensure that tagged fish had access to air to adjust their buoyancy to compensate for the weight of the transmitter.



After surgery, tagged fish were monitored by hydrophones gently placed in the recovery buckets at TFCF to confirm the operational status of each transmitter prior to transportation to the release sites. A total of ten transmitters were found to be non-functional during evaluation of the fish tagged for VAMP and three were found in fish tagged from the South Delta TBP study. All fish with non-functional tags were removed from the study and were euthanized at the TFCF.

In 2011, groups of 475 and 473 Chinook salmon were tagged for the VAMP and released at Durham Ferry in late May (Table 5-3). Similar sized groups (473 and 474) of Chinook salmon were tagged for the South Delta TBP study in June (Table 5-4). Each group of fish was tagged over a consecutive 4-day period and thus contained four separate sub-groups of approximately 120 fish (Tables 5-3 and 5-4). Tagging occurred in either the morning or afternoon (Table 5-3 and Table 5-4). Steelhead were tagged for the 6-year steelhead study on opposite shifts from the Chinook salmon as part of the integrated nature of the studies (see Chapter 6 for a discussion of the 6-year steelhead study program).

After tagging and tag validation, the 19L (5 gal) perforated buckets usually containing three tagged Chinook were held in the flume at the TFCF until they were loaded into the transport tanks. Water temperatures in the flume were set to match conditions at Durham Ferry or to be 1-2° C cooler than the river to allow for warming of water in the transport tanks during transport to the release site. Water temperatures in the flume were adjusted using a chiller at TFCF. The overall goal was to maintain water temperatures within a 1-2° C range from the holding tanks, to the flume, to the transport tanks, and to the release site to minimize stress to study fish.

Transport to Release Sites

In order to minimize the stress associated with moving fish and for tracking smaller groups of individual tagged fish, two specially designed transport tanks were used to move Chinook salmon from the TFCF where the tagging occurred, to the release site on the San Joaquin River at Durham Ferry. The transport tanks for Chinook salmon were designed to securely hold a series of 19 L (5 gal) perforated, containers (buckets) filled with fish. Tanks had an internal frame that held 21-30 buckets in individual compartments to minimize contact between containers and to prevent tipping. Both transport tanks were mounted on the bed of an 8 m (26') flatbed truck that was equipped with an oxygen tank and hosing to deliver oxygen to each of the tanks during transport.

As with the flume, water temperatures in the transport tanks were set to match conditions at Durham Ferry or to be 1-2° C cooler than the river to allow for warming during transport to the release site. Water temperatures in the transport tanks were adjusted using water from the chiller at TFCF and by adding ice to the transport tanks after loading as necessary.

Immediately prior to loading, all fish were visually inspected for mortalities or signs of poor recovery from tagging (e.g. erratic swimming behavior). Temperature and dissolved oxygen (DO) in the transport tanks were recorded after loading buckets into the transport tanks but before leaving the TFCF, and at the release site prior to unloading. Depending on water temperature conditions at Durham Ferry and ambient weather conditions, non-chlorinated ice was placed in the tanks as needed to minimize warming during transport to the release site.

Once at the release site, water temperature and dissolved oxygen levels were measured in the river and in the transport tanks. After recording water temperature and dissolved oxygen levels, tagged Chinook salmon were removed from the transport tanks and moved to the river. For all releases, perforated buckets were placed into "sleeves", transferred to a pick-up truck, and driven a short distance to the river's edge. A "sleeve" is a slightly larger non-perforated bucket that allows more water to stay in the perforated bucket than would be the case without placing it in a "sleeve."

Table 5-3
Tagging, Transport and Holding Date and Times and the Number Released for Chinook Salmon as Part of the 2011 Vernalis Adaptive Management Program (VAMP) Over a 24-hour Period after Being Held for a Minimum of 24 Hours at the Central Valley Project Tracy Fish Collection Facility (TFCF)

Tagging Date/Time	Transport Date/ Time	Start Holding Time	Total released (A+B+C+D)	Release A		Release B		Release C		Release D		Fish Health	Survival Model Release group
				Date/ Time	Number released	Date/ Time	Number released	Date/ Time	Number released	Date/ time	Number released	Dummy tagged	
5/16/2011 - morning	5/16/11; 1325-1412	5/16; 1514	120	5/17; 1500	30	5/17; 2100	30	5/18: 0300, 0301	30	5/18; 0900	30	12	1
5/17/2011- afternoon	5/17/11; 1800-1915	5/17; 2000	119	5/18; 1800	30	5/19; 0000, 0002	30	5/19; 0601	29	5/19; 1200	30	24[a]	1
5/18/2011 - morning	5/18/11; 1230-1330	5/18; 1410	117	5/19; 1500	28	5/19; 2100	30	5/20; 0300	29	5/20; 0902, 0903	30	12	1
5/19/2011 - afternoon	5/19/11; 1650-1737	5/19; 1815	119	5/20; 1800, 1802	29	5/21; 0000	30	5/21; 0559	30	5/21; 1200	30	12	1
Total			**475**										
5/21/2011- afternoon	5/21/11; 1605-1705	5/21; 1756	119	5/22; 1800	29	5/22; 2358	30	5/23; 0559	30	5/23; 1201, 1202	30	12	2
5/22/2011- morning	5/22/11; 1130-1215	5/22; 1303	119	5/23; 1500	30	5/23; 2100	30	5/24; 0300	30	5/24; 0902	29	12	2
5/23/2011- afternoon	5/23/11; 1530-1620	5/23; 1705	115	5/24; 1801	30	5/24; 2358	29	5/25; 0601	28	5/25; 1200, 1201	28	12[a]	2
5/24/2011- morning	5/24/11; 1139-1235	5/24; 1338	120	5/25; 1500	30	5/25; 2100	30	5/26; 0259	30	5/26; 0901, 0902	30	24[a]	2
Total			**473**										

[a] Given to USFWS CA-NV Fish Health Center for fish health study

Table 5-4
Tagging, Transport and Holding Date and Times and the Number Released (and Mortaltites) for Chinook Salmon as Part of South Delta Temporary Barriers Project (TBP) Study Over a 24-hour Period after Being Held for a Minimum of 24 Hours at the Central Valley Project Tracy Fish Collection Facility (TFCF)

Tagging Date/Time	Transport Date/ Time	Start Holding Time	Total released (A+B+C+D)	Release A		Release B		Release C		Release D		Fish Health	Survival Model Release group
				Date/Time	Number released	Date/ Time	Number released	Date/ Time	Number released	Date/ time	Number released	Dummy tagged	
6/6/11 - afternoon;	6/6/11; 1530-1604	6/6/11; 1645	119	6/7; 1800, 1081	29	6/8; 0000, 0001	30	6/8; 0601	30	6/8; 1201	30	12	3
6/7/11 - morning;	6/7/11; 1203-1250	6/7/11; 1335	116	6/8; 1500	28	6/8; 2100, 2101	30	6/9; 0259	30	6/9; 0900	28 (1)	12	3
6/8/11- afternoon;	6/8/11; 1555-1638	6/8/11; 1717	119	6/9; 1800	30	6/10; 0000	30	6/10; 0559	29	6/10; 1200	30	12	3
6/9/11 - morning;	6/9/11; 1131-1210	6/9/11; 1300	119	6/10: 1500	29	6/10; 2100	30	6/11; 0300	30	06/11; 0900	30	12	3
Total			**473**										
6/14/11 - morning;	6/14/11; 1217-1314	6/14/11; 1410	119	6/15; 1501, 1502	30	6/15; 2100, 2101	30	6/16; 0300	30	6/16; 0900, 0901	29	23[a]	4
6/15/11- afternoon;	6/15/11; 1624-1710	6/15/11; 1813	118	6/16; 1800	30	6/17; 0000	30	6/17; 0600	29	6/17; 1200	29	12[b]	4
6/16/11- morning;	6/16/11; 1130-1230	6/16/11; 1320	117	6/17; 1500, 1501	30	6/17; 2101, 2102	29	6/18; 0300	30	6/18; 0900	28	12	4
6/17/11- afternoon;	6/17/11; 1645-1735	6/17/11; 1828	120	6/18; 1800	30	6/19; 0000	30	6/19; 0600	30	6/19; 1200	30	12	4
Total			**474**										

[a] Given to USFWS CA-NV Fish Health Center for fish health study, [b] processed 3 hour early

Perforated buckets in sleeves were unloaded from the pick-up truck and carried to the river. Perforated buckets were separated from the sleeves at the shore and carried to the holding containers in the river about two to three feet from the shore. Fish were transferred from 19L buckets to 120 L (32 gal), perforated, plastic garbage cans held in the river. Perforations were drilled in the garbage cans to allow free flow of water through the can while fish were held at the release site. Each hole was 0.64 cm diameter. Five buckets, usually containing three salmon per bucket, were emptied into each perforated garbage can. Each bucket and each garbage can was labeled to track the specific tag codes and assure fish were transferred to the correct holding can for later release at the correct time. Tagged salmon were held in the perforated garbage cans for a minimum of approximately 24 hours prior to release.

Dummy tagged Chinook salmon were tagged and transported similarly as fish with live tags but were held for a minimum of 48 hours. A security guard or release crew remained onsite for the duration of the holding period for both the tagged and dummy-tagged Chinook salmon to ensure that study fish and equipment were not vandalized or otherwise tampered with.

Releases

For the VAMP in 2011, groups of 475 and 473 tagged Chinook salmon were released at Durham Ferry over a two-week period in mid to late May. Each group of tagged fish was released over a consecutive 5-day period and contained four separate sub-groups of approximately 120 fish (Table 5-3). Each of the four separate subgroups were released over a 24-hour period, with approximately one fourth of each subgroup (~30 tagged fish) released every 6 hours (Table 5-3).

A similar release strategy was used for Chinook salmon released as part of the South Delta TBP study. Chinook salmon for the South Delta TBP study were released later in the season than the VAMP fish, between June 7th and 19th (Table 5-4). As mentioned previously, all Chinook salmon released as part of these two studies were released at Durham Ferry on the San Joaquin River.

Specific releases times were based on the fish tagging period (morning or afternoon). Two set release schedules were used for the Chinook salmon releases in 2011; either a release schedule of 1500, 2100, 0300, 0900 hours for fish tagged in the morning or a release schedule of 1800, 0000, 0600, 1200 hours for fish tagged in the afternoon.

The releases of Chinook salmon were made from shore due to the high flows. Fish were to be released in the middle of the channel, downstream of the holding location, but flows were too high in 2011 to safely allow field personnel to use a boat to tow the release containers to mid-channel. Fish were to be released in the middle of the channel, downstream of the holding site, to potentially reduce initial predation of tagged fish immediately after release. The high flows in 2011 may have reduced this concern as it may have been more difficult for predators to congregate near the holding location with the high flows.

At the release time the lid was removed and the holding container was rotated to look for any dead or impaired fish. The container was then inverted to allow the fish to be released into the river. After the holding container was inverted, the time was recorded. As the holding containers were flipped back over, they were inspected to make sure that none of the released fish swam back into the container. During 2011, flows were very high, thus there were many times the holding containers remained clipped to the anchor rope so that they would not be lost in the current. Once the release was completed, the information on any dead fish was recorded and the tags were removed. The tags were bagged and labeled and returned to the tagging location or office to have the individual tag identified.

In 2011, no tagged fish were intentionally killed to determine the "behavior" of dead fish. In 2009 and 2010, dead fish with active tags were released as part of the study design to verify that dead fish did not move far enough downstream to be detected on receivers downstream and assumed to be in live fish. In 2009, two of the five dead fish with live tags were found in mobile

monitoring approximately 300 m (1000 ft) downstream. One additional dead fish was detected approximately 5 km (3 miles) downstream. It is not clear whether this fish was eaten by a predator, had been defecated or had drifted this far downstream. In 2010, of the 3 intentional mortalities released at Durham Ferry, two were found within 0.2 km (0.1 mile) of the release site. At Old River, of the three fish intentionally killed, two were detected within 0.4 km (0.25 miles) of the release site. Of the three fish intentionally killed and released at Stockton in 2010, only one was located by mobile tracking and was within 0.3 km (0.2 miles) of the release site. The first receiver downstream of the release site (with the exception of the dual receiver at the release site) was at Banta Carbona in 2011, approximately 10 km (6 miles) downstream of the release site. Given this information, and with releases only at Durham Ferry in 2011, the technical team recommended discontinuing this evaluation in 2011.

Dummy-tagged fish

In order to evaluate the effects of tagging and transport on survival, several groups of Chinook salmon were implanted with inactive or dummy transmitters. Dummy tags in 2011 were interspersed randomly into the tagging order for each release group. For each day of VAMP releases, 12 fish implanted with dummy transmitters were included in the tagging process. Procedures for tagging these fish, transporting them to the release site, and holding them at the release site were the same as for fish with active transmitters. Dummy-tagged fish were evaluated for condition and mortality after being held at the release site for approximately 48 hours.

After dummy-tagged fish were held for approximately 48 hours, they were examined for mortality, then euthanized with MS-222, measured (FL to nearest mm) and qualitatively examined for condition: percent scale loss, body color, fin hemorrhaging, eye quality, and gill coloration (Table 5-5). After assessment of the dummy-tagged fish, dummy tags were removed for reuse.

In addition, twenty-four dummy-tagged fish from two tagging days (May 17th and May 24th) were transported to the U.S. Fish and Wildlife Service California/Nevada Fish Health Center (FHC) after the fish were held for 48 hours. An additional 12 dummy-tagged fish, tagged on May 23rd were taken to FHC after they had been held for approximately 72 hours. Once at the FHC the dummy-tagged fish were held for 30 days. The primary purpose of these dummy-tagged groups was to monitor and diagnose mortality over a 30-day holding period. An additional 60 non-tagged Chinook salmon were obtained as a control for surgery effects and to increase sample numbers without tagging additional dummy-tagged fish. The non-tagged fish were transferred directly to the FHC from the tagging facility and sampled at two time points after they arrived at the FHC: after an overnight acclimation (1d) and after approximately 30 days (30d). The dummy-tagged fish were only sampled after 30 days.

At the FHC, temperature of the single-pass water supply was allowed to fluctuate with ambient conditions. Once temperatures began to exceed 18° C (July 29th), the water supply was switched to a constant 17° C source due to concerns of *Flavobacterium columnare* infection. Fish were fed a pelleted salmon diet daily. Tanks were checked daily for dead or moribund fish. Diagnostic sampling was performed on sick or dead fish to identify any associated pathology. In addition, a reference sample of 30 unmarked Chinook was sampled at MRH on May 18th. For more detail on the methods used for the fish health evaluations see Chapter 6.

Table 5-5
Characteristics Assessed for Chinook Salmon Smolt Condition and Short-Term Survival

Characteristic	Normal	Abnormal
Percent Scale Loss	Lower relative numbers based on 0-100%	Higher relative numbers based on 0-100%
Body Color	High contrast dark dorsal surfaces and light sides	Low contrast dorsal surfaces and coppery colored sides
Fin Hemorrhaging	No bleeding at base of fins	Blood present at base of fins
Eyes	Normally shaped	Bulging or with hemorrhaging
Gill Color	Dark beet red to cherry red colored gill filaments	Grey to light red colored gill filaments
Vigor	Active swimming (prior to anesthesia)	Lethargic or motionless (prior to anesthesia)

Figure 5-2
Locations of Acoustic Receivers and Release Site Used for the 2011 VAMP Study Including Locations of Acoustic Receivers Deployed by the California Department of Water Resources (DWR) for the South Delta Temporary Barriers Project Study. Site Descriptions, Locations and Codes are Shown in Table 5-6

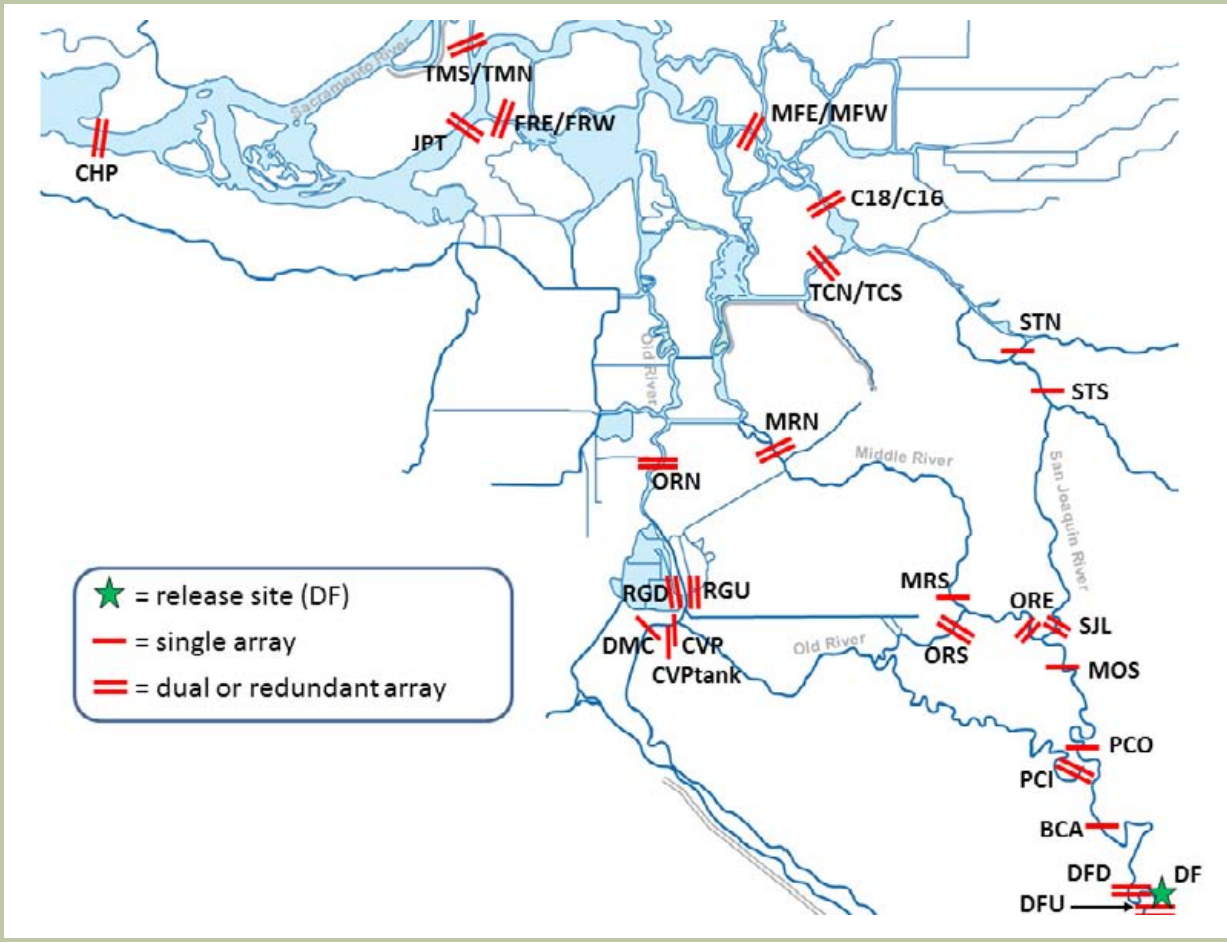


Table 5-6
Names and Descriptions of Receivers and Hydrophones Used in the 2011 VAMP Study, with Receiver Codes Used in Figure 5-2, Survival Model (Figures 5-4 and 5-5), and in Data Processing at the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS) in Cook, Washington. The Release Site was Located at Durham Ferry.

Individual Receiver Name and Description	Hydrophone Location		Receiver Code shown in Figure 5-2	Survival Model Code Shown in Figure 5-3	Data Processing Code Used in Figures 5-4 and 5-5
	Latitude (°N)	Longitude (°W)			
San Joaquin River near Durham Ferry upstream of the release site, upstream node	37.685333	121.256389	DFU1	A0a	901
San Joaquin River near Durham Ferry upstream of the release site, downstream node	37.687617	121.258150	DFU2	A0b	902
San Joaquin River near Durham Ferry; release site (no acoustic hydrophone located here)	37.686991	121.268258	DF	A1	
San Joaquin River near Durham Ferry downstream of the release site, upstream node	37.687550	121.271117	DFD1	A2a	903
San Joaquin River near Durham Ferry downstream of the release site, downstream node	37.688950	121.275667	DFD2	A2b	904
San Joaquin River near Banta Carbona	37.728183	121.298550	BCA	A3	905
San Joaquin River downstream of Paradise Cut	37.761650	121.309300	PCO	A4	937
San Joaquin River near Mossdale Bridge	37.794000	121.310900	MOS	A5	906
San Joaquin River near Lathrop, upstream	37.811167	121.319283	SJLU	A6a	909
San Joaquin River near Lathrop, downstream	37.811650	121.318683	SJLD	A6b	910
San Joaquin River at Stockton USGS gauge	37.933367	121.328667	STS	A7	911
San Joaquin River at Stockton Navy Drive Bridge	37.946550	121.339633	STN	A8	912
San Joaquin River at Shipping Channel Marker 18	38.021933	121.465983	C18	A9a	915
San Joaquin River at Shipping Channel Marker 16	38.026083	121.470817	C16	A9b	916
San Joaquin River near Medford Island, east	38.052767	121.510917	MFE	A10a	917
San Joaquin River near Medford Island, west	38.053200	121.513517	MFW	A10b	918
Old River East, near junction with San Joaquin, upstream	37.812217	121.335467	OREU	B1a	907
Old River East, near junction with San Joaquin, downstream	37.812600	121.335450	ORED	B1b	908
Old River South, upstream	37.819709	121.379215	ORSU	B2a	802
Old River South, downstream	37.818843	121.379814	ORSD	B2b	803
Old River North, upstream	37.889961	121.572875	ORNU	B3a	814
Old River North, downstream	37.892072	121.567887	ORND	B3b	815
Middle River South	37.824913	121.380829	MRS	C1	801
Middle River North, upstream	37.890200	121.489479	MRNU	C2a	816
Middle River North, downstream	37.892264	121.490199	MRND	C2b	817
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay), array 1	37.829600	121.556949	RGU1	D1a	810
Radial Gate at Clifton Court Forebay, upstream, array 2	37.829591	121.556949	RGU2	D1b	811
Radial Gate at Clifton Court Forebay, downstream (inside forebay), array 1	37.829852	121.557694	RGD1	D2a	812
Radial Gate at Clifton Court Forebay, downstream, array 2	37.829906	121.557670	RGD2	D2b	813
Central Valley Project trashracks	37.816658[a]	121.558690[a]	CVP	E1	701 - 713
Central Valley Project holding tank (all holding tanks pooled)	37.815910[a]	121.559090[a]	CVPtank	E2	715/716
Delta Mendota Canal (not used in survival model)	37.816240	121.560367	DMC	E3	714
Turner Cut, north (closer to San Joaquin)	37.991383	121.455200	TCN	F1a	914
Turner Cut, south (farther from San Joaquin)	37.989850	121.460017	TCS	F1b	913
San Joaquin River at Jersey Point, east (upstream)	38.056085[a]	121.686341[a]	JPTE	G1a	600
San Joaquin River at Jersey Point, west (downstream)	38.050615[a]	121.692585[a]	JPTW	G1b	610
False River, west (closer to San Joaquin)	38.056217	121.668150	FRW	H1a	922
False River, east (farther from San Joaquin)	38.056100	121.661467	FRE	H1b	921
Chipps Island, east (upstream)	38.047540[a]	121.890599[a]	CHPE	G2a	500/517
Chipps Island, west (downstream)	38.046090[a]	121.896439[a]	CHPW	G2b	510/516
Chipps Island, north (near Spoonbill Creek - not used in the survival model)	38.052640	121.889735	CHPN		515
Paradise Cut inside, east (upstream)[b]	37.760061	121.310481	PCIE	P1a	935
Paradise Cut inside, west (downstream)[b]	37.760897	121.315811	PCIW	P1b	936
Threemile Slough, south (not used in survival model)	38.097333	121.685200	TMS	T1a	920
Threemile Slough, north (not used in survival model)	38.111133	121.683067	TMN	T1b	919

[a] Average latitude and longitude given for sites with multiple hydrophones
[b] Not used in the survival model

Health assessments were also conducted on cohorts of acoustically tagged Chinook salmon used in the South Delta TBP study tagged on June 14th.

Receiver Deployment

The hydrophone receiver network in 2011 was similar to that developed in 2010 but added receiver sites at Jersey Point (JPT) and False River (FRE/FRW) (Figure 5-2). Principal objectives of the hydrophone layout for 2011 were to: (1) obtain fish survival estimates through the Delta from Mossdale to Chipps Island; (2) obtain estimates of fish survival in some key reaches of the Delta; the Old River and San Joaquin River mainstem routes; and (3) obtain fish route "selection" probabilities at critical flow splits (i.e., head of Old River (ORE and SJL) and Turner Cut (TCN/TCS)) (Figure 5-2). In addition, receivers were added just upstream and downstream of the release site (DFU and DFD, respectively) (Figure 5-2). A dual receiver was deployed upstream of the release site to remove any Chinook tags that moved upstream, presumably in a predator, prior to estimating survival. The dual receiver deployed just downstream of the release site was an attempt to verify that tags were still working at the time of release by detecting each tagged fish as it passed the receivers just downstream of the release site.

Due to the extremely high river flows during the VAMP 2011 study period, the need arose for additional receivers to be installed in, and downstream of Paradise Cut (PCI and PCO) (Figure 5-2), a location where fish passage is not normally possible. When flows at Vernalis rose above approximately 18,000 cfs, water from the San Joaquin River was able to flow over the weir at the head of Paradise Cut. Three additional receivers were added in, and around, Paradise Cut in mid-April, but by mid-May flows were no longer overtopping the weir.

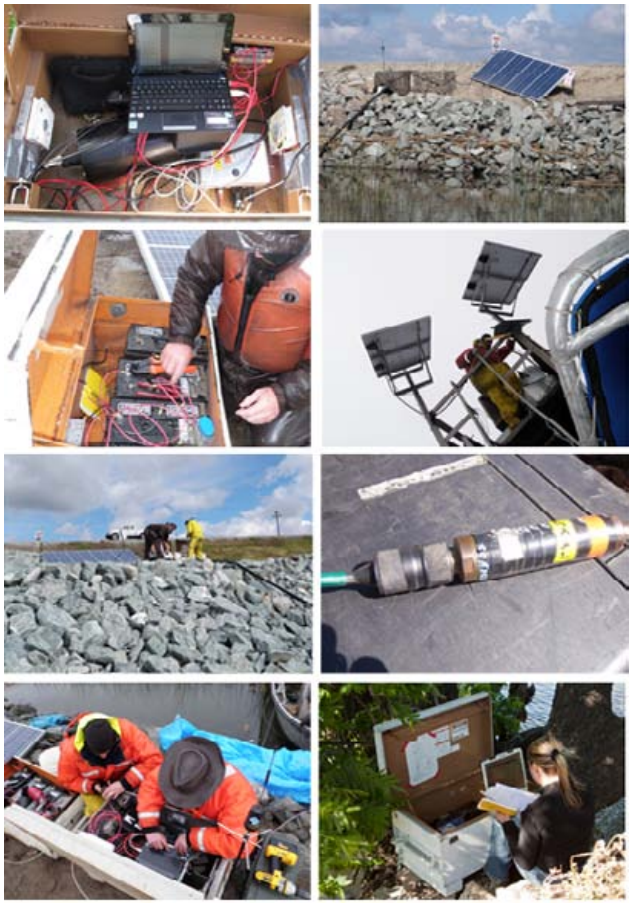
In 2011, receivers were deployed as in the past but three new components were added: the use of solar power, remote access to the receivers and telemetry of data to an FTP (File Transfer Protocol) site. The use of solar power allowed the sites to run continuously throughout the experiment without changing batteries as had been done over the last 5 years, while the ability to remotely access all receivers allowed us to monitor operational parameters and telemetry allowed us to determine whether data was being collected and if the equipment was working correctly.

Receiver sites were deployed and maintained by personnel from multiple agencies. The USFWS office in Stockton, with support from the USGS-CRRL, took primary responsibility for deploying and maintaining in-Delta receivers during 2011. With the assistance of personnel from USGS-CRRL, the FWS Stockton office initially set up 22 acoustic receiver sites within the San Joaquin River and Delta, and added 3 more later in Paradise Cut for a total of 25 receiver sites (Figure 5-2 and Table 5-6). The USGS-Sacramento office installed and maintained two four-port receivers (CHPE and CHPW), and two single-node receivers near Chipps Island (517 and 516), and a second set of four port receivers at Jersey Point (JPTE and JPTW) during the 2011 VAMP study (Table 5-6). One additional hydrophone (515) was deployed near Chipps Island, just upstream of Spoonbill Slough, but was not used in the modeling as a similar receivers was not deployed in 2010. Additional sites associated with the South Delta TBP study (ORSU, ORSD, ORNU, ORND, MRS, MRNU, and MRND), were maintained by personnel from DWR (Table 5-6). Receivers inside (RGD1 and RGD2) and outside (RGU1 and RGU2) of Clifton Court Forebay were also maintained by staff from DWR while the receivers at the CVP and in the CVP holding tanks (CVPtank) were maintained by USBR staff. One additional receiver in the Delta Mendota Canal (DMC) was also maintained by USBR staff (Table 5-6).

One of the receiver location sites was changed in 2011 relative to where it had been in 2010. The two redundant receivers (one site) on the mainstem San Joaquin River below the HOR (SJL, systems 909 and 910, Table 5-6) were relocated to a site closer to the flow split to decrease the probability that mortality would occur between the junction and the receiver. The assumption of 100% survival of the tagged fish between the flow split and the receiver is necessary for determining the route entrainment probability at this location.

Hydrophones were deployed in key areas, based on channel width, depth and in-water noise interference. Tag drags were conducted to make sure that each hydrophone was able to pick up a signal from an acoustic tag. Cross-sectional depth profiles were measured at each site to ensure that riverbed topography did not obscure direct passage of acoustic signals from transmitters to the hydrophones. Hydrophone locations were marked with an onboard GPS unit (Lowrance HDS-5). Each site contained an acoustic hydrophone, acoustic receiver, input/output box and four, 12V deep-cycle batteries to power the equipment. These batteries were attached to a four-panel solar array. The solar panels used were Sharp 80 watt off-module solar panels mounted on 1 ½" x 1 ½" x 10' angle iron. Sites that were co-located (redundant arrays) shared a four-panel solar array. The solar panels maintained the charge on the batteries and ran the electronic components. All equipment was housed in two metal joboxes. In past years, receivers were cooled by water; however, with the addition of sensitive electronic equipment, small 4" electric fans were added to the job boxes housing the electronics instead. A phidget box was installed to

monitor the condition of all electronic components. Continuously pinging "beacon" tags were programmed and anchored underwater near each site throughout the study period in order to verify that each receiver was operating properly. Receivers were turned on for the 6-year steelhead study on March 3, 2011. Receivers had been operating for over two months when the Chinook salmon were released as part of the VAMP study.



In previous years of the VAMP, each site would have to be visited three to four times a week to download data and to change batteries. For VAMP 2011, the use of telemetry equipment allowed data from each site to be uploaded automatically. A laptop computer (netbook) was connected to each receiver for automatic downloading from the receiver to the computer. The data was then uploaded from the computer to a FTP site, via a modem using an antenna and air card. The RAT files could then be accessed and examined to assure the equipment was working and files were being generated. This set-up also allowed personnel to remotely access the sites through the computer and phidget control program. The phidget control supplied solar panel charging information and allowed for temperature control through adjustment of the cooling fans. If a problem was observed, personnel were dispatched to the site to correct the issue. While this system worked,

the remoteness of sites created intermittent air card connectivity, leading to crews having to go out, almost daily, to check the receivers. A booster antenna and a software program to reboot the computer helped to solve some of these problems. In addition, some equipment was replaced during the course of the season (solar module controller). Due to the high flows, beacon tags and hydrophones needed to be moved on occasion.

Temperature Monitoring

Water temperature was monitored during the VAMP 2011 study using individual computerized temperature recorders (e.g., Onset Stowaway Temperature Monitoring/Data Loggers). Water temperatures were measured at locations along the longitudinal gradient of the San Joaquin River and interior Delta channels between Durham Ferry and Chipps Island – locations along the migratory pathway for the juvenile Chinook salmon released as part of these tests (Figure 1 and Table 1 in Appendix G). Depths of the measurements varied from near the water surface to approximately 4 feet below the water surface. As part of the 2011 VAMP monitoring program, additional temperature recorders were deployed in the south and central Delta (Figure 1 and Table 1 in Appendix G) to provide geographic coverage for characterizing water temperature conditions while juvenile salmon emigrated from the lower San Joaquin River through the Delta. Water temperature was recorded instantaneously at 24-minute intervals throughout the period of the 2011 VAMP investigations.

Tag life study

Two in-tank tag-life studies were conducted by FISHBIO and DWR to quantify the rate of tag extinction under the operating parameters used for the study (i.e., encoding, range, and pulse width). Each study used tag periods representative of the tag periods used in the salmon

survival study, with periods ranging from approximately 5000 to approximately 11000 in both studies. A stratified random sample of 50 tags per study was taken across all of the model 795 Lm tags purchased from HTI which were comprised of four manufacturing lots. Tags were programmed according to the same procedures used for the field study.

Tags were secured in a mesh bag that was placed into the study tank the day after programming. A hydrophone was suspended in the tank to continuously monitor tag function. Tags were considered dead when they were not detected during any single one-hour period. The date and time when the tag initially failed was recorded for each tag and used in conjunction with the time of initialization to determine the active life of each tag. Some tags functioned intermittently following failure and these observations were also recorded. The lifespan of each tag in the tag-life study was calculated as the difference between the time of tag programming and the time of last detection in the tank.

Data Processing

Data collected at individual monitoring sites were transferred to the USGS-CRRL in Cook, Washington. A multiple-step process was used to identify and verify detections of fish in the data files. The first step in identifying valid detections can be done using the vendor (HTI) software (hereafter referred to as MarkTags) to visually inspect each hourly data file from each monitoring receiver. When the number of tagged fish is relatively small, this can be a reasonable way to process the data. However, when the number of tagged fish is large, as was the case in this study, it becomes impractical to visually identify the fish detections. For example, for the combined studies of 90 days with 66 receivers and 4,000 tagged fish, visual inspection of each file using MarkTags would require 570 million (4000 tags in each of 24 hourly files for each of 90 days for each of 66 receivers) page-views in the MarkTags software. To compound this further, four of the sites were 4-port (Acoustic Tag Receiver) ATR and one was a 16-port ATR (CVP trashracks) which increases the number of files that need to be visually inspected. At an ambitious rate of 1 page viewed per second, it would require about 160,000 hours of continuous, uninterrupted work to visually identify valid detections. Based on an 8-hour work day and a 5-day-a-week work schedule, it would take one person 4,000 weeks to visually inspect all the files. Clearly, an automated way of selecting valid detections was needed to process the data in a timely manner.

A combination of automated processing and manually proofing was used to identify fish detections. A tag list was compiled to isolate the locations and time frames that a given fish would be present within the system. This list was used in conjunction with RAT files, input parameters, and algorithms for the automated process (hereafter referred to as FishCount). During the processing of the 2011 data, it was necessary to make modifications to FishCount to accommodate a 7-millisecond period spacing between tags. When tags are spaced this closely, it makes it difficult to separate valid detections from one another and from the ambient background noise. The modifications made to accommodate the 7-millisecond period spacing were tested on a number of data sets from previous studies that included similar tag spacing. After FishCount completed processing the 2011 data a detection history output was compiled and manually proofed for a final cleaning of the data. After the data were manually verified, it was sent to the University of Washington to determine survival probabilities.

The use of an automated process to identify fish detections clearly saves a tremendous amount of time when processing data. However, the savings in time does not come without a cost. While improvements to the accuracy of the automated process will continue, it was not, nor is it likely to be, 100% accurate at correctly identifying all fish detections all the time. Until automated algorithms are developed closer to 100% accuracy there will always be a small portion of missed detections: this is similar to what has been found with manual proofing. Due to the amount of data collected in 2011, manual processing of all the data was not an option and the probability of missing a few valid detections using the automated process was determined to be an acceptable cost to delivering the results in a timely manner. The effect of missing detections on the survival estimation results was mitigated by the survival model, which takes into account imperfect detection probabilities.

Documentation of the validation of FishCount was outside the scope of activities for this project. However, the USGS-CRRL have continued to refine the process and have applied it to data from a number of other studies. For example, the USGS-CRRL applied FishCount to data collected during the Department of Water Resources (DWR) implementation of the 2011 and 2012 Georgiana Slough Non-Physical Barrier (GSNPB) Study to test the effectiveness of using a nonphysical barrier to prevent out-migrating juvenile Chinook salmon and steelhead from entering Georgiana Slough in the Sacramento River portion of the Delta. As part of these studies USGS is working collaboratively with HTI Inc. to compare the results of using FishCount and MarkTags to identify echoes in the RAT files. The methods, results, and discussion of the comparison of

FishCount and MarkTag will be submitted for inclusion in the 2013 Final Report to DWR. Based on the initial comparisons of the two processes, the vendor (HTI) suggested that the data used in the final report should be based on the data that is processed with FishCount, not their MarkTag software.

The University of Washington received the primary database of autoprocessed detection data from the USGS lab in Cook, WA, and the manually processed detection data from the USFWS office in Stockton, CA. These data included the date, time, location, and tag period and subcode of each valid detection of the acoustic salmon tags on the fixed-site receivers. The period and subcode indicate the acoustic tag ID, and were used to identify the tag activation time, tag release time, and release group from the tagging database.

The autoprocessed and manually processed databases were both cleaned to remove obviously invalid detections. The University of Washington identified potentially invalid detections based on unreasonable travel times or unlikely transitions between detection sites, and queried the processor (USGS or USFWS) about the discrepancy. All corrections were noted and made to the database. After cleaning both the autoprocessed and the manually processed databases, the two databases were merged to form the complete database of detections. All subsequent analysis was based on this merged database.

The information for each tag in the merged database included the date and time of the beginning and end of the interval within the hourly RAT file when the tag was detected. The cleaned hourly detections were converted to detections denoting the beginning and end of receiver "visits," with consecutive visits to a receiver separated either by a gap of 12 hours or more between detections on the receiver, or by detection on a different receiver. Detections from receivers in dual or redundant arrays were pooled for this purpose.

Distinguishing between Detections of Salmon Smolts and Predators

The possibility of predatory fish eating tagged study fish and then moving past one or more fixed site receivers complicated analysis of the detection data. The salmon survival model depended on the assumption that all detections of the acoustic tags represented live salmon smolts, rather than a mix of live smolts and predators that temporarily had a salmon tag in their gut. Without removing the detections that came from predators, the survival model would produce potentially biased estimates of juvenile salmon survival through the Delta. The size of the bias would depend on the amount of predation by predatory fish and the spatial range of the predatory fish after eating the tagged salmon. In order to minimize bias, the detection data were filtered for predator detections, and detections assumed to come from predators were removed from the data set.

The predator filter was based on the predator analyses presented by Vogel (2010 and 2011), as well as conversations with fisheries biologists familiar with the San Joaquin River and Delta regions and the predator decision processes used in previous years (SJRGA, 2010 and 2011). The predator filter was applied to all detections of all tags. Two data sets were then constructed: the full data set including all detections, including those classified as coming from predators (i.e., "predator-type"), and the reduced data set, restricted to those detections classified as coming from live smolts (i.e., "smolt-type"). The survival model was fit to both data sets separately. The results from the analysis of the reduced "smolt-type" data set are presented as the final results of the VAMP 2011 study. Results from analysis of the full data set including "predator-type" detections were used to indicate the degree of uncertainty in survival estimates arising from the predator decision process.

The predator filter was based on assumed behavioral differences between salmon smolts and predators such as striped bass and channel catfish. As part of the decision process, environmental data including river flow, river stage, and water velocity were examined from several points throughout the Delta (Table 5-7), as available, downloaded from the California Data Exchange Center (CDEC) website (http://cdec.water.ca.gov/selectQuery.html) on April 10, 2012. All detections were considered when implementing the decision process, including detections from acoustic receivers that were not otherwise used in the survival model.

For each tag detection, several steps were performed to determine if it should be classified as predator or salmon. Initially, all detections were assumed to be of live smolts. Once a detection was classified as coming from a predator, all subsequent detections of that tag were likewise classified as predator detections. The assignment of predator status to a detection was made conservatively, with doubtful detections classified as coming from live salmon. In general, the decision process was based on the assumption that (1) salmon smolts were unlikely to move against the flow, and (2) salmon smolts were actively migrating and thus wanted to move downriver, although they may have temporarily moved upstream with the flow.

A tag could be given a predator classification at a detection site either on arrival or on departure from the site. A tag classified as being in a predator because of long travel time or movement against the flow was

Table 5-7
Environmental Monitoring Sites Used in Predator Decision Rule

Enivonmental Monitoring Site				Data Available				
Site Name	Latitude (°N)	Longitude (°W)	Detection Site	River Flow	Water Velocity	River Stage	Pumping	Reservoir Inflow
CLC	37.8298	121.5574	RGU, RGD	No	No	No	No	Yes
FAL	38.0555	121.6672	FRE/FRW	Yes	Yes	Yes	No	No
GLC	37.8201	121.4497	ORS	Yes	Yes	Yes	No	No
HLT	38.0031	121.5108	C18/C16, MFE/MFW	Yes	Yes	No	No	No
MAL	38.0428	121.9201	CHP	No	No	Yes	No	No
MDM	37.9425	121.534	MRN	Yes	Yes	Yes	No	No
MSD	37.7860	121.3060	BCA, PCO, MOS	Yes	Yes	Yes	No	No
ODM	37.8101	121.5419	CVP, DMC	Yes	Yes	Yes	No	No
OH1	37.8080	121.3290	ORE	Yes	Yes	Yes	No	No
OH4	37.8900	121.5697	ORN	Yes	Yes	Yes	No	No
ORI	37.8280	121.5526	RGU, RGD	Yes	Yes	No	No	No
SJG	37.9351	121.3295	STS, STN	Yes	Yes	Yes	No	No
SJJ	38.0520	121.6891	JPT	Yes	Yes	Yes	No	No
SJL	37.8100	121.3230	SJL	Yes	Yes	Yes	No	No
TRN	37.9927	121.4541	TCN/TCS	Yes	Yes	Yes	No	No
TRP	37.8165	121.5596	CVP, DMC	No	No	No	Yes	No
TSL	38.1004	121.6866	TMS/TMN	Yes	Yes	Yes	No	No
VNI	38.0500	121.4960	C18/C16	No	No	Yes	No	No
VNS	37.6670	121.2670	DFU, DFD, BCA	Yes	No	Yes	No	No

generally given a predator classification upon arrival at the detection site. On the other hand, a tag classified as being in a predator because of long residence time was given a predator classification upon departure from the detection site. Because the survival analysis estimated survival within reaches between sites, rather than survival during detection at a site, the predator classifications on departure from a site did not result in removal of detection at that site from the reduced data set. However, all subsequent detections were removed from the reduced data set.

The predator filter considered various criteria on several spatial and temporal scales. Criteria fit under several categories, described in more detail below: fish speed, residence time, upstream transitions, other unexpected transitions, travel time since release, and movements against flow. Each criterion was applied to each tag detection on the "visit" time scale (Table 5-8). The visit time scale was used in the survival model, with consecutive visits at a given detection site separated by a time gap of at least 12 hours or by detection elsewhere. For each visit detection, a "predator score" was assigned based on the number of criteria yielding a positive predator classification. Separate scores were assigned depending on whether the tag was classified as a predator on arrival or on departure from the detection site. The final predator classification for a given visit-level detection was based on the "arrival" and "departure" predator scores. The detection was classified as coming from a predator on arrival at the detection site if the "arrival" predator score was ≥ 2. Likewise, the detection was classified as coming from a predator on departure from the detection site if the total predator score ("arrival" + "departure") was ≥ 2, or if the detection was previously classified as coming from a predator on arrival. All detections of a tag subsequent to its first predator designation were also classified as coming from a predator.

Table 5-8
Cutoff Values Used in Predator Filter. Observed Values Past Cutoff or Unmet Conditions Indicate a Predator

Detection Site	Previous Site	Residence Time[a] (hr)	Migration Rate[b,c] (km/hr)		Number of Visits	Flow[d] (cfs)		Water Velocity[d] (ft/sec)			Extra conditions	Comment
		Maximum	Minimum	Maximum	Maximum	At arrival	At departure[e]	At arrival	At departuree	Average during transition		
DFU	DF	50	0.01	4	1	< 15,000						No repeat visits allowed.
	DFD	10	0.3	4	1	< 15,000						No repeat visits allowed.
DFD	DF	20	0.01	4	1							
	DFU	20	0.3	4	2							
	DFD, BCA	0	100	NA	0							Not allowed.
BCA	DF	5	0.5	4	1							
	DFU, DFD	5	0.5	4	1							
	BCA, PCO	0	100	NA	0							Not allowed.
PCO	DF	1	0.3	5.5	1							
	DFU, DFD, BCA	1	0.3	5.5	1							
	PCO, MOS	0	100	NA	0							
MOS	DF	15	0.3	5.5	1							
	DFU, DFD, BCA, PCO	15	0.3	5.5	1							
	SJL, ORE	10	0.3	4	2	< 5,000	< 3,000	< 0.1	< -0.1	< 0.1		
	MOS	0	100	NA	0							Not allowed.
SJL	DFD - MOS	5	0.3	5.5	1[f]							Allow 2 visits, upstream forays coming from MOS
	ORE	5	0.3	5.5	1		< 0		< -0.1	> -0.1		
	STS	5	0.3	4	2	< -500	< -500	< -0.5	< -0.5	< -0.2		
	SJL	0	100	NA	0							Not allowed.
STS	BCA, MOS, SJL	12	0.3	5	1 (2 from SJL)			< 0.5			Arrive at beginning of flood tide	Allow 2 (3) upstream forays coming from MOS (SJL)
	BCA, MOS, SJL	6	0.3	5	1 (2 from SJL)						Do not arrive at beginning of flood tide	Allow 2 (3) upstream forays coming from MOS (SJL)
	STN	6 (4)[f]	0.2	4	2	< 1,700	< 4,000	< 0.5	< 1	< 0.5		Alternative value if arrive at beginning of flood tide
	STS	3			2	< -300 (> -300)[g]	> -300 (< -300)[g]	< -0.5 (> -0.5)[g]	> -0.5 (<-0.5)[g]	< 0.2		
STN	DF	15	0.3	5	1			< -0.1			Arrive at beginning of flood tide	
	MOS, SJL, STS	15	0.3	5	1 (2 from STS)			< -0.1			Arrive at beginning of flood tide	
	DF	6	0.1	5	1						Do not arrive at beginning of flood tide	
	MOS, SJL, STS	6	0.1	5	1 (2 from STS)						Do not arrive at beginning of flood tide	
	STN	4			2	< -1,500 (> -1,500)[g]	> -1,500 (< -1,500)[g]	< -0.1 (> -0.1)[g]	> -0.1 (<-0.1)[g]	< 0.2		
C18/C16	DF	30	0.15	4	1							
	SJL, STS, STN	30	0.15	4	1							
	TCN/TCS	30	0.15	4	1		> -500	> -0.4	> -0.1	> -0.4		
	MFE/MFW	15	0.4	4	2			< -0.4	< 0.2	< 0.2		
	C18/C16	12			2			< -0.1 (> -0.1)[g]	> -0.1 (<-0.1)[g]	-0.2 to 0.2		
MFE/MFW	C18/C16	24	0.1	4	2			> -0.4				
	MFE/MFW	12			2			< -0.1 (> -0.1)[g]	> -0.1 (<-0.1)[g]	-0.2 to 0.2		
TCN/TCS	DF	30	0.15	4	1	< 1,200		< 0.2				
	SJL, STS, STN	30	0.15	4	1	< 1,200		< 0.2				
	C18/C16	30	0.15	4	2	< 1,200		< 0.2	< 0.2	< 0.2		
	TCN/TCS	12			2	< 500 (> 500)[g]	> 500 (< 500)[g]	< -0.1 (> -0.1)[g]	> -0.1 (<-0.1)[g]	-0.2 to 0.2		
TMN/TMS	MFE/MFW, CVPtank	10	0.1	3 (5)[f]	1							Alternative residence time if coming from CVPtank
	CHP, JPT	10	2.1 (0.5)[f]	3	1		< -7,000f		< -0.1[f]			Alternative migration rate, flow and velocity limits if coming from JPT
ORE	DF	3	0.3	5.5	1	> 0		> -0.1				
	DFD, BCA, PCO, MOS	3	0.3	5.5	1 (2 from MOS)	> 0		> -0.1				
	SJL	3	0.3	5.5	1	> 0	< -200	> -0.1	< -0.1	> -0.1		
	STN	3	0.3	5.5	1		< -300		< -0.5			
	ORS	3	0.3	4	2	< 0	< -2,500	< -0.1	< -0.5	< 0		
	ORE	0	100	NA	0							Not allowed.
ORS	BCA - ORE	12	0.2	5	1 (2 from ORE)	> -2,500		> -0.5				Allow 2 (3) upstream forays if coming from MOS (ORE)
	CVP	4	1.5	4	2	< -2,500	< -900	< -0.5	< -0.5		CVP pumping < 1,500 cfs at departure[e]	
	ORS	4			2	< -2,500 (> -2,500)[g]	> -2,500 (< -2,500)[g]	< -0.5 (> -0.5)[g]	> -0.5 (<-0.5)[g]			
MRS	MOS, ORE	12	0.2	5	2 (1 from MOS)							
MRN	ORS, MRS	40	0.2	5	2	> -6, 000	> -0.5					
	C18/C16, TCN/TCS, MFE/MFW	40	0.2	5	1					> -0.1		
	CVP[f], ORN	40	0.2	5	1	< -5,500		< -0.5			CVP pumping < 1,500 cfs at departure[e]	See "extra conditions" if coming from CVP
	MRN	20			2	< -2,500 (> -2,500)[g]	> -2,500 (< -2,500)[g]	< -0.5 (> -0.5)[g]	> -0.5 (<-0.5)[g]			
CVP	BCA, ORE, ORS	80 (40)[f]	0.2	4	1 (2 from ORS)	> -900		> -0.5				Alternative values if arrive at CVP after end of VAMP
	ORN	40 (20)[f]	0.8	5	2		< -700		< -0.3	< 0		Alternative values if arrive at CVP after end of VAMP
	RGU/RGD	40 (20)[f]	0.2	5	2		< -1,500		< -0.3	< 0	CCFB inflow < 2,500 cfs at departure[e]	Alternative values if arrive at CVP after end of VAMP
	MRN	40	1.1	5	2							Alternative values if arrive at CVP after end of VAMP
	SJL, STN[f]	0	100	0	0							Arrive at CVP during VAMP
	SJL[f]	40	0.3	2.2	1						CVP pumping > 1,000 at arrival	Arrive at CVP after end of VAMP
	STN[f]	40	0.6	3.8	1						CVP pumping > 1,000 at arrival	Arrive at CVP after end of VAMP
	CVPtank	8 (4)[f]	0.02	0.3	2							Alternative values if arrive at CVP after end of VAMP
	CVP	40 (20)[f]			2						Pumping < 1,500 at departure, > 1,000 at arrival	Alternative values if arrive at CVP after end of VAMP
CVPtank	CVP	20	0	NA	1							
DMC	CVP	12 (0)[f]			2 (0)[f]						CVP pumping < 1,500 cfs at departure[e]	Alternative values if arrive at CVP after end of VAMP
	DMC	12 (0)[f]			2 (0)[f]						CVP pumping < 1,500 cfs at departure[e]	Alternative values if arrive at CVP after end of VAMP
ORN	MOS, ORE, ORS	40	0.15	4	1	> -700		> -0.3				
	MRN, RGU/RGD	40	0.15	4	2	> -700[f]	> -1,500[f]	> -0.3[f]	> -0.3[f]			Flow and water velocity limits only if coming from RGU/RGD
	CVP	40	0.15	4	2	> -700	> -900	> -0.3	> -0.5		CVP pumping < 1,500 cfs at departure[e]	
	STN, C18/C16	40	0.5 (0.3)[f]	4	1							Alternative value if arrive from C18/C16
	ORN	25			2	< -700 (> -700)[g]	> -700 (< -700)[g]	< -0.3 (> -0.3)[g]	> -0.3 (<-0.3)[g]			
RGU/RGD	ORE, ORS, MRN	10 (80)[h]	0.2	4	1							
	ORN	10 (80)[h]	0.2	4	2	< -750	< -700	< -0.1	< -0.3	< 0.2		
	CVP	10 (80)[h]	0.2	4	2	> -750		> -0.1		> -0.2	CVP pumping < 1,500 cfs at departure[e]	
JPT	C18/C16, MFE/MFW, ORS	40	0.1	5	1							
	CVPtank, RGU/RGD	40	0.1	5	1							Trucking release sites are downstream of JPT
	TMN/TMS	40	0.1	5	2							
	FRE/FRW	30	0.1	5	3							
FRE/FRW	MFE/MFW, ORN	40	0.1	5	1							
	JPT	30	0.1	5	3							
CHP	Any site except CHP	40	0.1	5	1 (2)[f]		> -1,500[f]	> -0.1[f]				Flow, velocity limits only if coming from STN; alternative values coming from JPT, TMN/TMS
	CHP	30			3							

[a] Near field residence time includes up to 12 hours missing between detections.
[b] Approximate migration rate was calculated on most direct pathway.
[c] Missing values for transitions to and from single site (or between CVP and DMC): travel times must be 12 to 24 hours.
[d] Flow or velocity condition, if any, must be violated for predator classification.
[e] Condition at departure from previous site.
[f] See comments for alternative criteria.
[g] High flow/velocity on departure requires low values on arrival (and vice versa).
[h] If present in detection range < 70% of residence time, and most detections were at RGU (not RGD).

The scoring method was used to avoid placing undue weight on any single criterion. However, extra weight was given to the residence time criteria at the radial gates into the Clifton Court Forebay (sites RGU and RGD, model codes D1 and D2) in scoring, because very long residence time at these sites was both considered to be a strong indicator of predation and unlikely to be accompanied by other predation indicators. Several methods of final predator classification using the predator scores were considered, and results were compared against the full detection histories of numerous tags with a variety of types of detection histories before settling on the above method.

Criterion: Fish Speed

Fish speed was measured in two ways for each transition between detection sites and for each tag: average migration rate through the reach, and average body lengths per second through the reach. Migration rate was measured for all transitions except for return visits to the same site. Body lengths per second was based on migration rate, but accounted for water velocity and fish length at tagging.

Migration rate was defined as distance traveled divided by travel time (km/hr). Reach distances were approximated using hydrophone latitude and longitude locations and the ruler tool in Google Earth. For transitions with multiple possible pathways, the pathway deemed most likely was used. Travel time was measured as the difference between the time of final detection at the prior detection site and the time of first detection at the later detection site. The range of acceptable migration rate values was specified for each observed tag transition, allowing for a wider range in reaches with more complicated hydrology (e.g., downstream reaches and those near the water export facilities) (Table 5-8). For upstream-directed transitions, the acceptable minimum migration rate was calculated based on the joint assumptions that (1) smolts moving upstream on the scale of the study reaches were pushed upstream by reverse flow caused primarily by incoming tide, and (2) it was unlikely that tidal influences would affect smolt migration over a long time period. Thus, maximum travel times on upstream-directed transitions were set at 12 – 15 hours, allowing for non-linear or punctuated smolt movement. The minimum migration rate for upstream-directed transitions was calculated based on this maximum travel time.

Fish speed may be affected by water velocity. Thus, the perceived migration rate (as defined above) was adjusted first by the average measured water velocity in the reach during the fish transition through the reach, and then by the size of the fish at tagging. The adjusted fish velocity (V_{FA}) was estimated by $V_{FA} = m_r - V_w$, where m_r is the signed (i.e., +/-) migration rate and V_w is the signed average water velocity through the reach during the tag transition through the reach. Both migration rate and water velocity were signed (e.g., assigned + or -) to represent direction, with downstream (toward the ocean) assigned the positive direction and upstream negative. A fish that moves downstream slower than the water velocity would have $V_{FA}<0$, while a fish that moves downstream faster than the water velocity would have $V_{FA}>0$. Water velocity was measured at the nearest fixed-point environmental monitoring station, using data available from CDEC at http://cdec.water.ca.gov. In some cases, this station was adjacent to the acoustic receivers located at the upstream or downstream boundary of the reach; in other cases, this station was in the vicinity of the reach, but not actually in it. Each value of V_{FA} was then divided by measured body length of the study fish at tagging to produce body lengths per second (BL/S): $BL / S = V_{FA}/FL$, where FL = fish length at tagging. The values of BL/S may be either positive or negative, depending on whether the fish moved downstream or upstream and whether it moved faster than the observed water velocity. Observed measures of BL/S ranged from -13.1 to 65.5 (mean = 1.4). Hawkins and Quinn (1996) reported critical swimming speeds up to 7.5 – 7.9 BL/S for steelhead measuring approximately 100 mm. The maximum absolute value of BL/S suitable for salmon smolts was set at 8 (i.e., $-8 \leq BL/S \leq 8$), to account for uncertainty in the actual water velocity through the reach in question.

Criterion: Residence Time

Residence time was measured on three spatio-temporal scales. The near-field residence time was the duration of the visit-level detection event, where consecutive visits at a given acoustic array (i.e., a dual or redundant array, or a single line of hydrophones) were separated by either a time gap of ≥ 12 hours, or by detection elsewhere. The near-field residence time allowed for short-term delays in migration due to tidal influence (e.g., being pushed back into range of the receiver by reverse flow). Near-field behavior within the detection range of the receivers at Chipps Island was also considered, with flat line signals indicating predation (either predator or deposited tag). Maximum allowed near-field residence times for smolts were set by reviewing observed residence times in comparison with criteria used in previous years (Table 5-8; SJRGA, 2011). In addition, the hydraulic conditions upon arrival at the site were considered, with longer residence times allowed for smolts that arrived during flood tide or encountered reverse flow conditions. Discussions with salmon biologists familiar with the Delta also informed the near-field residence time criteria.

The mid-field residence time was the time delay from the first detection at a site to the time of the last detection there before detection elsewhere. That is, the mid-field residence time removed the 12-hour limit on detection gaps at a site used to define near-field residence time. Whereas the near-field residence time measured the time a tagged fish spent in or near the detection field of a receiver array, the mid-field residence time measured the time the tagged fish spent in the neighborhood of the site without detection elsewhere. Criteria for mid-field residence time were determined by near-field residence time criteria and the number of visits allowed.

The far-field residence time measured the time a tagged fish spent in the broader region of the study area. Regions were:

- San Joaquin River upstream of the head of Old River,
- San Joaquin River from the head of Old River through the Stockton receivers,
- San Joaquin River from the Turner Cut junction through Medford Island,
- Old River from its head to the Middle River junction,
- Old River from the head of Middle River to Highway 4 (including the water export facilities),
- Middle River from its head to Highway 4, and
- San Joaquin or Sacramento River from Threemile Slough to Chipps Island, including Jersey Point and False River.

Maximum regional residence times allowed for smolts were set at 48 hours for the San Joaquin River upstream of the head of Old River (6 hours if returning from downstream of the head of Old River), and 360 hours in all other regions.

Criterion: Upstream Transitions

Salmon smolts were assumed to be migrating toward the ocean. Upstream transitions were generally considered evidence of predation. Exceptions were made to allow for initial confusion immediately after release at Durham Ferry, temporary upstream movement in the presence of reverse river flow, and multi-directional movement in the neighborhood of the water export facilities in the southwestern portion of the study area. Based on conversations with salmon biologists, it was assumed that juvenile salmon would not make lengthy or numerous upstream forays large enough to be detected by the network of acoustic receivers used in the 2011 VAMP study. A maximum of 3 upstream forays and 15 upstream river kilometers was imposed. Upstream detection sites generally had stricter upstream foray requirements (e.g., maximum of 1 or 2).

Criterion: Unexpected Transitions

Certain transitions were observed in the data but were unexpected for salmon smolts. Such unexpected transitions included those from the CVP holding tank to the receivers located near the CVP trashracks or to the hydrophone in the Delta Mendota Canal, as well as transitions from the Delta Mendota Canal back to the CVP trashrack receivers. Several tags were observed moving from the release site at Durham Ferry to the Stockton receivers in a short time period with no intervening detections. Some such transitions may have come from predators, possibly including avian predators.

Criterion: Travel Time Since Release

Overall travel time since release at Durham Ferry was considered under the expectation that smolts would complete their migration through the Delta in 15 days or less (360 hours). This assumption was assessed by comparisons with observed detection histories. Tags with longer detection histories typically violated multiple predator filter criteria. Stricter criteria for upstream detection sites were determined by criteria for migration rate, residence time, and the number of visits allowed.

Criterion: Movements Against Flow

It was assumed that salmon smolts usually moved with downstream-directed flow, or during periods of slack or flood tide. Arrival at a detection site or departure from a detection site against relatively strong flow (i.e., not near slack or flood tide) was considered evidence of predation. Dual or redundant acoustic arrays aided in determination of fish direction, but depended on high detection probabilities and non-identical detection areas.

Constructing Detection Histories

For each tag, the detection data summarized on the visit scale were converted to a detection history ("capture history") that indicated the chronological sequence of detections on the fixed-site receivers throughout the study area (Figure 5-2, Table 5-6). In cases in which a tag was observed passing a particular receiver or river junction multiple times, the detection history represented the final route of the tagged fish past the receiver or river junction. Detections were pooled from the 13 receivers located between the trash racks and the trash boom at the Central Valley Project (CVP), and from the two receivers located within the holding tanks at CVP (CVPtank). Detections were also pooled from the receivers located in the San Joaquin River just downstream of the release site (DFD), the San Joaquin

River receivers near Lathrop (SJL), the San Joaquin River receivers at the channel markers just downstream of the Turner Cut Junction (C18/C16), the Old River receivers located near the head of the river (ORE), and the receivers located just outside the radial gates in the entrance channel to Clifton Court Forebay (RGU).

Survival Model

A multi-state statistical release-recapture model was developed and used to estimate salmon smolt survival and migration route entrainment probabilities throughout the study area to a single exit point at Chipps Island (Figures 5-3, 5-4 and 5-5). The release-recapture model was similar to the model developed by Perry et al. (2010) and the model developed for the 2009 VAMP study (SJRGA, 2010) and the 2010 VAMP study (SJRGA, 2011).

Fish moving through the Delta toward Chipps Island may have used any of several routes (Figure 5-3). The two primary routes modeled were the San Joaquin River route (Route A) and the Old River route (Route B). Route A followed the San Joaquin River until it joined the Sacramento River just upstream of Chipps Island. Route A included the possibility of exiting the San Joaquin River downstream of the city of Stockton and migrating to Chipps Island through the interior Delta. Route B used Old River from its head on the San Joaquin River just upstream of Lathrop through to Chipps Island, either via the Old River confluence with the San Joaquin River just west of Mandeville Island, or through Middle River or the state and federal water export facilities. Additional subroutes were monitored for fish use, but were contained in either Route A or Route B. Subroute C consisted of Middle River from its head on Old River to its confluence with the San Joaquin west of Medford Island, as well as the water export facilities. The water export facilities formed two subroutes: fish entering the State Water Project via Clifton Court Forebay (subroute D) or the Central Valley Project (subroute E) had the possibility of being trucked from those facilities and released in either the Sacramento River or the San Joaquin River upstream of Chipps Island. Subroutes D and E were both contained in subroute C (Middle River), while subroutes C, D, and E were all contained in route B (Old River). Finally, fish that remained in the San Joaquin River past Stockton may have exited the San Joaquin River via Turner Cut and migrated to Chipps Island via the interior Delta either through the confluence of Middle River or Old River with the San Joaquin River, or through the water export facilities (subroute F). Although subroute F included trucking from the water export facilities, passage of subroute F fish through subroutes D and E was not modeled directly. Fish in routes A, B, C, and F all had multiple unmonitored pathways available for passing through the Delta to Chipps Island.

Several exit points from the mainstem San Joaquin River were monitored and given route names for convenience, although these location did not actually determine a unique route to Chipps Island. The first encountered was Paradise Cut (Route P), which is accessible from the San Joaquin River between Durham Ferry and Banta Carbona in high water conditions. In low or normal water conditions, Paradise Cut is inaccessible. Fish that entered Paradise Cut may have entered Old River downstream of the junction with Middle River, and have moved either to the water export facilities or to downstream reaches of Old River or Middle River. Because Paradise Cut originates upstream of Mossdale Bridge, it was located outside of the study area, and was monitored to account for entry to Old River via that route. Another departure point from the San Joaquin River was False River, just east of Jersey Point. Fish entering False River from the San Joaquin River would have entered the interior Delta headed away from Chipps Island, and would not be expected to reach Chipps Island without detection in another route. Thus, False River was considered an exit point of the study area, rather than a waypoint on a route to Chipps Island. Although departure at False River was unexpected for a live migrating salmon smolt, the presence of reverse tidal flows in this region combined with potentially high mortality made this type of detection history possible. False River was given a route name (H) for convenience. Both Jersey Point and Chipps Island were included in multiple routes. Jersey Point was included in many of the previously named routes (in particular, routes A, B, C, and F), while Chipps Island (the final exit point) was included in all previously named routes and subroutes except routes P and H. Thus, Jersey Point and Chipps Island were given their own route name (G). An additional set of receivers located in Threemile Slough (Route T) and a single receiver in the Delta Mendota Canal (accessed via Route E) were not used in the survival model. The routes and the study area exit points are summarized as follows:

A = San Joaquin River: survival

B = Old River: survival

C = Middle River: survival

D = State Water Project: survival

E = Central Valley Project: survival

F = Turner Cut: survival

G = Jersey Point, Chipps Island: survival, exit point

H = False River: exit point

P = Paradise Cut: survival

T = Threemile Slough: not used in survival model

Figure 5-3
Locations of Acoustic Receivers ("Detection Sites") Used in the Statistical Survival Model for the 2011 VAMP Study, Including Locations of Acoustic Receivers Deployed by the California Department of Water Resources for the South Delta Temporary Barriers Project Study. Site A1 is the Release Site at Durham Ferry. Sites A0, E3, P1, and T1 Were Excluded from the Survival Model.

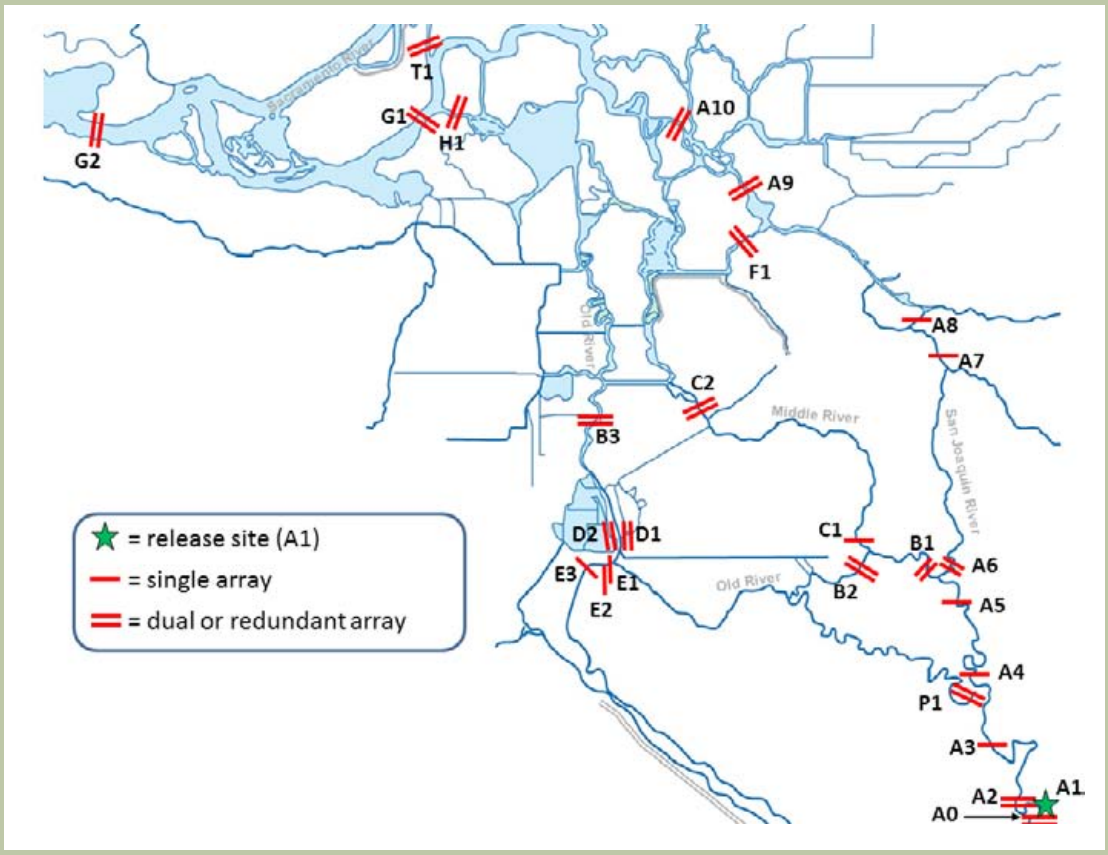


Figure 5-4
Schematic of Mark-Recapture Model Showing Estimable Parameters for Acoustic-Tagged Juvenile Chinook Salmon Tagged and Released in the 2011 VAMP Study, Using the Layout of Telemetry Stations in Figure 5-3. Parameters Include: Probabilities of Survival (S_{hi}), Route Entrainment (ψ_{hi}), Transition ($\phi_{kj,hi}$), and Detection (P_{hi}). Single Lines Denote Single-Array or Pooled Telemetry Stations, and Double Lines Denote Double-Array Telemetry Stations. Names of Telemetry Stations Correspond to Site Labels in Figure 5-3. Migration Pathways to Sites B3 (ORN), C2 (MRN), D1 (RGU), and E1 (CVP) are Color-Coded by Departure Site.

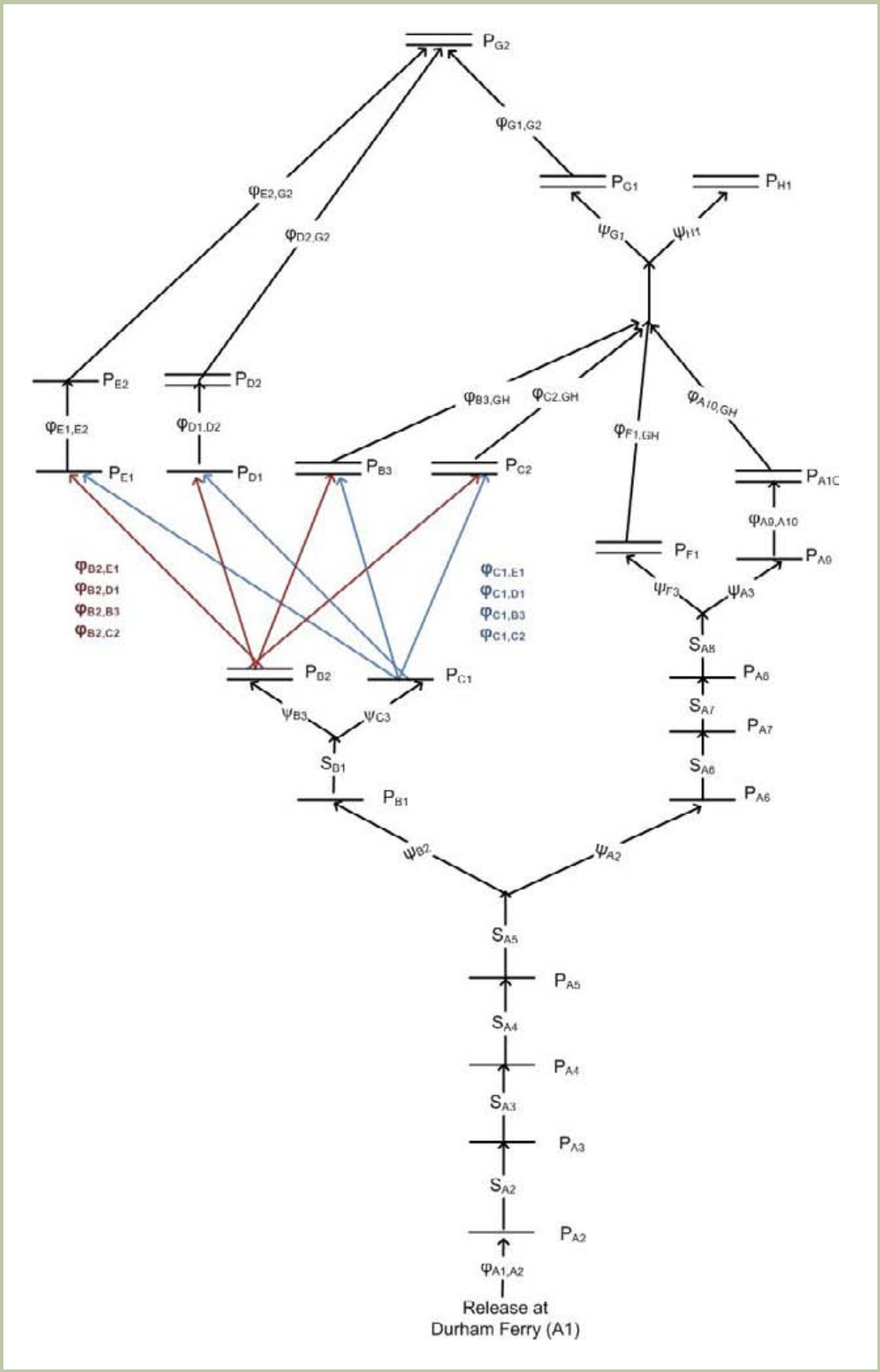


Figure 5-5
Schematic of Simplified Mark-Recapture Model Showing Estimatble Parameters for Acoustical-Tagged Juvenile Chinook Salmon in Release Group 3 of 2011 VAMP Study, Using the Layout of Telemetry Stations in Figure 5-3. Parameters Include: Probabilities of Survival (S_{hi}), Route Entrainment (ψ_{hi}), Transition ($\phi_{kj,hi}$), and Detection (P_{hi}). Single Lines Denote Single-Array or Pooled Telemetry Stations, and Double Lines Denote Double-Array Telemetry Stations. Names of Telemetry Stations Correspond to Site Labels in Figure 5-3

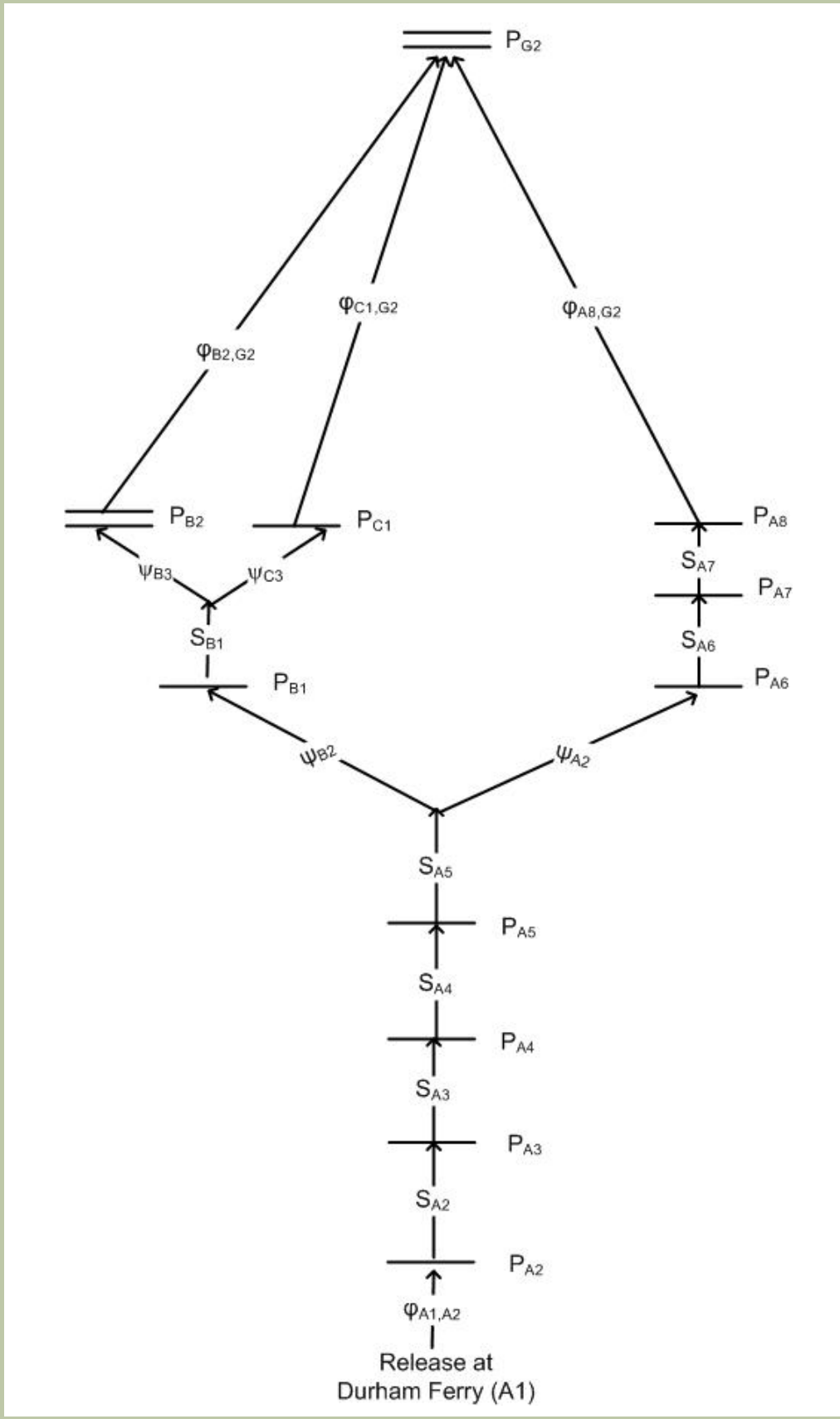


Figure 5-3 shows the layout of the receivers with the labels used in the survival model and in the predator filter. Each site is identified by route (A – G, P, or T) and the index of site within the route (0 – 10). Individual receivers comprising dual arrays were identified separately, with "a" representing the upstream receiver and "b" representing the downstream receiver.

Some detection sites (receivers) were used in the predator filter but were omitted from the survival model. These sites were the dual receivers located just upstream of the release site (A0a, A0b), the receivers located inside Paradise Cut (P1a, P1b), the single receiver located inside the Delta Mendota Canal (E3), and the dual receivers in Threemile Slough (T1a, T1b). The Paradise Cut dual array was omitted because no detections were recorded on those receivers from any release groups. This was consistent with the assumption that reduced river flow had closed access to Paradise Cut by the time of the first Chinook salmon release in mid-May. Detections were omitted from the receivers just upstream of the release site (A0a, A0b) because very few tags were detected there (22 out of 1,895), and these detections did not contribute to survival estimation through the study area. Additionally, detections from the single hydrophone located nearest the north shore in the eastern acoustic receiver line at Chipps Island (CHPn, system 515; Table 5-6) were omitted from the survival model because the entrance to Spoonbill Creek, just west of this hydrophone, violated the closure assumption of the dual array at Chipps Island. The locations of the remaining hydrophones at Chipps Island were deemed far enough from the entrance to Spoonbill Creek to make detections on those receivers unlikely to violate the closure assumption.

The release-recapture model used parameters denoting the probability of detection (P_{hi}), route entrainment (ψ_{hl}), salmon survival (S_{hi}), and transition probabilities equivalent to the joint probability of movement and survival ($\phi_{kj,hi}$) (Figures 5-4, 5-4 and Table 2 in Appendix H). Unique detection probabilities were estimated for the individual receivers in a dual array, with P_{hia} representing the detection probability of the upstream array at station i in route h, and P_{hib} representing the detection probability of the downstream array. The full model consisted of 80 parameters for each release occasion: 39 detection probabilities, 8 survival probabilities, 5 route entrainment probabilities, and 28 transition probabilities. The model parameters were:

P_{hi} = detection probability: probability of detection at telemetry station i within route h, conditional on surviving to station i, where $i = ia, ib$ for the upstream, downstream receivers in a dual array, respectively.

S_{hi} = survival probability: probability of survival from telemetry station i to i+1 within route h, conditional on surviving to station i.

ψ_{hl} = route entrainment probability: probability of a fish entering route h at junction l (l =1, 2, 3), conditional on fish surviving to junction l.

$\phi_{kj,hi}$ = transition probability: joint probability of route entrainment and survival, the probability of surviving and moving from station j in route k to station i in route h.

The parameter ψ_{A1} is the probability of remaining in the San Joaquin River at the head of Paradise Cut. Because no Chinook salmon tags were actually detected on the receivers located inside Paradise Cut in 2011, it was assumed that Paradise Cut was inaccessible by the time of the first Chinook salmon releases. Thus, it was assumed that ψ_{A1} =1, and this parameter was omitted from the survival model and from Figures 5-4 and 5-5.

The transition and detection parameters involving the receivers outside Clifton Court Forebay (site D1, RGU) depended on the status of the radial gates upon tag arrival at D1. Although fish that arrived at D1 when the gates were closed could not immediately enter the gates to reach site D2 (RGD), these fish could linger in the area until the gates open. Thus, parameters $\phi_{B2,D10}$, $\phi_{C1,D10}$ and $\phi_{D10,D2}$ represented transition to and from site D1 when the gates were open, and parameters $\phi_{B2,D1C}$, $\phi_{C1,D1C}$, and $\phi_{D1C,D2}$ represented transition to and from D1 when the gates were closed. It was not possible to estimate unique detection probabilities at D1 for times when the gates were closed versus when the gates were open. Differences in D1 transition probabilities attributable to gate status were assessed using the Akaike Information Criterion (AIC), with an AIC ≥ 2 indicating a significant effect of gate status (Burnham and Anderson, 2002). In the case where there was no significant effect of gate status, common transition probabilities at D1 were used regardless of gate status. It was also not possible to estimate the detection probability at CVPtank (in the holding tanks at the Central Valley Project) because there were no receivers located downstream of this detection site and unique to subroute E. Therefore, it was necessary to assume that the detection probability at this site was 100% (i.e., P_{E2} = 1). Because site E2 consisted of receivers located in the constrained environment of the holding tanks, this assumption was deemed reasonable as long as the monitoring equipment was operating. Records of receiver performance indicated no outages at site E2 during the 2011 tagging study.

A variation on the parameter naming convention

was used for parameters representing the transition probability to the junction of False River with the San Joaquin River (site H1), just upstream of Jersey Point (Figure 5-3). This river junction marks the distinction between routes G and H, so transition probabilities to this junction were named $\phi_{kj,GH}$, for the joint probability of surviving and moving from station *j* in route *k* to the False River junction. Once at the junction between the San Joaquin River and False River, fish in the San Joaquin River may have either exited to False River or else remained in the San Joaquin River to reach Jersey Point. Alternatively, fish that approached the San Joaquin River from the interior Delta through False River may have either moved downstream in the San Joaquin River to Jersey Point, or else moved upstream away from Jersey Point (deemed less likely for migrating smolts). The complex tidal forces present in this region precluded distinguishing between smolts using False River as an exit from the San Joaquin River and smolts using False River as an entrance to the San Joaquin River. Thus, the available information included whether a fish was at False River, but not its direction of movement there. Regardless of which approach the fish used to reach this junction, the $\phi_{kj,GH}$ parameter (i.e., $\phi_{A10,GH}$, $\phi_{B3,GH}$, $\phi_{C2,GH}$ or $\phi_{F1,GH}$) was the transition probability to the junction of False River with the San Joaquin River, via any route; ψ_{G1} was the probability of moving downstream toward Jersey Point from the junction; and $\psi_{H1} = 1-\psi_{G1}$ was the probability of exiting (or re-exiting) the San Joaquin River to False River from the junction (Figure 5-4).

For fish that reached the interior receivers at the Clifton Court Forebay (D2) or the Central Valley Project (E2), the parameters $\phi_{D2,G2}$ and $\phi_{E2,G2}$, respectively, represented the joint probability of migrating and surviving to Chipps Island, including survival during and after collection and transport (Figure 5-4). The parameter $\phi_{D2,G2}$ also included survival through the Clifton Court Forebay and into the holding tank at the State Water Project. Some salvaged and transported smolts were released in the San Joaquin River between Jersey Point and Chipps Island, and others were released in the Sacramento River upstream of the confluence with the San Joaquin River. Only the overall probability of making the transition to Chipps Island was estimated for fish passing through the water export facilities.

In addition to the model parameters, derived performance metrics measuring migration route probabilities and survival were estimated as functions of the model parameters. Both route entrainment (i.e., route use or route selection) and route-specific survival were estimated for the two primary routes determined by routing at the head of Old River (routes A and B). Route entrainment and route-specific survival were also estimated on a finer spatial scale, in particular for the major subroutes of routes A and B. These subroutes were identified by a two-letter code, with the first letter indicating the route used at the head of Old River (A or B), and the second letter indicating the route used at the next river junction encountered: A or F at the Turner Cut Junction, and B or C at the head of Middle River. Thus, the route entrainment probabilities for the subroutes were:

$\psi_{AA} = \psi_{A2}\psi_{A3}$: probability of remaining in the San Joaquin River past the head of Old River and the Turner Cut Junction,

$\psi_{AF} = \psi_{A2}\psi_{F3}$: probability of remaining in the San Joaquin River past the head of Old River, and exiting to the interior Delta at Turner Cut,

$\psi_{BB} = \psi_{B2}\psi_{B3}$: probability of entering Old River at the head of Old River, and remaining in Old River past the head of Middle River,

$\psi_{BC} = \psi_{B2}\psi_{C3}$: probability of entering Old River at the head of Old River, and entering Middle River at the head of Middle River,

where $\psi_{B2} = 1-\psi_{A2}$, $\psi_{F3} = 1-\psi_{A3}$, and $\psi_{C3} = 1-\psi_{B3}$. The probability of surviving from the entrance of the Delta near Mossdale Bridge (site A5, MOS) through an entire migration pathway to Chipps Island was estimated as the product of survival probabilities that trace that pathway:

$S_{AA} = S_{A5}S_{A6}S_{A7}S_{A8}\phi_{A9,A10}\phi_{A10,G2}$: Delta survival for fish that remained in the San Joaquin River past the head of Old River and Turner Cut,

$S_{AF} = S_{A5}S_{A6}S_{A7}S_{A8}\phi_{F1,G2}$: Delta survival for fish that entered Turner Cut from the San Joaquin River,

$S_{BB} = S_{A5}S_{B1}S_{B2}$: Delta survival for fish that entered Old River at its head, and remained in Old River past the head of Middle River,

$S_{BC} = S_{A5}S_{B1}S_{C1}$: Delta survival for fish that entered Old River at its head, and entered Middle River at its head.

The parameters $\phi_{A10,G2}$ and $\phi_{F1,G2}$ represent the probability of getting from A10 and F1, respectively, to Chipps Island. Both parameters represent multiple pathways around or through the Delta to Chipps Island (Figure 5-3). For example, for fish that reached the Medford Island receivers on the San Joaquin River (site A10), the simplest pathway was to remain in the San Joaquin past Jersey Point to Chipps Island (Figure 5-3).

Alternatively, these fish may have reached Jersey Point via the confluence of Old River with the San Joaquin River, Frank's Tract, and False River on their way to Chipps Island. In either case, the probability of getting from the Medford Island receivers to Chipps Island is written as $\phi_{A10,G2} = \phi_{A10,GH}\psi_{G1}\phi_{G1,G2}$. Fish that left the San

Joaquin River at Turner Cut also had multiple ways of reaching Chipps Island. One option was to use interior, unmonitored channels to reach False River, Jersey Point, and Chipps Island, with probability $\phi_{F1,G2} = \phi_{F1,GH}\psi_{G1}\phi_{GH,G2}$. The parameter $\phi_{F1,GH}$ represents all ways of getting to the False River junction via the unmonitored channels of the northern interior Delta, as well as returning to the San Joaquin River downstream of Medford Island and migrating to Jersey Point in the river. Other migration options for Turner Cut fish used monitored routes (e.g., the water export facilities), but were nevertheless not modeled directly.

Survival probabilities S_{B2} and S_{C1} represented survival of fish that remained in the Old River at B2 (ORS), or entered the Middle River at C1 (MRS), respectively. Fish in both of these routes may have subsequently moved toward the State Water Project (D1), Central Valley Project (E1), or the downstream receivers on Old River (B3) or Middle River (C2) (Figures 5-3 and 5-4). Each of these routes leads eventually to Chipps Island (G2). Because there were many unmonitored river junctions within the "reach" between sites B2 or C1 and Chipps Island, it was impossible to separate the probability of taking a specific pathway from the probability of surviving to a given receiver. Thus, only the joint probability of movement and survival could be estimated to the next receivers (i.e., the $\phi_{kj,hi}$ parameters defined above and in Figure 5-4). However, the overall survival probability from B2 (S_{B2}) or C1 (S_{C1}) to Chipps Island could be defined by summing products of the $\phi_{kj,hi}$ parameters:

$$S_{B2} = \left(\phi_{B2,D1O}\phi_{D1O,D2} + \phi_{B2,D1C}\phi_{D1C,D2}\right)\phi_{D2,G2} + \phi_{B2,E1}\phi_{E1,E2}\phi_{E2,G2} + \left(\phi_{B2,B3}\phi_{B3,GH} + \phi_{B2,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}$$

$$S_{C1} = \left(\phi_{C1,D1O}\phi_{D1O,D2} + \phi_{C1,D1C}\phi_{D1C,D2}\right)\phi_{D2,G2} + \phi_{C1,E1}\phi_{E1,E2}\phi_{E2,G2} + \left(\phi_{C1,B3}\phi_{B3,GH} + \phi_{C1,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}$$

Fish leaving the southern Delta in Old River or Middle River past the Highway 4 receivers (B3 or C2, respectively) may have used any of several routes to reach Chipps Island. These fish may have remained in Old or Middle rivers until these rivers rejoined the San Joaquin River downstream of Medford Island, and then migrated in the San Joaquin River. Alternatively these fish may have passed through Frank's Tract and False River or Fisherman's Cut to rejoin the San Joaquin River. Although these routes were largely unmonitored, all fish moving from Highway 4 to Chipps Island must have passed Jersey Point (site G1), located on the San Joaquin River just downstream of the junction with False River (site H1). Thus, both S_{B2} and S_{C1} used the transition probabilities $\phi_{B3,GH}$ and $\phi_{C2,GH}$ to represent the probability of moving from site B3 or C2, respectively, to the False River junction with the San Joaquin River.

In cases where the use of unique D1 transition probabilities by gate status introduced no significant improvement to model fit (according to AIC < 2), the S_{B2} and S_{C1} parameters were defined as follows:

$$S_{B2} = \phi_{B2,D1}\phi_{D1,D2}\phi_{D2,G2} + \phi_{B2,E1}\phi_{E1,E2}\phi_{E2,G2} + \left(\phi_{B2,B3}\phi_{B3,GH} + \phi_{B2,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}$$

$$S_{C1} = \phi_{C1,D1}\phi_{D1,D2}\phi_{D2,G2} + \phi_{C1,E1}\phi_{E1,E2}\phi_{E2,G2} + \left(\phi_{C1,B3}\phi_{B3,GH} + \phi_{C1,C2}\phi_{C2,GH}\right)\psi_{G1}\phi_{G1,G2}$$

Both route entrainment and route-specific survival were estimated on the large routing scale, as well, focusing on routing only at the head of Old River. The route entrainment parameters were defined as:

$\psi_A = \psi_{A2}$: probability of remaining in the San Joaquin River at the head of Old River

$\psi_B = \psi_{B2}$: probability of entering Old River at the head of Old River.

The probability of surviving from the entrance of the Delta (site A5, MOS) through an entire large-scale migration pathway to Chipps Island can be written as a function of the finer-scale route-specific survival probabilities and route-entrainment probabilities:

$S_A = \psi_{A3}S_{AA} + \psi_{F3}S_{AF}$: Delta survival (from Mossdale to Chipps Island) for fish that remained in the San Joaquin River at the head of Old River, and

$S_B = \psi_{B3}S_{BB} + \psi_{C3}S_{BC}$: Delta survival for fish that entered Old River at the head of Old River.

Using the estimated migration route probabilities and route-specific survival for these two primary routes (A and B), survival of the population from A5 (Mossdale) to Chipps Island was estimated as:

$$S_{Total} = \psi_A S_A + \psi_B S_B .$$

Survival was also estimated from Mossdale to the Jersey Point/False River junction, both by route and overall. Survival through this region ("Mid-Delta" or MD) was estimated only for fish that migrated entirely in-river, without being trucked from either of the water export facilities. Thus, the route-specific Mid-Delta survival for the large-scale San Joaquin River and Old River routes was defined as follows:

$S_{A(MD)} = S_{A5}S_{A6}S_{A7}S_{A8}\left(\psi_{A3}\phi_{A9,A10}\phi_{A10,GH} + \psi_{F3}\phi_{F1,GH}\right)$: Mid-Delta survival for fish that remained in the San Joaquin River past the head of Old River, and

$S_{B(MD)} = \psi_{B3}S_{BB(MD)} + \psi_{C3}S_{BC(MD)}$:

Mid-Delta survival for fish that entered Old River at its head, and remained in Old River past the head of Middle River, where

$$S_{BB(MD)} = S_{A5}S_{B1}\left(\phi_{B2,B3}\phi_{B3,GH} + \phi_{B2,C2}\phi_{C2,GH}\right), \text{ and}$$

$$S_{BC(MD)} = S_{A5}S_{B1}\left(\phi_{C1,B3}\phi_{B3,GH} + \phi_{C1,C2}\phi_{C2,GH}\right).$$

Total Mid-Delta survival (i.e., from Mossdale to the Jersey Point/False River junction) was defined as $S_{Total(MD)} = \psi_A S_{A(MD)} + \psi_B S_{B(MD)}$. Mid-Delta survival was estimated only for those release groups with sufficient tag detections to model transitions through the entire south Delta and to the Jersey Point/False River junction.

In order to compare 2011 results with results from the 2009 study, when no detections were available from Chipps Island, regional survival ("Southern Delta", or SD) was also estimated through the southern portion of the Delta, both within each primary route and overall:

$$S_{A(SD)} = S_{A5}S_{A6}S_{A7}S_{A8}, \text{ and}$$

$$S_{B(SD)} = S_{A5}S_{B1}\left(\psi_{B3}S_{B2(SD)} + \psi_{C3}S_{C1(SD)}\right)$$

where $S_{B2(SD)}$ and $S_{C1(SD)}$ are defined as:

$$S_{B2(SD)} = \phi_{B2,B3} + \phi_{B2,C2} + \phi_{B2,D1O} + \phi_{B2,D1C} + \phi_{B2,E1}, \text{ and}$$

$$S_{C1(SD)} = \phi_{C1,B3} + \phi_{C1,C2} + \phi_{C1,D1O} + \phi_{C1,D1C} + \phi_{C1,E1}.$$

In the absence of a gate effect on transitions probabilities at D1, $S_{B2(SD)}$ and $S_{C1(SD)}$ were defined as:

$$S_{B2(SD)} = \phi_{B2,B3} + \phi_{B2,C2} + \phi_{B2,D1} + \phi_{B2,E1}, \text{ and}$$

$$S_{C1(SD)} = \phi_{C1,B3} + \phi_{C1,C2} + \phi_{C1,D1} + \phi_{C1,E1}.$$

Total survival through the Southern Delta was defined as:

$$S_{Total(SD)} = \psi_A S_{A(SD)} + \psi_B S_{B(SD)}.$$

In some cases (i.e., release group 3), sparse detections on receivers in the interior Delta or downstream San Joaquin River receivers prevented fitting the full survival model to the detection histories. In these cases, the model was simplified to estimate Delta survival on a larger spatial scale than in the full model. In particular, subroute F was not distinguished from the primary San Joaquin River Route (A), and the routes through the interior Delta were not modeled. Instead, the overall probability of transition from the northern Stockton receiver (A8, STN) to Chipps Island was estimated directly (parameter $\phi_{A8,G2}$), along with transition probabilities from ORS (B2) and MRS (C1) to Chipps Island (parameters $\phi_{B2,G2}$ and $\phi_{C1,G2}$, respectively) (Figure 5-5). Although transition probabilities to the Central Valley Project trashracks (E1) and the radial gates at the Clifton Court Forebay (D1) could not be estimated, it was possible to use the tags detected at those sites to estimate transition probabilities through the CVP and Clifton Court Forebay to Chipps Island. This approach provided for relatively robust estimation of parameters in the southern Delta along with total Delta survival and route-specific survival in the primary routes.

In other cases (i.e., release group 2), sparse detections on receivers located at Jersey Point and False River prevented fitting the full survival model through that region. In these cases, the model was simplified to estimate Delta survival without the Jersey Point and False River parameters for routes A, B, C, and F. Instead, transition probabilities were estimated directly from the final sites in these routes to Chipps Island. For example, the transition probability $\phi_{A10,G2}$ was estimated directly from the model, replacing the product $\phi_{A10,GH}\psi_{G1}\phi_{G1,G2}$. Likewise, the parameters $\phi_{B3,G2}$, $\phi_{C2,G2}$, and $\phi_{F1,G2}$ were estimated from the model directly.

Individual capture histories were constructed for each tag as described above. Each capture history consisted of one or more fields representing initial release (field 1) and the sites where the tag was detected, in chronological order. Detection on both receivers in a dual array was denoted by the code "ab", detection on only the upstream receiver was denoted "a0", and detection on only the downstream receiver was denoted "b0". For example, the detection history DF A2 A4 A6 A7 A8 A9 G1a0 G2ab represented a tag that was released at Durham Ferry and detected just downstream of the release site (A2), on the San Joaquin River receiver just downstream of Paradise Cut (A4), at Lathrop (A6), on both receivers near Stockton (A7, A8), at the channel marker array in the San Joaquin River just downstream of Turner Cut (A9), on the first receiver located at Jersey Point (G1a0), and at both receivers at Chipps Island (G2ab). This detection history had probability

$$\phi_{A1,A2}P_{A2}S_{A2}(1-p_{A3})S_{A3}P_{A4}S_{A4}(1-P_{A5})S_{A5}\psi_{A2}P_{A6}S_{A6}P_{A7}S_{A7}P_{A8}S_{A8}$$
$$\times\ \psi_{A3}P_{A9}\phi_{A9,A10}\left(1-P_{A10}\right)\phi_{A10,GH}\psi_{G1}P_{G1a}\left(1-P_{G1b}\right)\phi_{G1,G2}P_{G2a}P_{G2b}.$$

A second example was the detection history DF A3 A4 A5 B2ab D1O D2b0. A fish with this detection history was released at Durham Ferry, migrated downstream without detection on the receivers just downstream of Durham Ferry but with detection at Banta Carbona (A3), the San Joaquin site just downstream of Paradise Cut (A4), and at the site near Mossdale Bridge (A5), entered Old River without detection until the array in Old River just past the head of Middle River (B2ab), and then moved to Clifton Court Forebay with detection at the

receivers outside the radial gates when the gates were open (D1O), and finally on the downstream receiver inside the radial gates (D2b0). The tag was not detected again after passing the inside receiver. The probability of having this detection history was

$$\phi_{A1,A2}(1-P_{A2})S_{A2}P_{A3}S_{A3}P_{A4}S_{A4}P_{A5}S_{A5}\psi_{B2}(1-P_{B1})S_{B1}\psi_{B3}$$
$$\times P_{B2a}P_{B2b}\phi_{B2,D1O}P_{D1O}\phi_{D1O,D2}\left(1-P_{D2a}\right)P_{D2b}\chi_{D2},$$

where

$$\chi_{D2}=1-\phi_{D2,G2}+\phi_{D2,G2}(1-P_{G2a})(1-P_{G2b})$$

was the probability of not being detected again after reaching site D2.

A third example of a detection history was DF A2 A3 A5 B1 C1 B3ab H1a0. A fish with this detection history moved downstream after release at Durham Ferry, with detection on the receivers at the downstream Durham Ferry site (A2), at Banta Carbona (A3), and at Mossdale (A5). The fish then entered Old River with detection at ORE (B1), entered Middle River (C1), moved to the Old River site near Highway 4 and was detected on both receivers there (B3ab), and was last detected on the first receiver of the dual array located at False River (H1a0). The probability of this detection history occurring was parameterized as

$$\phi_{A1,A2}P_{A2}S_{A2}P_{A3}S_{A3}(1-P_{A4})S_{A4}P_{A5}S_{A5}\psi_{B2}P_{B1}S_{B1}\psi_{C3}P_{C1}$$
$$\times\ \phi_{C1,B3}P_{B3a}P_{B3b}\phi_{B3,GH}\psi_{H1}P_{H1a}\left(1-P_{H1b}\right).$$

Under the assumptions of common survival, route entrainment, and detection probabilities and independent detections among the tagged fish in each release group, the likelihood function for the survival model for each release group was a multinomial likelihood with individual cells denoting each possible capture history.

Parameter Estimation

Release and detection data were organized by tag into four release groups, ranging in size from 473 to 475. The first two release groups were released on the San Joaquin River at Durham Ferry during the VAMP period (Table 5-3), and the last two release groups were released at Durham Ferry after the VAMP period (Table 5-4). For each release group, the multinomial likelihood model described above was numerically fit to the observed set of capture histories according to the principle of maximum likelihood using Program USER, software developed at the University of Washington (Lady and Skalski, 2009). Point estimates and standard errors were computed for each parameter. Standard errors of derived performance measures were estimated using the delta method (Seber, 2002: 7-9). Sparse data meant that some parameters could not be freely estimated for some release groups. For example, for release group 1, only 2 tags were detected at the Middle River South receiver (MRS, site C1). Such few detections prevented estimation of the detection probability at that site, thus site C1 was removed from the model and performance metrics were redefined accordingly. In all cases, transition, survival, and detection probabilities were fixed to 1.0 or 0.0 as appropriate, based on the observed detections. The model was fit separately for each release. For each release, the complete data set that included possible detections from predatory fish was analyzed separately from the reduced data set restricted to detections classified as salmon smolt detections. Population-level estimates of parameters and performance measures were estimated from fitting the survival model to the pooled data set, using all four release groups. This is approximately equivalent to calculating a weighted average of the release-specific estimates, with weights proportional to release size, in the case where all releases provide each parameter estimate. In the event that some parameters are inestimable from particular releases because of sparse data, pooling across release groups provides more robust parameter estimates than a weighted average.

The significance of the radial gates status on arrival at the outside receiver (RGU, site D1) was assessed for all release groups pooled, using a difference in Akaike Information Criterion (AIC) ≥ 2 to indicate a significant difference in model fit (Burnham and Anderson, 2002). If the effect of the gates was found to be insignificant using this criterion, then a simplified model was used for parameter estimation in which $\phi_{B2,D1O}=\phi_{B2,D1C}$, $\phi_{C2,D1O}=\phi_{C1,D1C}$, and $\phi_{D1O,D2}=\phi_{D1C,D2}$. For each model, goodness-of-fit was assessed visually using Anscombe residuals (McCullagh and Nelder, 1989).

For each release group, the effect of primary route (San Joaquin River or Old River) on estimates of survival to Chipps Island was tested with a two-sided Z-test on the log scale:

$$Z=\frac{\ln\left(\hat{S}_A\right)-\ln\left(\hat{S}_B\right)}{\sqrt{\hat{V}}},$$

where

$$V=\frac{Var\left(\hat{S}_A\right)}{\hat{S}_A}+\frac{Var\left(\hat{S}_B\right)}{\hat{S}_B}-\frac{2Cov\left(\hat{S}_A,\hat{S}_B\right)}{\hat{S}_A\hat{S}_B}.$$

The parameter V was estimated using Program USER. It was also tested whether tagged Chinook salmon smolts showed a preference for either the San Joaquin River route or the Old River route using a one-sided Z-test with the test statistic:

$$Z = \frac{|\hat{\psi}_A - 0.5|}{SE(\hat{\psi}_A)}.$$

Statistical significance was tested at the 5% level (α=0.05).

Analysis of Tag Failure

The first of the two tag-life studies began on May 23rd, with the last tag failure recorded on July 4th. The second study began on July 12th, with the last tag failure recorded on August 21st. Observed tag survival was modeled using the 4-parameter vitality curve model (Li and Anderson, 2009).

Receiver malfunction during the May tag-life study resulted in missing failure times for three tags, resulting in interval-censored failure time data for these three tags (e.g., failure occurred sometime between day 25.9 and day 26.4). Although the precise failure times were missing, the failure time intervals for these tags were accounted for in the observed cumulative tag survival (i.e., the proportion of tags surviving to a given time). Several methods were used to account for the missing data while fitting the tag survival model, and the fit of the resulting models to the observed (non-missing) survival data was compared. One approach censored the missing values with no attempt to impute the missing failure times. An alternative method iteratively generated random failure times within the observed failure intervals, and estimated parameters of the tag survival model using averages over the iterations. The censoring method resulted in a superior model fit to the observed survival data. Thus, results from the censoring method are reported and were used to adjust fish survival estimates from the salmon survival study for tag failure.

Tag life is expected to vary with both tag period and water temperature. Differences in observed tag life were investigated both between the May and July tag-life studies, and among tags with different periods. For each tag-life study, both the observed tag survival data and the fit of the estimated tag survival model to the data were examined graphically. Two methods of stratifying the combined tag survival data from the two tag-life studies were compared: (1) stratify by study month (i.e., May vs. July) and group across all tag periods, and (2) stratify by tag period (i.e., 5000-7999 vs. 8000-11000) and group across month. Stratifying by both study month and tag period resulted in small sample sizes, and so was not considered. For the second method, data from the two tag-life studies were pooled. It was necessary to impute values for the missing data when calculating cumulative tag survival in the pooled data set. In this case, the use of randomly generated failure times was compared to the conservative approach of using the latest possible failure time from the interval of missing data. The conservative approach produced a better model fit to the observed survival data. The imputed failure times were censored for fitting of the tag survival model. Both methods of stratification were compared to the full data set that pooled across month and tag period using the AIC. The stratification method associated with the smallest AIC was used to fit the final tag survival model, and used for adjustments to the fish survival estimates for tag failure.

The resulting tag-survival model was used to adjust estimated fish survival and transition probabilities for premature tag failure using methods adapted from Townsend et al. (2006). In Townsend et al. (2006), the probability of tag survival through a reach is estimated based on the average observed travel time of tagged fish through that reach. In order to account for possible differences in travel time to Chipps Island using the various routes (e.g., San Joaquin route vs. Old River route), travel time and the probability of tag survival to Chipps Island were estimated separately for the different routes. Subroutes using truck transport were handled separately from subroutes using only in-river travel. Standard errors of the tag-adjusted fish survival and transition probabilities were estimated using the inverse Hessian matrix of the fitted joint fish-tag survival model. The additional uncertainty introduced by variability in tag survival parameters was not estimated, with the result that standard errors may be slightly low. In previous studies, however, variability in tag-survival parameters has been observed to contribute little to the uncertainty in the fish survival estimates when compared with other, modeled sources of variability (Townsend et al., 2006); thus, the resulting bias in the standard errors was expected to be small.

Analysis of Tagger Effects

Tagger effects were assessed using contingency tests of independence on the number of tag detections at key detection sites throughout the study area. Specifically, a lack of independence (i.e., heterogeneity) between the detections distribution and tagger was tested using a chi-squared test (α=0.05; Sokal and Rohlf, 1995). Lack of independence may be caused by differences in survival, route entrainment, or detection probabilities. The reduced data set (without predator detections), pooled over release groups, was used for this analysis.

Analysis of Travel Time

Travel time through each reach was calculated for tags detected at the beginning and end of the reach, and summarized across all tags with observations. Travel time between two sites was defined as the time delay between the last detection at the first site and the first detection at the second site. In cases where the tagged

fish was observed to make multiple visits to a site, the final visit was used for travel time calculations. The harmonic mean was used to summarize travel times.

Route Entrainment Analysis

The effects of changes in hydrologic conditions on route entrainment at the head of Old River were explored using statistical generalized linear models (GLMs) with a binomial error structure and logit link (McCullagh and Nelder, 1989). Acoustic tag detections used in this analysis were restricted to those detected at either of the acoustic receiver arrays just downstream of the head of Old River: site SJL (model code A6) or site ORE (code B1). Predator-type detections were excluded. Detections from a total of 1,575 tags were used in this analysis.

Hydrologic conditions were represented in several ways, primarily total river flow (discharge) and water velocity. Flow and water velocity were recorded at 15-minute intervals at DWR gaging stations located just downstream of the head of Old River in both the San Joaquin River (station SJL) and Old River (station OH1) (Table 5-7). Conditions measured at the SJL station were labeled route A, and conditions at the OH1 station were labeled route B.

For each tag, conditions were measured at the estimated time of arrival of the tagged fish at the gaging station in its route. Time of arrival had to be estimated because the acoustic receivers were located at some distance from the gaging stations (0.34 to 0.93 km). Arrival time for tag i (t_i) was estimated based on the first-order assumption of constant movement during the transition from the previous detection site.

The gaging stations typically recorded flow and velocity measurements every 15 minutes. Some observations were missing. In 2011, measurements at the SJL station were sporadic before May 20th. Linear interpolation was used to estimate the flow and velocity conditions at the time of tag arrival at the gauging station:

$$Q_{ih} = w_i Q_{t_1(i)h} + (1 - w_i) Q_{t_2(i)h}$$

$$V_{ih} = w_i V_{t_1(i)h} + (1 - w_i) V_{t_2(i)h}$$

where $Q_{t_1(i)h}$ ($V_{t_1(i)h}$) and $Q_{t_2(i)h}$ ($V_{t_2(i)h}$) are the two observed measures of flow (velocity) at the gaging station in route h (h=A,B) nearest in time to the time t_1 of tag i arrival such that $t_1 \leq t_i \leq t_2$. The weights w_i were defined as

$$w_i = \frac{t_{2(i)} - t_i}{t_{2(i)} - t_{1(i)}} ,$$

and resulted in weighting Q_{ih} and V_{ih} toward the closest flow or velocity observation.

In cases with a short time delay between consecutive flow and velocity observations (i.e., $t_2 - t_1 \leq 60$ minutes), the change in conditions between the two time points was used to represent the tidal stage (Perry, 2010):

$$\Delta Q_{ih} = Q_{t_2(i)h} - Q_{t_1(i)h}$$

$$\Delta V_{ih} = V_{t_1(i)h} - V_{t_1(i)h}$$

for h = route A or B and tag i.

The proportion of total flow entering each river at the time of tag arrival was measured as

$$pQ_{iA} = \frac{Q_{iA}}{Q_{iA} + Q_{iB}} \text{ into the San Joaquin River, and}$$

$$pQ_{iB} = 1 - pQ_{iA} \quad \text{into Old River.}$$

Likewise, the flow proportion into the San Joaquin River was measured at the two time points before and after tag arrival:

$$pQ_{t_1(i)A} = \frac{Q_{t_1(i)A}}{Q_{t_1(i)A} + Q_{t_1(i)B}} \quad \text{and}$$

$$pQ_{t_2(i)A} = \frac{Q_{t_2(i)A}}{Q_{t_2(i)A} + Q_{t_2(i)B}} \quad .$$

If $t_2 - t_1 \leq 30$ minutes, then the change in flow proportion into the San Joaquin River at the time of arrival of tag i was measured by

$$\Delta pQ_{iA} = pQ_{t_2(i)A} - pQ_{t_1(i)A}.$$

In the event of negative flow into the San Joaquin River (i.e., $Q_{iA} < 0$), the flow proportion into the San Joaquin River pQ_{iA} was negative. Negative values of pQ_{iA} close to 0 indicated a small proportion of negative flow past the SJL gauging station relative to OH1 flow, while negative values farther from 0 indicated a larger proportion of negative flow past the SJL gaging station.

Flow reversal in the San Joaquin River was represented by the indicator variable U (Perry, 2010):

$$U_i = \begin{cases} 1, & Q_{iA} < 0 \\ 0, & Q_{iA} \geq 0 \end{cases}$$

Daily export rate was measured at the Central Valley Project E_{iCVP} and State Water Project E_{iSWP}, and total exports throughout the Delta E_{iTot} (data downloaded from DayFlow on October 26, 2012). Fork length at tagging L_i and release group (RG_i) were also considered. All continuous covariates were standardized, i.e.,

$$\tilde{x}_{ij} = \frac{x_{ij} - \bar{x}_j}{s(x_j)}$$

for the observation of covariate *j* from tag *i*.

The form of the generalized linear model was

$$\ln\left(\frac{\psi_{iA}}{\psi_{iB}}\right) = \beta_0 + \beta_1\left(\tilde{x}_{i1}\right) + \beta_2\left(\tilde{x}_{i2}\right) + \cdots + \beta_p\left(\tilde{x}_{ip}\right),$$

where $\tilde{x}_{i1}, \tilde{x}_{i2}, \ldots, \tilde{x}_{ip}$ are the observed values of standardized covariates for tag *i* (covariates 1, 2, …, *p*, see below), and ψ_{iA} is the predicted probability that the fish with tag *i* selected route A (San Joaquin River route), with $\psi_{iB} = 1 - \psi_{iA}$ (B = Old River route).

Single-variate regression was performed first, and covariates were ranked by P-values from the appropriate F-test (McCullagh and Nelder, 1989). Covariates found to be significant alone $\alpha = 0.05$ were then analyzed together in a series of multivariate regression models. Because of high correlation between flow and velocity, flow and velocity models were considered separately. Likewise, exports at CVP and SWP were considered separately. The general forms of the three multivariate models were:

Flow model: $Q_A + Q_B + \Delta Q_A + \Delta Q_B + U_A + E_{Tot} + L + RG$

Flow proportion model: $pQ_A + \Delta pQ_A + U_A + E_{Tot} + L + RG$

Velocity model: $V_A + V_B + \Delta V_A + \Delta V_B + U_A + E_{Tot} + L + RG.$

Backwards selection with F-tests was used to find the most parsimonious model that explained the most variation in the data (McCullagh and Nelder, 1989). AIC was used to select among the flow, flow proportion, and velocity models. Model fit was assessed by grouping data into discrete classes according to the independent covariate, and comparing predicted and observed frequencies of route entrainment into the San Joaquin using the Pearson chi-squared test (Sokal and Rohlf, 1995).

Mobile Telemetry Monitoring

Mobile telemetry surveys were used to determine where fish may have been lost in reaches between the fixed receiver stations. The majority of mobile monitoring effort was dedicated to systematic coverage of three reaches: (1) the San Joaquin River from Banta Carbona to the Head of Old River split; (2) Old River from the split to the federal pumping facilities and Clifton Court Forebay; and (3) the San Joaquin River from Old River downstream to Turner Cut. Weekly surveys were conducted in each reach between May 9th and June 10th.

A HTI Model 295G datalogger and omni-directional HTI model 590-Series hydrophone were used to record acoustic data. The datalogger was attached to a laptop computer and data files were reviewed in real-time using HTI's AcousticTag program. Every 0.25 mi. of river length (to stay within minimum tag detection ranges) the boat was turned to face upstream, anchored in the center of the channel, the engine was turned off, and the boat remained stationary for a minimum of 5 minutes to detect tags in smolts that may have been moving downstream, holding, or immobile (deceased). At locations where multiple tags or excessive background noise was detected, sampling was extended for an additional 5 minutes. The Model 295G datalogger is equipped with an integrated GPS receiver which provided coordinates where the receiver was located for each holding point, which was used as an estimator of tag location.

Data files generated during mobile tracking were processed using the Auto-Mark feature built into the HTI MarkTags program to identify tag detections. All files were then manually examined to verify marked tag codes and identify tag codes that were not identified by the auto-marking process.

Results

Transport to Release Sites

Average water temperature in the transport tanks, after buckets were loaded and prior to transport for the VAMP fish, was approximately 17° C (range between 15.7° and 17.9° C). Dissolved oxygen was between 13 and 14 mg/l (range between 12.4 and 14.9 mg/l). Over the course of the 45-60 minute drive from TFCF to the release sites, water temperatures in the transport tanks changed by -0.3° to 1.2° C and dissolved oxygen changed by -3.6 to 1.5 mg/l (Table 5-9). For the salmon released as part of the South Delta TBP study, average water temperature in the truck after loading was similar for the first group and higher for the second group than for the VAMP fish (Table 5-10). The dissolved oxygen levels were somewhat lower, for the South Delta TBP study fish than for the VAMP fish, although still relatively high, prior to transport. Water temperature and dissolved oxygen levels during transport did not change much (Table 5-10).

Water temperatures in the river were between 14° C and almost 18° C for the VAMP releases, with lower water temperatures during the first week (Table 5-9). The dissolved oxygen levels were consistently around 9 mg/l in the river at the time of release. Water temperatures in the river ranged between 15° C and almost 19° C for the South Delta TBP salmon released in June (Table 5-10).

No fish were removed for signs of poor recovery from the 948 Chinook salmon transported and released as part of VAMP in 2011. There were no dead or impaired salmon collected after transport and prior to fish being transferred to the holding containers or observed prior to release for the VAMP fish in 2011 (Table 5-3 and 5-9). There were no mortalities after transport and only one mortality prior to release from the 947 Chinook salmon released as part of the South Delta TBP study in 2011 (Table 5-4 and 5-10).

Dummy-Tagged Fish

None of the 120 fish dummy-tagged for VAMP were found dead when evaluated after 48 hours in 2011 (Table 5-11). All fish evaluated for condition were found swimming vigorously, with normal gill coloration, normal eye quality, normal body coloration and no fin hemorrhaging. Mean scale loss, for the fish dummy-tagged for VAMP, ranged from 1.0 to 8.4% (Table 5-11). None of the examined fish had loose sutures or hemorrhaging around the sutures. Mean fork length (FL) of fish examined ranged from 104.7 to 107.3 mm (Table 5-11). Short-term survival was 100% within the perforated garbage cans. These data indicate that the fish used for the VAMP in 2011 were in generally good condition.

Chinook salmon dummy-tagged for the South Delta TBP study also appeared to be in good condition, with no mortality of the fish after being held for 48 hours (Table 5-12).

Fish Health

Health assessments were conducted on cohorts of acoustic-tagged MRH juvenile Chinook salmon used in the VAMP and South Delta TBP studies corresponding to the May 19th and 26th and June 16th study fish releases. Health assessment control (HAC) groups were transferred to the CA-NV Fish Health Center wet lab, and sampled at 1 and 30 days post transfer. No obligate viral or bacterial pathogens were detected in any of the 3 HAC groups sampled 1 day post transfer. External infections with *Flavobacterium columnare* (the bacteria which causes columnaris disease) and *Ichthyophthirius multifiliis* (the protozoan which causes ich or white spot disease) were observed on fish from all 3 HAC groups sampled 30 days post transfer. *Tetracapsuloides bryosalmonae* parasites, the causative agent of proliferative kidney disease (PKD), were detected in 0-7% of fish in HAC groups at 1 day post transfer and 27-46% of fish from HAC groups sampled at 30 days post transfer. Survival for the 30-day holding periods was high and ranged from 96-100%. Gill ATPase activity levels were consistent with fish undergoing smoltification in all except the May 26th HAC group. Overall, HAC groups demonstrated low mortality and only mild PKD prevalence; indicating, fish health was not a concern in survival of 2011 VAMP and South Delta TBP study fish. The fish health study is further described in Chapter 6.

Receiver Performance

Receiver performance was much improved in 2011. The use of modified Joboxes was continued because it seemed to eliminate overheating; however, the use of water was eliminated. Instead, two fans were placed, one at each end of the Jobox and wired into a temperature sensor. As temperatures started to rise, the receivers began to overheat and shut down; resulting in data gaps. This was addressed by changing the settings in the phidget control; allowing the fans to run continuously, which seemed to minimize the overheating problem.

While most of the issues associated with receiver performance in 2010 were eliminated, there were a limited number of sites that had some non-operation issues in 2011 (Table 5-13). Most periods of down time were well after the VAMP fish were released (Table 5-13). One issue encountered was the loss of files when files were being uploaded from the netbook to the FTP sites. One explanation may be that during the uploading period from netbook to the FTP site, the FTP site may have gone offline resulting in the data gap. These data gaps were limited to one hour blocks and occurred very infrequently. In the future the use of a better air card and upgraded antenna may eliminate this occurrence.

Temperature Monitoring

Five temperature recorders deployed as part of the 2011 VAMP were taken or irretrievable. This resulted in missing data for the Confluence Top, Confluence Bottom, "Q" Piling 0.5 miles Upstream of Channel Marker 13, Jersey Point USGS Gauging Station, and Holland Riverside Marina sites. Additionally, the temperature recorder at the Dos Reis site had been occasionally dewatered, which resulted in chaotic, but still meaningful, temperature readings.

Results of water temperature monitoring at Durham Ferry, Old River at HOR, and Clifton Court Forebay Radial Gates during the April-June smolt emigration from the San Joaquin River through the Delta are shown in Figures 4, 6 and 15 in Appendix G. Water

Table 5-9
Water Temperature and Dissolved Oxygen in the Transport Tank after Loading Prior to Transport, After Transport, and in the River at the Durham Ferry Release Site, Just Prior to Placing Fish in Holding Containers and the Number of Mortalities after Transport Just Prior to Release After the 24-hour Holding Period and for Dummy-tagged Fish After the 48-hour Holding Period for Chinook Salmon Released as Part of the 2011 VAMP

Transport Date	Tank 1 after loading		Tank 2 after loading		Tank 1 after transport		Tank 2 after transport		# morts after transport	River		# morts just prior to release
	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)		Temp (˚C)	DO (mg/L)	
5/16/11	17.2	14.9	17.2	13.7	16.9	13.8	16.9	15.2	0	15.2	9.3	0
5/17/11	16.0	14.8	16.0	14.2	15.7	13.6	15.7	---[a]	0	14	9.51	0
5/18/11	16.1	13.3	16.2	13.4	16.4	11.6	16.3	12.3	0	14.1	9.1	0
5/19/11	17.7	14.6	17.6	13.5	18.6	12.2	17.9	12.5	0	15.6	9.42	0
Average	16.8	14.4	16.8	13.7	16.9	12.8	16.7	13.3		14.7	9.3	
5/21/11	17.8	13.2	17.9	14.3	17.7	11.4	18.1	10.7	0	16.9	9.41	0
5/22/11	16.5	12.8	16.1	12.4	16.6	11.1	16.5	10.9	0	17.0	9.14	1
5/23/11	16.7	13.4	16.5	12.8	17.8	13.2	16.9	13.1	0	17.7	9.49	0
5/24/11	15.8	12.8	15.7	12.5	16.6	10.7	16.9	10.5	0	16.8	9.22	0
Average	16.7	13.0	16.6	13.0	17.2	11.6	17.1	11.3		17.1	9.3	

[a] DO meter was not operating correctly

Table 5-10
Water Temperature and Dissolved Oxygen in the Transport Tank after Loading Prior to Transport, After Transport, and in the River at the Durham Ferry Release Site, Just Prior to Placing Fish in Holding Containers and the Number of Mortalities after Transport for Chinook Salmon Released as Part of the South Delta Temporary Barrier Project Study in 2011

Transport Date	Tank 1 after loading		Tank 2 after loading		Tank 1 after transport		Tank 2 after transport		# morts after transport	River		# morts just prior to release
	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)		Temp (˚C)	DO (mg/L)	
6/6/11	16.1	12.0	15.9	11.9	16.6	11.0	16.3	11.4	0	15.3	9.56	0
6/7/11	15.4	12.9	15.5	12.8	15.9	11.1	16.3	10.9	0	15.2	9.55	1
6/8/11	17.2	12.6	17.0	11.6	16.6	12.7	16.8	11.9	0	16.8	10.04	0
6/9/11	16.4	12.3	16.5	12.3	16.9	11.4	17.2	11.2	0	16.5	9.34	0
Average	16.3	12.5	16.2	12.1	16.5	11.6	16.7	11.3		16.0	9.6	
6/14/11	17.2	11.9	17.4	11.9	18.7	11.7	19.5	12.1	0	17.8	9.72	0
6/15/11	19.5	10.9	19.2	10.9	18.1	10.3	17.3	11.7	0	18.8	8.87	0
6/16/11	19.5	11.1	19.9	11.0	17.5	10.6	17.6	11.2	0	17.3	9.69	0
6/17/11	18.3	11.3	17.9	11.3	17.1	12.4	17.0	11.6	0	18.3	9.95	0
Average	18.6	11.3	18.6	11.3	17.9	11.3	17.9	11.7		18.1	9.6	

Table 5-11
Results of Dummy Tagged Juvenile Chinook Salmon Evaluated After Being Held for 48 Hours at the Release Sites as Part of the 2011 Vernalis Adaptive Management Program (VAMP) Study

Holding Site	Examination Date, Time	Mean (sd) Forklength (mm)	Mortality	Mean (sd) scale loss	Normal Body Color	No Fin Hemorrhaging	Normal Eye Quality	Normal Gill Color
Durham Ferry	5/18/11, 0905	103 (2.5)	0/12	5.25 (3.2)	12/12	12/12	12/12	12/12
Durham Ferry	5/19/11, 1200		0/24[a]					
Durham Ferry	5/20/11, 0905	104.7 (2.8)	0/12	8.4 (6.0)	12/12	12/12	12/12	12/12
Durham Ferry	5/21/11, 1207	107 (4.2)	0/12	3.3 (2.3)	12/12	12/12	12/12	12/12
Durham Ferry	5/23/11, 1210	105.8 (3.4)	0/12	1 (0)	12/12	12/12	12/12	12/12
Durham Ferry	5/24/11, 0915	107.3 (3.7)	0/12	1.1 (0.3)	12/12	12/12	12/12	12/12
Durham Ferry	5/26/11, 0912		0/36[a]					

[a]Fish given to CA/NV Fish Health Center for further evaluation, 12 of the 36 had been held since 5/23.

Table 5-12
Results of Dummy Tagged Juvenile Chinook Salmon Evaluated After Being Held for 48 Hours at the Release Sites as Part of the South Delta Temporary Barriers Project (TBP) Study in 2011

Holding Site	Examination Date, Time	Mean (sd) Forklength (mm)	Mortality	Mean (sd) scale loss %	Normal Body Color	No Fin Hemorrhaging	Normal Eye Quality	Normal Gill Color
Durham Ferry	6/8/11, 1208	112 (3.2)	0/12	5.4 (3.3)	12/12	12/12	12/12	12/12
Durham Ferry	6/9/11, 0900	114 (2.9)	0/12	5.8 (6.0)	12/12	12/12	12/12	12/12
Durham Ferry	6/10/11, 1210	115.9 (4.8)	0/12	4.2 (3.6)	12/12	12/12	12/12	12/12
Durham Ferry	6/11/11, 0910	114.2 (3.7)	0/12	10.0 (4.2)	12/12	12/12	12/12	12/12
Durham Ferry	6/16/11, 0905		0/24[a]					
Durham Ferry	6/17/11, 0906[b]	114.5 (5.7)	0/12	6.3 (2.3)	12/12	12/12	12/12	12/12
Durham Ferry	6/18/11, 0906	113.3 (4.4)	0/12	5.8 (1.9)	12/12	12/12	12/12	12/12
Durham Ferry	6/19/11, 1201	115.3 (9.9)	0/12	13.7 (3.7)	12/12	12/12	12/12	12/12

aFish given to CA/NV Fish Health Center for further evaluation
[b] Assessed 3 hours early

Table 5-13
Periods of Non-operation of Acoustic Receivers During the 2011 VAMP Study and the South Delta Temporary Barriers Project (TBP) Study. Refer to Figure 5-2 for Receiver Locations

Study Code	System Code	Site ID	Type	Location	Non-Operational Period				Footnotes
					Start		End		
					Date	Time	Date	Time	
VAMP	909	SJLU	Node	San Joaquin River at Lathrop - Upstream (Shared)	5/11/11	0300	5/11/11	1200	2
VAMP	910	SJLD	Node	San Joaquin River at Lathrop - Downstream (Shared)	5/11/11	0300	5/11/11	1200	2
VAMP	920	TMS	Node	Threemile Slough	6/21/11	1700	6/21/11	2200	3
SD TBP	810	RGU1	Node	Radial Gates - Upstream # 1 (Shared)	7/3/11	0400	7/5/11	1000	1
SD TBP	811	RGU2	Node	Radial Gates - Upstream # 2 (Shared)	6/21/11	0700	6/21/11	0800	1
					7/3/11	0400	7/3/11	1300	
					7/4/11	0000	7/4/11	1400	
					7/5/11	0000	7/5/11	1000	
SD TBP	812	RGD1	Node	Radial Gates - Downstream # 1 (Shared)	6/1/11	1000	6/1/11	1700	4
SD TBP	813	RGD2	Node	Radial Gates - Downstream # 2 (Shared)	6/14/11	1900	6/14/11	2300	1
					6/15/11	0000	6/15/11	2000	
					6/17/11	0900	6/17/11	1100	
VAMP	603	JPTe	4prt	Jersey Point - East	7/13/11		7/14/11		1
VAMP	604	JPTw	4prt	Jersey Point - West	5/23/11		5/24/11		5
VAMP	500	CHPe	4prt	Chipps Island - East	7/11/11	1400	7/13/11	1300	1
					7/19/11	1400	7/25/11	1100	
					7/26/11	1200	7/26/11	1300	6
					7/27/11	1200	7/27/11	1300	
					7/29/11	1200	7/29/11	1300	
					7/30/11	1200	7/30/11	1300	
VAMP	504	CHPw	4prt	Chipps Island - West	7/7/11				7
VAMP	515	CHPn	Node	Chipps Island North	5/24/11	0900	5/24/11	1000	1
					6/3/11	1000	6/3/11	1100	
					6/13/11	1300	6/13/11	1400	
					7/24/11	1300	7/24/11	1400	
					8/3/11	1900	8/3/11	2000	
VAMP	516	CHPw	Node	Chipps Island West	5/21/11	0600	5/21/11	0700	1
					5/31/11	1200	5/31/11	1300	
					6/7/11	1800	6/7/11	1900	
					6/20/11	2300	6/20/11	0000	
					7/4/11	1000	7/4/11	1300	
					7/4/11	1600	7/4/11	1800	
					7/4/11	1900	7/4/11	2200	
					7/5/11	1000	7/5/11	0000	
					7/5/11	1800	7/5/11	2000	
					7/6/11	0100	7/14/11	1400	
					7/23/11	1700	7/23/11	1800	
					8/2/11	2300	8/2/11	0000	
					8/13/11	0400	8/13/11	0500	
					8/17/11	0600, 1100, 1500, 1900	8/17/11	0700, 1200, 1600, 2000	
					8/22/11	0200, 0400, 1000	8/22/11	0300, 1300, 1800	
					8/23/11	0200, 0400, 1000	8/23/11	0300, 0500, 1100	
					8/24/11	2100, 2300	8/24/11	2200, 2400	
					8/25/11	0300, 0600, 1500	8/25/11	0400, 0700, 1600	
VAMP	517	CHPe	Node	Chipps Island East	5/18/11	0300	5/18/11	0400	1
					5/20/11	0700	5/23/11	0500	
					6/4/11	0000	6/4/11	0100	
					6/14/11	0600	6/14/11	0700	
					6/17/11	0600	6/17/11	0700	

1 Unknown
2 Defective Solar Module
3 Overheating issue
4 Data Logger memory full
5 Probably battery and power failure
6 One hour off between 1200 and 1300 for two consecutive days, on for the next full day, off again for one hour (1200 to 1300) for the next two days: pattern continued until end of the season.
7 Cable was cut on 7/7/2011

temperatures measured within the lower San Joaquin River and Delta were within a range considered to be suitable (typically < 20° C; 68° F) during April and May in the mainstem San Joaquin River (e.g., Durham Ferry, Mossdale, and Old River at HOR (Figures 4, 5 and 6 in Appendix G)). Temperatures were slightly higher but still under 20° C (68° F) further downstream within the Delta (e.g., Old River/Indian Slough Confluence, CCF Radial Gates (Figures 14 and 15 in Appendix G)). Results of the 2011 water temperature monitoring showed a longitudinal gradient of temperatures that generally increased slightly as a function of distance downstream within the mainstem river and Delta. Water temperatures measured in the river and downstream within the Delta during April-May would not be expected to result in adverse effects or reduced survival of emigrating juvenile Chinook salmon released as part of the VAMP 2011 investigations. However, temperatures during the middle of June were within the range considered to be stressful for juvenile Chinook salmon.

Detections of Acoustic-Tagged Fish

Of the 1,895 tags released in juvenile Chinook salmon at Durham Ferry in 2011, 1,847 (97%) were detected on one or more receivers downstream of the release site (Table 5-14), including the predator-type detections. In general, the number of tags detected at each site in the San Joaquin River route declined with distance from Durham Ferry, with 1,447 tags detected at Mossdale, 902 tags detected at Lathrop, 779 detected at the Navy Drive Bridge in Stockton, and 150 tags detected at Medford Island (Table 5-15). A total of 100 tags were detected leaving the San Joaquin River at Turner Cut (Table 5-15). Fewer tags were detected in the Old River route than in the San Joaquin River route, with 657 tags detected at Old River East (near the head of Old River). Only seven tags were detected leaving Old River at Middle River (MRS), with no tags detected at that receiver from the final release group (Table 5-15). Many tags were observed moving among the receivers at the Central Valley Project trashracks (CVP), radial gates at the Clifton Court Forebay (RGU, RGD), and Old River North receivers (ORN). Among these sites, the route with the final tag detection was used in the survival model (Table 5-15). Approximately equal numbers of tags from Old River South (ORS) were observed finally moving to the Central Valley Project as to the radial gates at the Clifton Court Forebay, with fewer moving to the Old River North receivers (ORN). Most of the tags detected at the Old River North receivers came from the first two release groups, with no tags detected at ORN from the final release group (Table 5-15). Very few tags were detected moving from the head of Old River to the Middle River North receivers (MRN) near Highway 4 (Table 5-15). Tag detections dropped considerably from Medford Island, Turner Cut, and Old River North (ORN) to the receivers located at Jersey Point (JPT) and False River (FRE/FRW). Twelve tags from across all release groups were detected at Jersey Point, and only one tag was detected at False River (Table 5-15). Only 35 tags were finally detected at Chipps Island (Table 5-15), including detections of tags classified as being in predators.

Some tag detections were not used in the survival model because the tags were assigned to a different migration route based on previous or subsequent tag detections. For example, tag 6311.13 (tag period and subcode) was detected at Middle River North (MRN) with subsequent detections at the radial gates receivers (RGU) and the Chipps Island receivers. Because the tag was detected at RGU after the MRN detections, it was assigned to subroute D (Clifton Court Forebay) within the primary Old River route (route B), rather than the Middle River subroute (C), and so the MRN detection was not used in the survival model. (The Chipps Island detection was used in the model.) Other tags were detected at MRN after being detected at receivers in the San Joaquin River route. For example, tag 6353.13 was detected at the Navy Drive Bridge receiver in Stockton (STN) and at Turner Cut before being detected at MRN and then at the radial gates (RGU). This tag was assigned to route A (San Joaquin River route) at the head of Old River, so the detections at both MRN and RGU were not used in the survival model. This tag was not detected at Chipps Island, but any detections from similar tags at Chipps Island would have been used in the survival model. In total, 17 tags were detected at the Middle River North (MRN) receivers (including predator-type detections), with 9 tags arriving at MRN from the Old River route (6 tags via MRS, 1 via ORN, 1 via CVP, and 1 with unknown route from ORS) and 8 tags arriving at MRN from the San Joaquin River route. Twelve of the 17 tags detected at MRN were subsequently detected at other receivers in the primary Old River route: 8 at the Clifton Court Forebay Radial Gates, 1 at the Central Valley Project trashracks (CVP), and 2 at the Old River North receivers near Highway 4. All but three of the

Table 5-14
Number of Tags from each Release Group that were Detected Downstream of the Release Site in 2011, Including Predator-type Detections

Release Group	1	2	3	4	Total
Number Released	475	473	473	474	1,895
Total Number Detected	468	465	455	459	1,847

Table 5-15
Number of Tags Observed from each Release Group at each Detection Site in 2011 and Used in the Survival Analysis, Including Predator-type Detections. Pooled Counts are Summed over all Receivers in the Array

Detection Site	Site Code	Survival Model Code	Release Group				Total
			1	2	3	4	
Durham Ferry Upstream	DFU	A0	3[a]	5[a]	4[a]	7[a]	19
Durham Ferry Downstream	DFD	A2	466	448	412	443	1,769
Banta Carbona	BCA	A3	431	417	378	396	1,622
Paradise Cut (Outside)	PCO	A4	72	186	157	179	594
Mossdale	MOS	A5	423	377	302	345	1,447
Lathrop	SJL	A6	251	240	206	205	902
Stockton USGS Gauge	STS	A7	238	205	175	171	789
Stockton Navy Drive Bridge	STN	A8	233	208	175	163	779
Shipping Channel Markers	C18/C16	A9	111	108	66[a]	88	373
Medford Island East	MFE	A10a	57	32	14[a]	38	141
Medford Island West	MFW	A10b	62	34	14[a]	38	148
Medford Island (Pooled)	MFE/MFW	A10	62	34	14[a]	40	150
Turner Cut North	TCN	F1a	39	24	26[a]	8	97
Turner Cut South	TCS	F1b	38	23	26[a]	8	95
Turner Cut (Pooled)	TCN/TCS	F1	41	24	26[a]	9	100
Old River East	ORE	B1	183	180	131	163	657
Old River South Upstream	ORSU	B2a	162	161	113	151	587
Old River South Downstream	ORSD	B2b	173	173	123	157	626
Old River South (Pooled)	ORS	B2	181	178	129	160	648
Old River North Upstream	ORNU	B3a	46	40	2[a]	0	88
Old River North Downstream	ORND	B3b	41	39	2[a]	0	82
Old River North (Pooled)	ORN	B3	52	46	2[a]	0	100
Middle River South	MRS	C1	2	3	2	0	7
Middle River North Upstream	MRNU	C2a	0	2	0[a]	1	3
Middle River North Downstream	MRND	C2b	0	2	0[a]	1	3
Middle River North (Pooled)	MRN	C2	0	2	0[a]	1	3
Radial Gates Upstream	RGU	D1	44	39	35[a]	50	168
Radial Gates Downstream #1	RGD1	D2a	40	34	44[a]	45	163
Radial Gates Downstream #2	RGD2	D2b	38	30	44[a]	46	158
Radial Gates Downstream (Pooled)	RGD	D2	41	35	44[a]	46	166
Central Valley Project Trashrack	CVP	E1	35	29	41[a]	55	160
Central Valley Project Holding Tank	CVPtank	E2	0	8	10[a]	19	37
Jersey Point East	JPTE	G1a	4	1[a]	5[a]	2	12
Jersey Point West	JPTW	G1b	3	1[a]	5[a]	2	11
Jersey Point (Pooled)	JPT	G1	4	1	5[a]	2	12
False River East	FRE	H1a	1	0[a]	0[a]	0	1
False River West	FRW	H1b	1	0[a]	0[a]	0	1
False River (Pooled)	FRE/FRW	H1	1	0	0[a]	0	1
Chipps Island East	CHPE	G2a	2	5	12	14	33
Chipps Island West	CHPW	G2b	2	6	8	11	27
Chipps Island (Pooled)	CHP	G2	3	6	12	14	35

[a] = not used in survival model.

tags detected at Middle River North were assigned to a different migration route. Only 1 of the 17 tags ever detected at MRN was subsequently detected at Chipps Island (tag 6311.13, see above), and it was assigned to the Clifton Court subroute of the primary Old River route rather to the Middle River subroute (described above). None of these 17 tags were detected at either False River or Jersey Point.

Some detection locations were used in the predator filter, but were purposely omitted from the survival model. The receiver located in the Delta Mendota Canal (DMC) recorded detections of 21 tags, 7 of which were subsequently detected on the CVP receivers. Seven tags were detected on the Threemile Slough receivers: 3 tags came directly from the San Joaquin River receivers (Medford Island, Channel Markers), 3 from Jersey Point, and 1 from CVP holding tank. One of the Threemile Slough tags from Medford Island was later detected at Chipps Island, but it was then subsequently detected at Threemile Slough a second time, by which time it was assumed to have been in a predator. A total of 24 tags were detected on the Chipps Island North receiver (CHPn; Table 5-6). Because of this receiver's proximity to the entrance to Spoonbill Creek, these detections were omitted from the survival model. All but one of the 24 tags detected at CHPn were also detected on the Chipps Island array receivers used in the survival model.

The predator filter used to distinguish between detections of Chinook salmon smolts and detections of predatory fish that had eaten the tagged smolts classified 593 of the 1,895 tags (31%) released as being detected in a predator at some point during the study (Table 5-16). Of the 1,666 tags detected in the study area (i.e., at Mossdale or points downstream), 562 tags (34%) were classified as being in a predator at some point in the study area. The detection sites with the largest number

Table 5-16
Number of Tags from each Release Group First Classified as in a Predator at each Detection Site in 2011 as a Result of the Predator Filter

Detection Site and Code			Durham Ferry Release Groups									
			Classified as Predator on Arrival at Site					Classified as Predator on Departure from Site				
Detection Site	Site Code	Survival Model Code	1	2	3	4	Total	1	2	3	4	Total
Durham Ferry Upstream	DFU	A0	2	0	0	0	2	0	0	1	0	1
Durham Ferry Downstream	DFD	A2	1	4	5	3	13	0	0	1	0	1
Banta Carbona	BCA	A3	4	1	1	3	9	1	0	0	0	1
Paradise Cut (Outside)	PCO	A4	1	0	0	1	2	1	1	0	0	2
Mossdale	MOS	A5	9	5	6	1	21	0	0	0	0	0
Lathrop	SJL	A6	0	4	2	0	6	2	1	2	3	8
Stockton USGS Gauge	STS	A7	2	1	2	3	8	6	3	2	4	15
Stockton Navy Drive Bridge	STN	A8	2	1	1	3	7	20	12	29	48	109
Shipping Channel Markers	C18/C16	A9	6	5	7	9	27	5	16	14	9	44
Medford Island	MFE/MFW	A10	3	1	1	1	6	3	4	0	2	9
Old River East	ORE	B1	0	1	1	1	3	0	0	1	1	2
Old River South	ORS	B2	0	1	0	2	3	1	3	1	1	6
Old River North	ORN	B3	15	8	1	0	24	10	13	0	0	23
Middle River South	MRS	C1	0	0	0	0	0	1	0	0	0	1
Middle River North	MRN	C2	0	0	2	1	3	0	0	0	0	0
Radial Gates Upstream	RGU	D1	6	1	0	0	7	4	0	1	1	6
Radial Gates Downstream	RGD	D2	1	0	0	0	1	21	25	30	30	106
Central Valley Project Trashrack	CVP	E1	10	11	11	5	37	15	12	17	23	67
Central Valley Project Holding Tank	CVPtank	E2	0	0	0	0	0	0	0	0	0	0
Turner Cut	TCN/TCS	F1	3	1	0	1	5	5	0	0	0	5
Jersey Point	JPT	G1	0	0	0	0	0	0	0	0	0	0
Chipps Island	CHP	G2	0	1	0	0	1	0	0	0	0	0
Chipps Island North, near Spoonbill Creek	CHPn		0	1	0	0	1	0	0	0	0	0
False River	FRE/FRW	H1	0	0	0	0	0	0	0	0	0	0
Threemile Slough	TMS/TMN	T1	0	0	0	1	1	0	0	0	0	0
Total Tags			65	47	40	35	187	95	90	99	122	406

of first-time predator-type detections were the receiver near the Navy Drive Bridge in Stockton (STN, code A8) and the receivers at the radial gates inside the Clifton Court Forebay (RGD). A total of 7 tags were classified as being in predators upon arrival at the Navy Drive Bridge receivers, with 109 tags classified as being predators upon departure from that receiver. Long nearby or regional residence time and moving against the flow were the primary indicators of predation at STN, with long residence time comprising the majority of predation indicators. Only one tag was classified as in a predator on arrival at RGD, but 106 tags were classified as in a predator on departure from RGD, all indicated by long residence time. The other site that stands out with many first-time predator detections was the Central Valley Project trashracks (CVP), with 104 tags first classified as in predators there. A total of 37 tags were classified as predators upon arrival at CVP, generally due to unusual migration rates to those receivers or moving against the flow; 67 tags were classified as predators upon departure from CVP, nearly all because of long residence times (Table 5-16).

When the detections classified as coming from predators were removed from the detection data, fewer detections were available for the survival analysis (Tables 5-17 and 5-18). Nevertheless, the number of tags from the predator-filtered data with detections downstream of the release site was nearly the same as from the unfiltered data, with 1,842 of the 1,895 tags (97%) detected (Table 5-17). Without the predator-type detections, the number of tags detected at Mossdale changed from 1,447 to 1,344 (Tables 5-15 and 5-18). The number of tag detections at Lathrop used in the survival analysis actually increased from 902 to 919 when the predator-type detections were omitted, because some tags were classified as predators after first reaching Lathrop and then appeared back upstream with predator-type detections. Most (94%) of the predator-type detections at the Navy Drive Bridge in Stockton (STN) were classified as predators only on departure, so there was little change in the number of detections at that site without those detections. Also, because most tags first classified as in predators at STN were not detected again elsewhere, the tag count at Medford Island decreased only slightly from 150 tags with predator-type detections to 141 tags without those detections. There was essentially no change in the number of detections at Old River East (ORE, near the head of Old River), Middle River South (MRS), and Middle River North (MRN) without the predator-type detections (Tables 5-15 and 5-18). Tag detections at the radial gates at the Clifton Court Forebay (RGU, RGD) and at the Central Valley Project trashrack (CVP) declined slightly after predator-type detections were removed. There was little difference in the tag count at Jersey Point and False River after the predator filter, and the number of tags detected at Chipps Island declined only by 2 to a total of 33 smolt detections. In general, a smaller proportion of tags were classified as in predators in 2011 than in 2010 (31% in 2011 vs 61% in 2010).

Tagger Effects

Fish in the release groups were evenly distributed across tagger (Table 5-19). A chi-squared test found good distribution of taggers across all release groups (P=1.0). The distribution of tags detected at various key detection sites was also well-distributed across taggers, with no evidence of a tagger effect on survival, route entrainment, and detection probabilities at these sites (P=0.8894; Table 5-20).

Tag-Survival Model and Tag-Life Adjustment

The AIC indicated that pooling data from both tag-life studies and also across all tag periods was preferable to stratifying either by study month (May or July) or by tag period. Thus, a single tag survival model was fit and used to adjust fish survival estimates for premature tag failure. The estimated mean time to tag failure was 28.8 days ($\widehat{SE}$ = 6.7) (Figure 5-6). The complete set of detection data, including detections classified as coming from predators, included many detections that occurred well after the tags began dying in the tag-life study (Figures 5-7 and 5-8). In the San Joaquin River route, the Stockton North receiver near the Navy Drive Bridge (STN) and the receivers on the Channel Markers in the San Joaquin River near the Turner Cut junction (C18/C16) both had detections occurring toward the end of the observed tag life (Figure 5-7). In the Old River route, long detection histories were observed at the CVP trashracks receivers and at the Old River North receivers near Highway 4 (Figure 5-8). The very long detection histories and late detections observed at these sites were interpreted as coming from predatory fish that had eaten the study fish. When the detections classified as coming from predators were removed, the remaining detections occurred well before most of the tag failure observed in the tag-life study (Figures 5-9 and 5-10). Tag-life corrections were made to survival estimates for both sets of detections (with and without predator-type detections).

Survival and Route Entrainment Probabilities

The model selection process identified the most parsimonious model that adequately fit the data, based on AIC. For the reduced data set that excluded predator-type detections, estimating unique transition parameters to and from the radial gates at the Clifton Court Forebay (RGU, RGD) based on gate status (open and closed) did not significantly improve model fit (AIC was smaller without gate effect; ΔAIC = 21.770). A similar pattern

Table 5-17
Number of Tags from each Release Group that were Detected Downstream of the release Site During 2011, Excluding Predator-type Detections

Release Group	1	2	3	4	Total
Number Released	475	473	473	474	1,895
Total Number Detected	466	467	456	453	1,842

Table 5-18
Number of Tags Observed from each Release Group at each Detection Site in 2011 and Used in the Survival Analysis, Excluding Predator-type Detections. Pooled Counts are Summed Over all Receivers in the Array

Detection Site	Site Code	Survival Model Code	Release Group				Total
			1	2	3	4	
Durham Ferry Upstream	DFU	A0	4[a]	2[a]	3[a]	5[a]	14
Durham Ferry Downstream	DFD	A2	464	450	413	445	1,772
Banta Carbona	BCA	A3	428	419	379	397	1,623
Paradise Cut (Outside)	PCO	A4	70	186	158	180	594
Mossdale	MOS	A5	417	379	202	346	1,344
Lathrop	SJL	A6	257	247	211	204	919
Stockton USGS Gauge	STS	A7	235	205	174	170	784
Stockton Navy Drive Bridge	STN	A8	231	209	177	161	778
Shipping Channel Markers	C18/C16	A9	107	106	66[a]	82	361
Medford Island East	MFE	A10a	58	32	11[a]	33	134
Medford Island West	MFW	A10b	61	33	11[a]	33	138
Medford Island (Pooled)	MFE/MFW	A10	62	33	11[a]	35	141
Turner Cut North	TCN	F1a	40	25	26[a]	7	98
Turner Cut South	TCS	F1b	38	24	26[a]	7	95
Turner Cut (Pooled)	TCN/TCS	F1	40	25	26[a]	8	99
Old River East	ORE	B1	181	179	130	166	656
Old River South Upstream	ORSU	B2a	160	162	113	153	588
Old River South Downstream	ORSD	B2b	171	174	123	159	627
Old River South (Pooled)	ORS	B2	179	178	129	162	648
Old River North Upstream	ORNU	B3a	58	49	1[a]	0	108
Old River North Downstream	ORND	B3b	46	42	1[a]	0	89
Old River North (Pooled)	ORN	B3	58	49	1[a]	0	108
Middle River South	MRS	C1	2[a]	3	2	0	7
Middle River North Upstream	MRNU	C2a	0	2	0[a]	1	3
Middle River North Downstream	MRND	C2b	0	2	0[a]	1	3
Middle River North (Pooled)	MRN	C2	0	2	0[a]	1	3
Radial Gates Upstream	RGU	D1	36	40	38[a]	51	165
Radial Gates Downstream #1	RGD1	D2a	28	30	44[a]	45	147
Radial Gates Downstream #2	RGD2	D2b	28	27	44[a]	46	145
Radial Gates Downstream (Pooled)	RGD	D2	29	31	44[a]	46	150
Central Valley Project Trashrack	CVP	E1	31	24	39[a]	54	148
Central Valley Project Holding Tank	CVPtank	E2	0	8	9[a]	17	34
Jersey Point East	JPTE	G1a	4	1[a]	4[a]	2	11
Jersey Point West	JPTW	G1b	3	1[a]	4[a]	2	10
Jersey Point (Pooled)	JPT	G1	4	1	4[a]	2	11
False River East	FRE	H1a	1	0[a]	0[a]	0	1
False River West	FRW	H1b	1	0[a]	0[a]	0	1
False River (Pooled)	FRE/FRW	H1	1	0	0[a]	0	1
Chipps Island East	CHPE	G2a	2	5	12	13	32
Chipps Island West	CHPW	G2b	2	5	8	11	26
Chipps Island (Pooled)	CHP	G2	3	5	12	13	33

[a] = not used in survival model.

Table 5-19
Number of Juvenile Chinook Salmon Tagged by Tagger in each Release Group During the 2011 Tagging Study

Tagger	Release Group 1	2	3	4	Total Tags
A	119	117	117	117	470
B	118	119	117	119	473
C	118	120	119	119	476
D	120	117	120	119	476
Total Tags	475	473	473	474	1,895

Table 5-20
Release Size and Counts of Tag Detections at Key Detection Sites by Tagger, Excluding Predator-type Detections

Detection Site	Tagger A	B	C	D
Release at Durham Ferry	470	473	476	476
Mossdale (MOS)	339	367	363	375
Lathrop (SJL)	223	228	232	236
Shipping Channel Markers (C18/C16)	84	89	83	105
Turner Cut (TCN/TCS)	29	25	23	22
Medford Island (MFE/MFW)	26	36	34	45
Old River East (ORE)	155	166	172	163
Old River South (ORS)	154	165	171	158
Old River North (ORN)	25	29	33	21
Clifton Court Forebay Interior (RGD)	40	36	44	30
Central Valley Project Holding Tank (CVPtank)	6	12	10	6
Chipps Island (CHP)	5	10	12	6

Figure 5-6
Observed Tag Failure Times from the 2011 Tag-Life Study, Color-Coded by Tag Period, and Fitted Four-Parameter Vitality Curve. Failure Times of Three Tags Were Missing

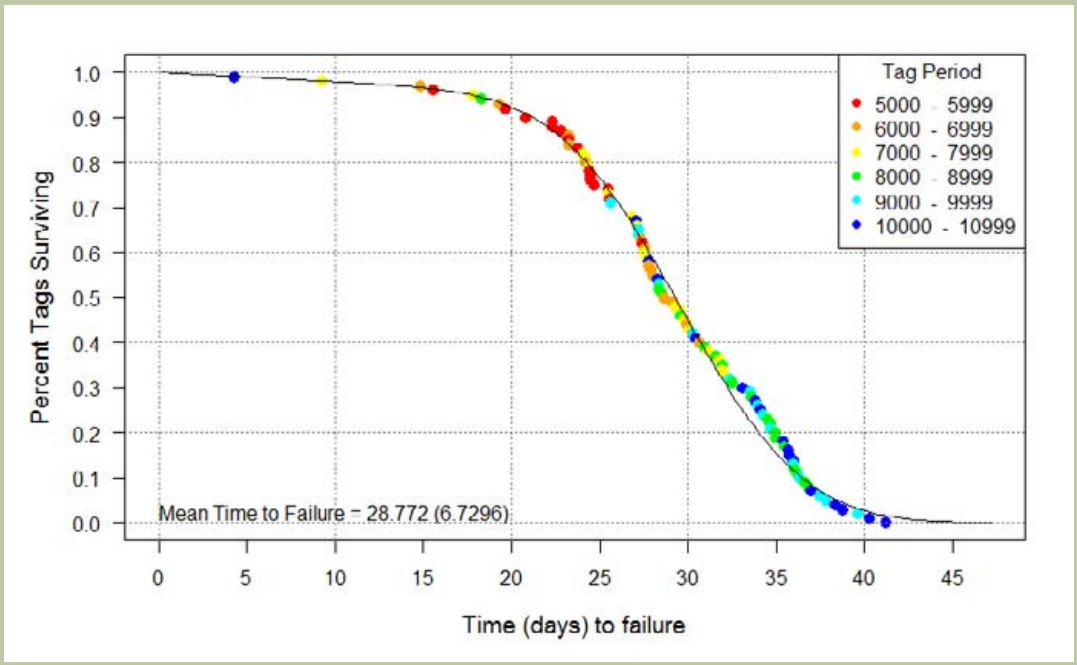


Figure 5-7
Four-Parameter Vitality Survivorship Curve for Tag Life, and the Cumulative Arrival Timing of Acoustic-Tagged Chinook Salmon Smolt at Receivers in the San Joaquin River Route to Chipps Island, Including Detections Classified as Predator Detections

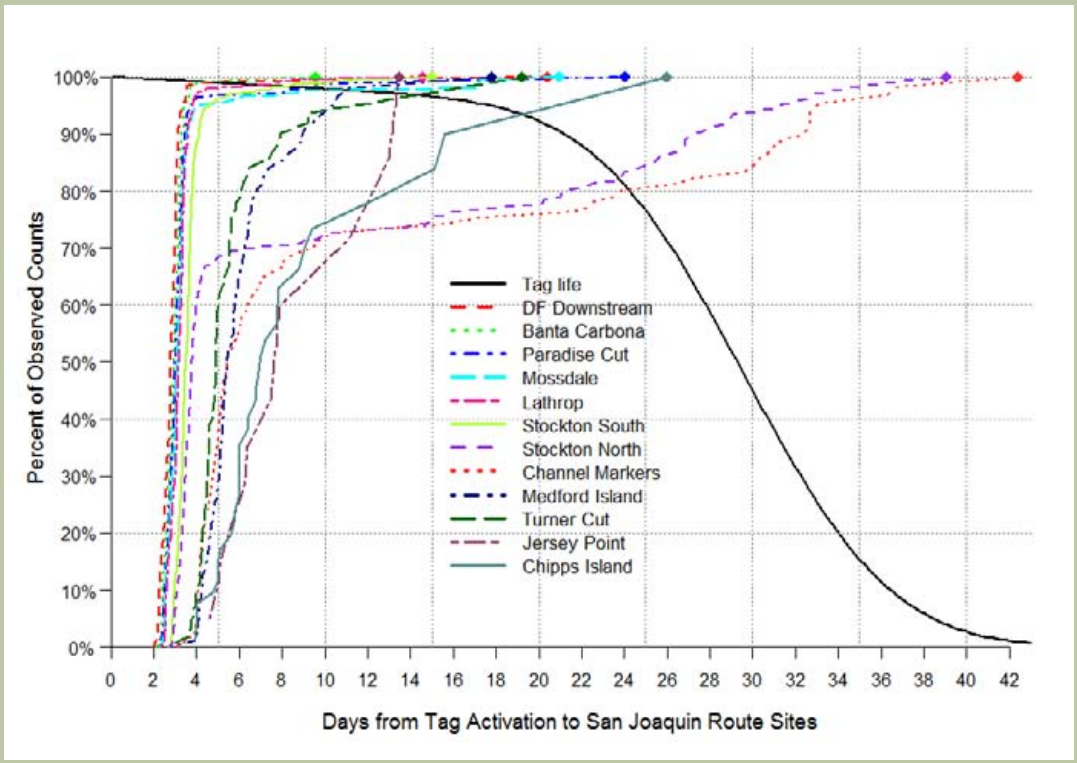


Figure 5-8
Four-Parameter Vitality Survivorship Curve for Tag Life, and the Cumulative Arrival Timing of Acoustic-Tagged Chinook Salmon Smolt at Receivers in the Old River Route to Chipps Island, Including Detections Classified as Predator Detections

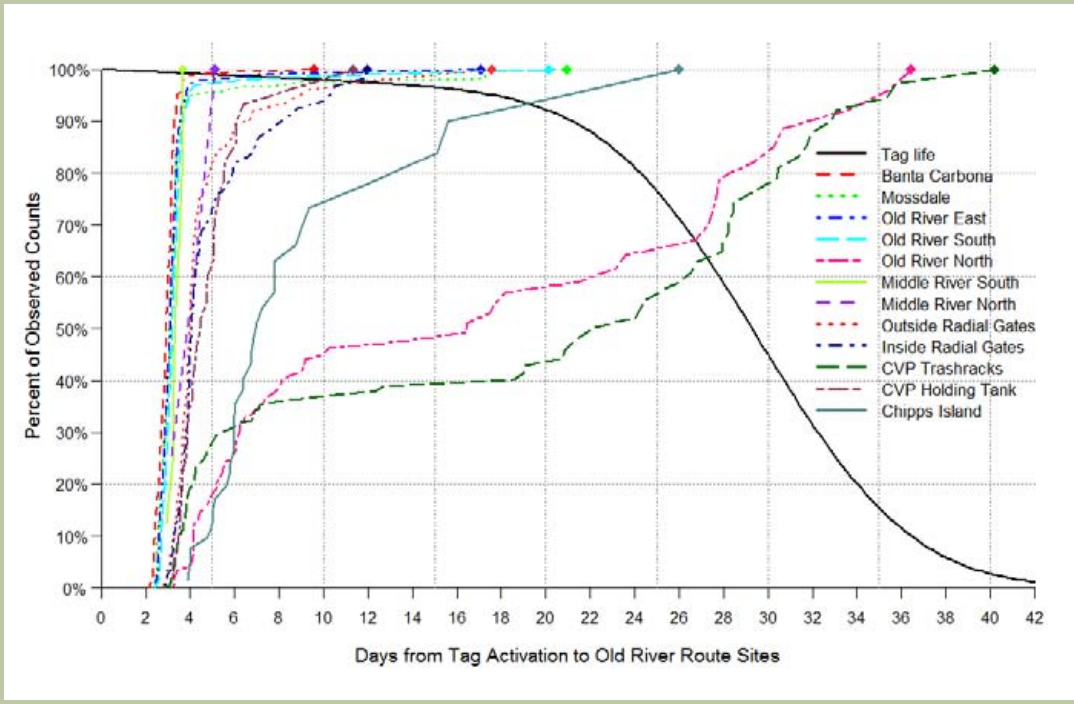


Figure 5-9
Four-Parameter Vitality Survivorship Curve for Tag Life, and the Cumulative Arrival Timing of Acoustic-Tagged Chinook Salmon Smolt at Receivers in the San Joaquin River Route to Chipps Island, Excluding Detections Classified as Predator Detections

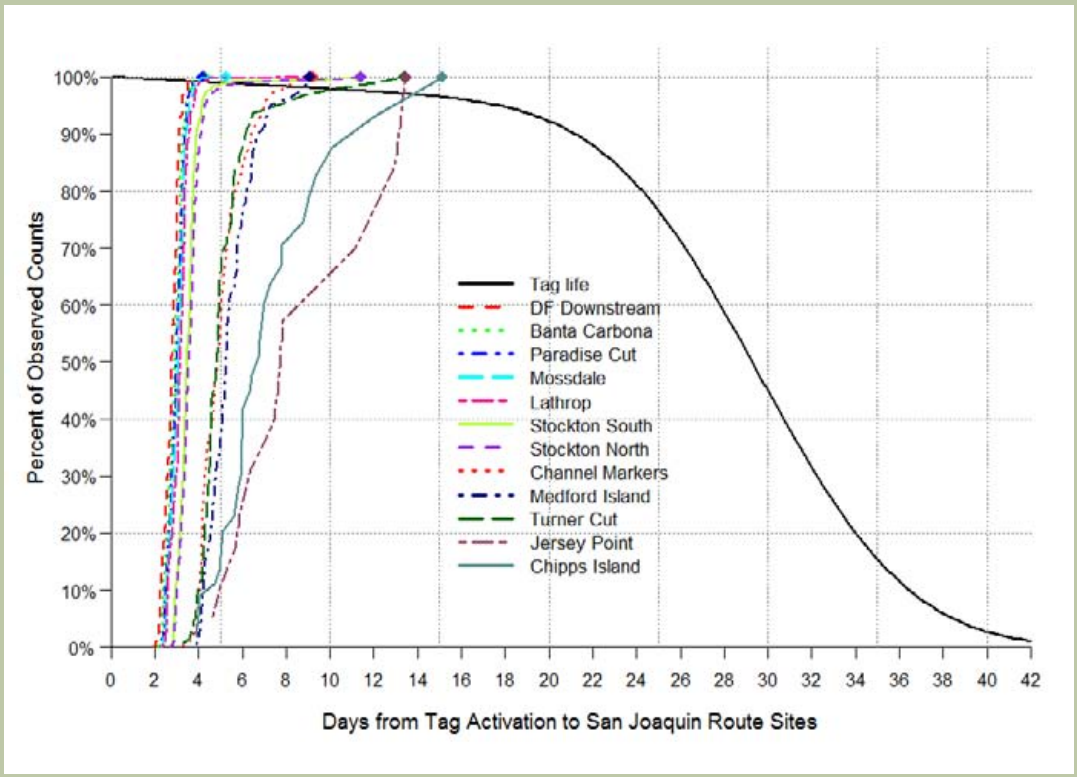
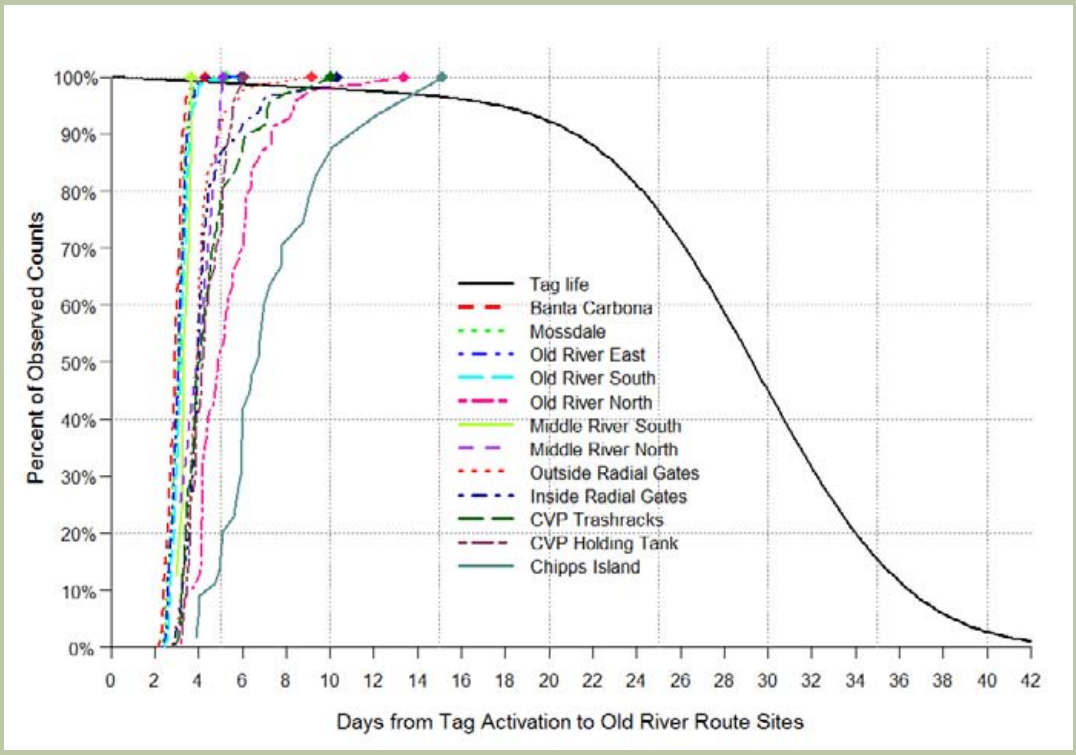


Figure 5-10
Four-Parameter Vitality Survivorship Curve for Tag Life, and the Cumulative Arrival Timing of Acoustic-Tagged Chinook Salmon Smolt at Receivers in the Old River Route to Chipps Island, Excluding Detections Classified as Predator Detections



was seen from the full data set that included predator-type detections, with the simpler non-gate model indicated (AIC was smaller without gate effect; ΔAIC = 21.587). Thus, all parameter estimation for both the reduced and the full data sets came from models using common transition parameters with respect to gate status.

Some parameters were unable to be estimated for certain release groups because of sparse data. Using the predator-filtered data from the first release group, the combination of sparse detections at the Middle River South (MRS) receiver and a lack of subsequent detections of the few tags detected at MRS prevented estimation of parameters involving that site (transition probabilities, route entrainment probability, and detection probability). This in turn meant that only the transition probability $\phi_{B1,B2} = S_{B1}\psi_{B3}$ from the Old River East receiver to the Old River South receiver could be estimated for the first release group, rather than its survival and route entrainment probability components (S_{B1} and ψ_{B3}, respectively). It was also impossible to estimate transition probabilities from MRS to downstream sites (i.e., parameters $\phi_{C1,hi}$) for this release group. Also for the first release group, it was not possible to estimate the detection probability at the CVP trashracks receivers because no tags were subsequently detected in the CVP holding tank (Table 5-18). For all other release groups, the detection probability at the CVP trashracks receivers was estimated at $\widehat{P}_{E1} = 1$, so this assumed value was used for the first release group, as well.

For the second release group, sparse detections at Jersey Point and False River prevented estimation of transition probabilities to and from those sites, and the route entrainment probability at that river junction. Instead, transition probabilities were estimated directly to Chipps Island from the Medford Island, Old River North, and Middle River North receivers (parameters $\phi_{A10,G2}$, $\phi_{B3,G2}$, and $\phi_{C3,G2}$, respectively).

Several phenomena complicated estimation and limited the spatial precision of the parameter estimation for the third release group. Sparse detection data at the Jersey Point, False River, Old River North, and Middle River North sites required removing many receivers from the survival model. Instead of reach-specific survival through the interior Delta and lower reaches of the San Joaquin River, the transition parameters to Chipps Island from the Stockton Navy Drive Bridge, Old River South, and Middle River South were estimated directly (parameters $\phi_{A8,G2}$, $\phi_{B2,G2}$, and $\phi_{C1,G2}$, respectively). See Methods: Survival Model for more information.

The limitations of the data for the individual releases were not observed when data were pooled across release groups to estimate population parameters. Total survival through the Delta was estimable for each release group, as well as route-specific survival in the primary routes at the head of Old River.

Using only those detections classified as coming from juvenile Chinook salmon and excluding the predator-type detections, the estimates of the total survival from Mossdale to the receivers at Chipps Island, S_{Total}, ranged from 0.01 ($\widehat{SE}$ = 0.01) for releases 1 and 2 (i.e., during the VAMP), to 0.03 ($\widehat{SE}$ = 0.01) for releases 3 and 4 (i.e., after the VAMP), with a population estimate of 0.02 ($\hat{S}$ <0.01) (Table 5-21). Estimates of the probability of remaining in the San Joaquin River at the junction with Old River (ψ_{A2}) ranged from 0.55 ($\widehat{SE}$ =0.03) for release group 4 to 0.63 ($\widehat{SE}$ =0.03) for release group 3, with a population estimate of 0.58 ($\widehat{SE}$ =0.01). For all releases, there was a significant preference for the San Joaquin River route over the Old River route at the head of Old River (P<0.05) (Table 5-21). Estimates of survival from Mossdale to Chipps Island through the San Joaquin River route (S_A) ranged from 0.004 ($\widehat{SE}$ =0.004) for release 2 to 0.01 ($\widehat{SE}$ =0.01) for releases 1 and 3, with a population estimate of 0.01 ($\widehat{SE}$ <0.01). In the Old River route, estimates of survival from Mossdale to Chipps Island ranged from 0 for release 1 to 0.07 ($\widehat{SE}$ =0.02) for releases 3 and 4, with a population estimate of 0.04 ($\widehat{SE}$ =0.01). The small number of tags detected at Chipps Island limited the precision with which survival could be estimated, especially in the San Joaquin River route. Despite that limitation, survival to Chipps Island was significantly higher (P<0.05) in the Old River route than in the San Joaquin River route for releases 3 and 4 (i.e., post-VAMP release groups), although not for releases 1 and 2 (Table 5-21). For the population overall, estimated survival to Chipps Island was significantly higher in the Old River route than in the San Joaquin River route (P<0.0001). The majority of the tags detected at Chipps Island (21 of 33, 64%) came through the CVP holding tank in the Old River route.

Survival was estimated to the Jersey Point/False River junction for fish that did not migrate through the holding tanks at the CVP or the SWP. This survival measure ($S_{Total(MD)}$) was successfully estimated for release groups 1 and 4, with estimates of 0.01 ($\widehat{SE}$ <0.01) in each case (Table 5-21). Sparse data at Jersey Point and False River prevented estimation of survival to those sites in releases 2 and 3. In all releases, very few tags were observed leaving the San Joaquin River for False River (Table 5-18, and Table 3 in Appendix H). Survival to Jersey Point and False River was not significantly different for the two primary routes at the head of Old River (i.e., San Joaquin and Old River routes) (P>0.05).

Table 5-21
Performance Metric Estimates (Standard Error in Parentheses) for Tagged Juvenile Chinook Salmon Released in the 2011 Tagging Study, Excluding Predator-Type Detections. South Delta ("SD") Survival Extended to the Shipping Channel Markers and Turner Cut in Route A, and the Central Valley Project Trash Rack, Exterior Radial Gate Receiver at Clifton Court Forebay, and Old River North and Middle River North Receivers in Route B. (Population-level estimates were estimated from the pooled release groups.)

Parameter	Release Occasion				Population Estimate
	1	2	3	4	
ψ_{AA}	0.43 (0.03)	0.46 (0.03)		0.50 (0.03)	0.46 (0.01)
ψ_{AF}	0.16 (0.02)	0.11 (0.02)		0.05 (0.02)	0.13 (0.01)
ψ_{BB}		0.42 (0.02)	0.36 (0.03)	0.45 (0.03)	0.41 (0.01)
ψ_{BC}		0.01 (0.00)	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)
S_{AA}	0.02 (0.01)	0.01 (0.00)		0.01 (0.01)	0.01 (0.00)
S_{AF}	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)
S_{BB}		0.02 (0.01)	0.06 (0.02)	0.07 (0.02)	0.04 (0.01)
S_{BC}		0.00 (0.00)	0.48 (0.34)	0.00 (0.00)	0.01 (0.00)
ψ_{A}	0.59[a] (0.02)	0.57[a] (0.02)	0.63[a] (0.03)	0.55[a] (0.03)	0.58[a] (0.01)
ψ_{B}	0.41[a] (0.02)	0.43[a] (0.02)	0.37[a] (0.03)	0.45[a] (0.03)	0.42[a] (0.01)
S_{A}	0.01 (0.01)	0.004 (0.004)	0.01[b] (0.01)	0.005[b] (0.005)	0.01[b] (0.00)
S_{B}	0.00 (0.00)	0.02 (0.01)	0.07[b] (0.02)	0.07[b] (0.02)	0.04[b] (0.01)
S_{Total}	0.01 (0.01)	0.01 (0.01)	0.03 (0.01)	0.03 (0.01)	0.02 (0.00)
$S_{A(MD)}$	0.02 (0.01)			0.01 (0.01)	0.01 (0.00)
$S_{B(MD)}$	0.01 (0.01)			0.00 (0.00)	0.003 (0.002)
$S_{Total(MD)}$	0.01 (0.00)			0.01 (0.00)	0.01 (0.00)
$S_{A(SD)}$	0.55[b] (0.03)	0.52 (0.03)		0.42[b] (0.03)	0.48[b] (0.02)
$S_{B(SD)}$	0.68[b] (0.03)	0.61 (0.04)		0.71[b] (0.04)	0.66[b] (0.02)
$S_{Total(SD)}$	0.61 (0.02)	0.56 (0.02)		0.55 (0.03)	0.56 (0.01)

[a] = significant preference for route A (San Joaquin Route) at head of Old River (α=0.05).
[b] = significant difference between route A and route B estimate (α=0.05).

Survival was estimated through the South Delta ($S_{A(SD)}$, $S_{B(SD)}$, and $S_{Total(SD)}$) for all but the third release group. The "South Delta" corresponded to the region studied in the 2009 VAMP study (SJRGA, 2010). Estimates of survival in the San Joaquin River from Mossdale to the Shipping Channel Markers (C18/C16) or Turner Cut (TCN/TCS) ($S_{A(SD)}$) ranged from 0.42 ($\widehat{SE}$ =0.03) for release group 4 to 0.55 ($\widehat{SE}$ =0.03) for release group 1, with a population estimate of 0.48 ($\widehat{SE}$ =0.02) (Table 5-21). In the Old River route, estimated survival from Mossdale to the entrances of the water export facilities (CVP, RGU) or the northern Old River and Middle River receivers near Highway 4 (ORN, MRN) ($S_{B(SD)}$) ranged from 0.61 ($\widehat{SE}$ =0.04) for release group 2 to 0.71 ($\widehat{SE}$ =0.04) for release group 4, with an average population survival estimate of 0.66 ($\widehat{SE}$ =0.22). Total estimated survival through the entire South Delta region ($S_{Total(SD)}$) ranged from 0.55 ($\widehat{SE}$ =0.03) for release 4 to 0.61 ($\widehat{SE}$ =0.02) for release group 1, with a population estimate of 0.56 ($\widehat{SE}$ =0.01) (Table 5-21).

Including predator-type detections in the analysis produced little change in the estimates of overall survival through the Delta, with the population estimate of survival from Mossdale to Chipps Island $\hat{S}_{Total}$ = 0.02 ($\widehat{SE}$ <0.01) (Table 5-22). Route-specific survival remained higher in the Old River route than in the San Joaquin River route for releases 3 and 4, and for the population overall (P<0.0001). While individual releases exhibited minor differences in route entrainment probabilities when predators were included, there was no effect of predators on the overall population estimate (Table 5-22). There was no difference in estimated survival from Mossdale to the Jersey Point/False River junction for in-river fish (i.e., excluding those passing through the water export facilities) when predator detections were included (Tables 5-21 and 5-22). South Delta survival in the San Joaquin River route increased slightly when predator detections were included, with a population estimate of $\hat{S}_{A(SD)}$ = 0.50 ($\widehat{SE}$ =0.02). South Delta survival in the Old River route increased some when predator detections were included, to $\hat{S}_{B(SD)}$ = 0.70 ($\widehat{SE}$ =0.01) (Table 5-22). The increase may be due to the typically high density of predators at the CVP trashracks and radial gates.

Table 5-22
Performance Metric Estimates (Standard Error in Parentheses) for Tagged Juvenile Chinook Salmon Released in the 2011 Tagging Study, Including Predator-type Detections. South Delta ("SD") Survival Extended to the Shipping Channel Markers and Turner Cut in Route A, and the Central Valley Project Trash Rack, Exterior Radial Gate Receiver at Clifton Court Forebay, and Old River North and Middle River Receivers in Route B. (Population-level estimates were estimated from the pooled release groups)

Parameter	Release Occasion				Population Estimate
	1	2	3	4	
ψ_{AA}	0.42 (0.03)	0.46 (0.03)		0.52 (0.03)	0.46 (0.01)
ψ_{AF}	0.16 (0.02)	0.10 (0.02)		0.05 (0.02)	0.12 (0.01)
ψ_{BB}	0.42 (0.02)	0.43 (0.02)	0.37 (0.03)	0.43 (0.03)	0.41 (0.01)
ψ_{BC}	0.005 (0.003)	0.01 (0.00)	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)
S_{AA}	0.02 (0.01)	0.01 (0.01)		0.01 (0.01)	0.01 (0.00)
S_{AF}	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)
S_{BB}	0.004 (0.005)	0.03 (0.01)	0.06 (0.02)	0.07 (0.02)	0.04 (0.01)
S_{BC}	0.00 (0.00)	0.01 (0.01)	0.47 (0.33)	0.00 (0.00)	0.02 (0.01)
ψ_{A}	0.58[a] (0.02)	0.56[a] (0.02)	0.62[a] (0.03)	0.57[a] (0.03)	0.58[a] (0.01)
ψ_{B}	0.42[a] (0.02)	0.44[a] (0.02)	0.38[a] (0.03)	0.43[a] (0.03)	0.42[a] (0.01)
S_{A}	0.01 (0.01)	0.01 (0.01)	0.01[b] (0.01)	0.01[b] (0.01)	0.01[b] (0.00)
S_{B}	0.004 (0.005)	0.03 (0.01)	0.06[b] (0.02)	0.07[b] (0.02)	0.04[b] (0.01)
S_{Total}	0.01 (0.01)	0.01 (0.01)	0.03 (0.01)	0.04 (0.01)	0.02 (0.00)
$S_{A(MD)}$	0.02 (0.01)			0.01 (0.01)	0.01 (0.00)
$S_{B(MD)}$	0.01 (0.01)			0.00 (0.00)	0.004 (0.003)
$S_{Total(MD)}$	0.01 (0.00)			0.01 (0.00)	0.01 (0.00)
$S_{A(SD)}$	0.58[b] (0.03)	0.55[b] (0.03)		0.44[b] (0.03)	0.50[b] (0.02)
$S_{B(SD)}$	0.75[b] (0.04)	0.67[b] (0.04)		0.73[b] (0.04)	0.70[b] (0.02)
$S_{Total(SD)}$	0.65 (0.02)	0.6 (0.03)		0.57 (0.03)	0.58 (0.01)

[a] = significant preference for route A (San Joaquin Route) at head of Old River (α=0.05).
[b] = significant difference between route A and route B estimate (α=0.05).

Travel Time

For tags classified as being in salmon smolts, average travel time through the reaches ranged from 0.01 days ($\widehat{SE}$ < 0.01) (approximately 14 minutes) moving from the upstream receivers to the downstream receivers at the radial gates, to 3.63 days ($\widehat{SE}$ =0.06) moving from Medford Island to Chipps Island (Table 5-23). There were multiple paths between Medford Island and Chipps Island; the path that used only the San Joaquin River was approximately 41 rkm. The majority of the travel time between Medford Island and Chipps Island (2.43 days, $\widehat{SE}$ =0.03) was spent moving from Medford Island to the Jersey Point/False River junction (approximately 21.9 rkm through the San Joaquin River route).

When all detections were considered, including predator-type detections, travel times changed only slightly (Table 5-23). Tagged fish took slightly longer moving through the Old River route in the western Delta, e.g. between the Old River South and Old River North receivers (1.67 days, $\widehat{SE}$ = 0.04 including predators *vs.* 1.21 days, $\widehat{SE}$ = 0.02 without predators, Table 5-23). Likewise, the average travel time from the Old River South receivers to the CVP trashrack increased from 0.56 days ($\widehat{SE}$ = 0.01) without predator-type detections to 0.70 ($\widehat{SE}$ =0.01) with predator-type detections. These longer travel times when predator-type detections are included reflect the travel time criteria in the predator filter, which assumes that predators may move more slowly through the study area than migrating salmon smolts. For most reaches, including the predator-type detections resulted in little if any difference in observed travel times. Travel times through many reaches were shorter in 2011 than in 2010.

Route Entrainment Analysis

River flow at the San Joaquin River gauging station at Lathrop (station SJL) ranged from 4,157 cfs to 5,840 cfs (average = 5,070 cfs) during the arrival times of the tagged Chinook salmon smolts in 2011. The flow in the San Joaquin River never reversed direction during the 2011 tagging study. River flow at the Old River gauging station near the head of Old River (station OH1) ranged from 4,480 to 5,645 (average = 5,111 cfs) during the same time. There was little correlation between flow

Table 5-23
Average Travel Time in Days (Harmonic Mean) of Acoustic-tagged Juvenile Chinook Salmon Through the San Joaquin River Delta During the 2011 Tagging Study

Reach		Without Predator-Type Detections			With Predator-Type Detections		
Upstream Boundary	**Downstream Boundary**	**N**	**Travel Time**	**SE**	**N**	**Travel Time**	**SE**
Durham Ferry Release Site	Banta Carbona (BCA)	1,623	0.17	<0.01	1,622	0.17	<0.01
Banta Carbona (BCA)	Mossdale (MOS)	1,325	0.14	<0.01	1,325	0.15	<0.01
Mossdale (MOS)	Lathrop (SJL)	798	0.06	<0.01	783	0.06	<0.01
	Old River East (ORE)	581	0.06	<0.01	580	0.06	<0.01
Lathrop (SJL)	Stockton USGS Gauge (STS)	755	0.32	<0.01	759	0.32	<0.01
Stockton USGS Gauge (STS)	Stockton Navy Drive Bridge (STN)	728	0.06	<0.01	728	0.06	<0.01
Stockton Navy Drive Bridge (STN)	Shipping Channel Markers (C18/C16)	358	1.00	0.01	364	1.10	0.02
	Turner Cut (TCN/TCS)	96	1.04	0.01	96	1.09	0.01
Shipping Channel Markers (C18/C16)	Medford Island (MFE/MFW)	141	0.27	0.01	150	0.29	0.01
Medford Island (MFE/MFW)	Jersey Point/False River Junction (JPT/FRE/FRW)	8	2.43	0.03	9	2.45	0.03
Old River East (ORE)	Old River South (ORS)	631	0.10	<0.01	631	0.10	<0.01
	Middle River South (MRS)	6	0.12	<0.01	6	0.12	<0.01
Old River South (ORS)	Old River North (ORN)	105	1.21	0.02	96	1.67	0.04
	Middle River North (MRN)	2	0.68	0.01	2	0.68	0.01
	Clifton Court Forebay Access Channel (RGU)	162	0.54	0.01	163	0.56	0.01
	Central Valley Project Trashrack (CVP)	144	0.56	0.01	156	0.70	0.01
Old River North (ORN)	Jersey Point/False River Junction (JPT/FRE/FRW)	1	1.34	NA	2	0.77	0.01
Middle River South (MRS)	Old River North (ORN)	1	2.62	NA	1	2.62	NA
	Middle River North (MRN)	1	0.84	NA	1	0.84	NA
	Clifton Court Forebay Access Channel (RGU)	2	2.16	0.01	3	2.68	0.03
	Central Valley Project Trashrack (CVP)	0	NA	NA	0	NA	NA
Clifton Court Forebay Access Channel (RGU)	Clifton Court Forebay Interior (RGD)	127	0.01	<0.01	142	0.01	<0.01
Central Valley Project Trashrack (CVP)	Central Valley Project Holding Tank (CVPtank)	34	0.02	<0.01	37	0.02	<0.01
Jersey Point (JPT)	Chipps Island (CHP)	7	0.86	0.01	8	0.90	0.01
Medford Island (MFE/MFW)		6	3.63	0.06	7	3.99	0.07
Turner Cut (TCN/TCS)		0	NA	NA	0	NA	NA
Old River North (ORN)		1	1.84	NA	1	1.84	NA
Middle River North (MRN)		0	NA	NA	0	NA	NA
Clifton Court Forebay Interior (RGD)		3	1.83	0.01	4	2.25	0.03
Central Valley Project Holding Tank (CVPtank)		21	0.94	0.01	21	0.94	0.01

in the San Joaquin River and flow in Old River at the time of tag arrival at the river junction (r=-0.06). Water velocities ranged from 1.5 ft/s to 2.2 ft/s (average = 2.0 ft/s) at SJL, and from 1.7 ft/s to 2.1 ft/s (average = 1.9 ft/s) at OH1 during this time (r=0). Flow and velocity at the SJL station at the time of tag arrival were highly correlated (r=0.76), as were flow and velocity at the OH1 station at that time (r=0.73). The proportion of river flow entering the San Joaquin River averaged 0.50, ranging from 0.43 to 0.53, and was highly correlated with flow into the San Joaquin (r=0.81). Export levels were held fairly steady for the first two release groups, averaging 1,058 cfs at CVP and 1,583 cfs at SWP, with higher levels for the last two release groups, averaging 3,035 cfs at CVP and 6,287 cfs at SWP. There was moderate correlation between combined exports levels and flow at SJL (r=-0.33), and combined export levels and flow at OH1 (r=0.47).

The single-variate analyses found that the probability of remaining in the San Joaquin River at the head of Old River in 2011 was significantly related to both velocity and flow at the SJL gauging station (P<0.05, Table 5-24), with increased probability of staying in the San Joaquin River observed with increases in both flow and velocity at SJL. No other covariates had a significant effect on route entrainment into the San Joaquin River at the 5% level (Table 5-24).

Table 5-24
Results of Single-Variate Analyses of Route Entrainment at the Head of Old River

Covariate	F-test		
	F	df1, df2	P
Velocity at SJL[a]	12.4238	1, 1571	0.0004
Flow at SJL[a]	4.8088	1, 1571	0.0285
Flow proportion into San Joaquin	3.0189	1, 1571	0.0825
Velocity at OH1	2.8630	1, 1571	0.0908
Change in velocity at OH1	2.2363	1, 1569	0.1350
Change in flow proportion into San Joaquin	1.7360	1, 953	0.1880
Change in flow at OH1	1.7235	1, 1569	0.1894
Fork Length	1.1461	1, 1573	0.2845
Release Group	0.8255	3, 1571	0.4797
Change in flow at SJL	0.0938	1, 954	0.7595
Exports at SWP	0.0765	1, 1573	0.7822
Combined Exports	0.0563	1, 1573	0.8125
Change in velocity at SJL	0.0167	1, 954	0.8971
Exports at CVP	0.0113	1, 1573	0.9153
Flow at OH1	<0.0001	1, 1571	0.9936

[a] = Significant at 5% level

Table 5-25
Results of Multivariate Analyses of Route Entrainment at the Head of Old River

Model Type	Covariate[a]	Estimate	S.E.	t-Test		
				t	df	P
Velocity	Intercept	0.3407	0.0514	6.623	1,571	<0.0001
	V_A	0.2098	0.0515	4.072	1,571	<0.0001
	Goodness-of-fit: χ^2=9.3616, df=11, P=0.5886; AIC = 2123.70					
Flow	Intercept	0.3389	0.0513	6.612	1,571	<0.0001
	Q_A	0.1308	0.0514	2.547	1,571	0.0110
	Goodness-of-fit: χ^2=11.6756, df=11, P=0.3885; AIC = 2133.94					

[a] = continuous covariates (Q_A, V_A) are standardized

Multivariate analyses came to the same conclusion, with both flow and velocity at the SJL station individually explaining a significant amount of the variability in route entrainment at the head of Old River in 2011 (Table 5-25). Both models adequately fit the data (P=0.39 to 0.59), but velocity at SJL accounted for more of the variation in route entrainment than flow (ΔAIC=10.24; Table 5-25). The velocity model predicted the route entrainment probability according to:

$$\widehat{\psi_A} = \frac{\exp(-3.14 + 1.77 V_A)}{1 + \exp(-3.14 + 1.77 V_A)}.$$

Increases in water velocity in the San Joaquin River at Lathrop were predicted to increase the probability of route entrainment into the San Joaquin River at the head of Old River (Figure 5-11).

Mobile Telemetry Monitoring

Mobile tracking efforts in previous years identified three sites of high juvenile salmon mortality or tag defecation by predators: in the deep scour hole in the San Joaquin River near the head of Old River, near a railroad bridge

in Stockton, and in front of the Tracy Fish Facility trash racks (Vogel, 2007 and 2010). Based on the 2011 mobile monitoring, predation did not appear to be a problem near the Head of Old River or near the railroad bridge in Stockton. However, predation did still appear to be an issue in front of the Tracy Fish Facility trash racks, with a total of 37 acoustic tags detected near this location. Two additional areas that appeared to be predation "hot-spots" in 2011 were around the Tracy Blvd Bridge in Grant Line canal, and in the Stockton Deep Water Ship Channel (DWSC) near Turner Cut. A total of 48 immobile tags were detected near the Tracy Blvd Bridge (Figure 5-12), and 78 tags were identified in the 2 miles above Turner Cut (Figure 5-13).

A total of 952 tag detections were recorded during the sampling period, representing detection of 668 individual tags. Of these detections, 361 had been implanted in Chinook, 290 in Steelhead, and 17 in various predators. The final location of all Chinook tag detections is shown in Figure 5-14. During one sampling event on May 25th, the GPS receiver malfunctioned so detection locations were not recorded for 34 tags.

Survival in the San Joaquin River between Banta Carbona and Old River appeared to be high during the 2011 VAMP. Of the few tags lost in this reach that had been released at Durham Ferry, eight Chinook tags were detected by mobile tracking and were found to be distributed evenly throughout the reach with no apparent hot spots.

A total of 172 tags from marked salmon were detected in the San Joaquin River between Old River and Turner Cut. Seventy-three percent (73%) of the detected Chinook tags in this reach of the San Joaquin River were found in the Stockton DWSC (n=126), while the remaining 46 were detected spread fairly evenly throughout the reach between its junction with Old River and the Stockton DWSC.

A total of 162 Chinook tags were detected in Old River and Grant Line Canal between the Head of Old River and the State and federal pumping facilities. The highest concentration of the tags detected by mobile monitoring in this reach were detected in Grant Line Canal 54% (n=88), while 29% (n=47) were found in the vicinity of the State and federal pumping facilities, and the remaining 17% (n=27) were detected in Old River upstream of Grant Line Canal. The number of tags detected in Grant Line Canal was much higher than previous years. It is unknown whether the fish were preyed upon in this location, or if they were eaten at other locations and later deposited where they were detected.

Unmarked and Marked Salmon Captured at Mossdale

The general time period for VAMP (mid-April to mid-May) was determined based on historical data, which indicates that a high percentage of salmon smolts emigrating from the San Joaquin River tributaries pass Mossdale (MOS) during this time. The 2011 VAMP period was May 1st through May 31st, and trawl sampling at Mossdale was conducted three days per week from January until March, five days per week from April to mid-June (with the exception of a two-week period from May 9th to the 22nd when the trawl was operated daily); and three days per week for the remainder of June.

Densities (catch per 10,000 cubic meters) of unmarked juvenile salmon captured at Mossdale from January through June are shown in Figure 5-15. Unmarked salmon do not have a clipped adipose fin or any other external mark (i.e., Panjet or Bismark brown) and may be juveniles from natural spawning or unmarked hatchery fish from the Merced River Hatchery (MRH). Unmarked hatchery fish (n=1,818) were released into the Merced River on July 15th. All other Chinook released from the MRH were either coded-wire tagged with their adipose-fin clipped (n=122,973) or released with an external Panjet mark (n=19,805)[2]. A combined total of 660 adipose fin-clipped (n=316) and Panjet marked (n=344) Chinook were captured in the trawl. The trawl captured zero acoustic-tagged fish in 2011.

Average daily densities of unmarked juvenile salmon were extremely low from January through mid-April (i.e., less than 0.2 salmon per 10,000 cubic meters). Densities began to rise in late-April, as river flows began to decrease, and remained elevated through mid-June (Figure 5-15). Juvenile Chinook emigrated from the San Joaquin Basin later than usual due to higher flows and lower water temperatures in 2011. The size of juvenile salmon captured in the Mossdale trawl between January and June is shown in Figure 5-16.

[2] *6,669 of the Panjet marked fish were also coded-wire tagged with their adipose-fin clipped. These fish were not included in the total number of CWT fish listed. These fish were released above Mossdale on May 27th and June 10th. Recaptures were designated as having either a Panjet or an ad-clip (i.e., both marks were not indicated).*

Salmon Salvage and Losses at Delta Export Pumps

Fish salvage operations at the CVP and SWP export facilities capture juvenile salmon and transport them by tanker truck to release sites away from the pumps in the northern Sacramento-San Joaquin Delta. The exact origin of these untagged salmon is unknown. It is uncertain which of the unmarked salmon recovered are of San Joaquin River basin origin, although the timing of salvage and fish size can be compared with Mossdale trawl data to provide a general indication as to the extent of potential overlap. The combined exports in 2011 exceeded the flow at Vernalis prior to April and during the majority of June, and ranged from 40 to 62% less than Vernalis flow from April to early June (Figure 5-17) (see Chapter 4 for more discussion of Vernalis flow and export rates).

The density of salmon encountering each of the export and fish salvage facilities off Old River is represented by the combined salvage and loss estimated per acre-foot of water pumped. The CDFG and DWR maintain a database of daily, weekly, and monthly salvage data. The number and density of juvenile salmon that migrated through the Delta, the placement of the head of Old River barrier (HORB), and the amount of water pumped by each facility are some of the factors that influence the number of juvenile salmon that are salvaged or lost. Salmon density at the facilities can be an indicator of time periods when more juvenile salmon may be susceptible to the export and salvage system. Since salvage efficiency is likely lower for smaller-sized salmon (fry and parr), their salvage numbers and estimated losses could be underrepresented.

Weekly salvage and loss data for the CVP and SWP were provided by CDFG Delta Fish Salvage Monitoring Project. A review of weekly data for January through June indicates that salvage and losses started to increase in May at CVP and in mid-May at SWP, then remained elevated through the entire month of June (Figures 5-18 and Figure 5-19). Salmon densities (based on combined salvage and loss estimates divided by 1,000 acre feet of export) were highest at both facilities following the conclusion of the VAMP period (Figure 5-20) when exports increased. Densities at the SWP had a distinct peak in late-May, whereas the CVP did not show a well-defined peak during the smolt emigration.

The size and timing distributions of unmarked salmon in the Mossdale trawl (Figure 5-16) during January through June corresponds well with the distributions of the fish salvaged at the facilities during this same time period (Figure 5-21, Source: A. Llaban, DWR). Based on comparisons with Mossdale data, it appears that many salmon salvaged from the late-May through June period could have originated from the San Joaquin River basin.

These results demonstrate that the primary 2011 San Joaquin River basin salmon smolt migration period from the beginning of May to late-June coincided with the higher salvage period of the CVP/SWP facilities. Sampling frequency at Mossdale during the smolt emigration period has decreased from 7 to 5-days per week during the last several years. In 2011, CDFG operated the Mossdale trawl 7-days per week for a two-week period beginning in mid-May when abundance began to increase. Unfortunately, the increased sampling frequency did not coincide with peak abundance, which occurred two weeks later when CDFG returned to the reduced sampling frequency (i.e., 5-days per week). Production estimates at Mossdale could be improved by ensuring that sampling is conducted daily when most salmon smolts are emigrating.

Discussion

Detections Not Used in the Survival Model

Several detections of acoustic tags at Chipps Island were not used in the survival analysis. One tag (tag ID = 6990.13) was detected at Threemile Slough after its final Chipps Island detection, and was not detected again. Using all detections (i.e., without the predator filter), this tag's detection history ignored the Chipps Island detections because the tag was detected upstream after being detected at Chipps Island; although the fish reached Chipps Island, it did not either stay there or move downstream, but rather returned to the Delta. Using the predator-filtered data, however, the tag was classified as in a predator at its Threemile Slough detection but not at its Chipps Island detection. In this case, the Chipps Island detection was used in the survival analysis, but it is unlikely that the salmon smolt survived to points downstream of Chipps Island. Another tag (tag ID = 9377.13) was detected at Chipps Island, but only on the single hydrophone closest to the entrance to Spoonbill Creek. The possibility of tagged fish leaving the river for Spoonbill Creek violated the closure assumption of the dual array at Chipps Island, so detections on this single receiver were omitted from the survival analysis. This tag had previously been classified as a predator at the Central Valley Project, so even if the Spoonbill Creek detections had been included, this tag's detection would not have contributed to estimates of survival to Chipps Island. All other detections at Chipps

Figure 5-11
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus Water Velocity Measured at the SJL Gaging Station near Lathrop, CA, with 95% Confidence Bands, in 2011

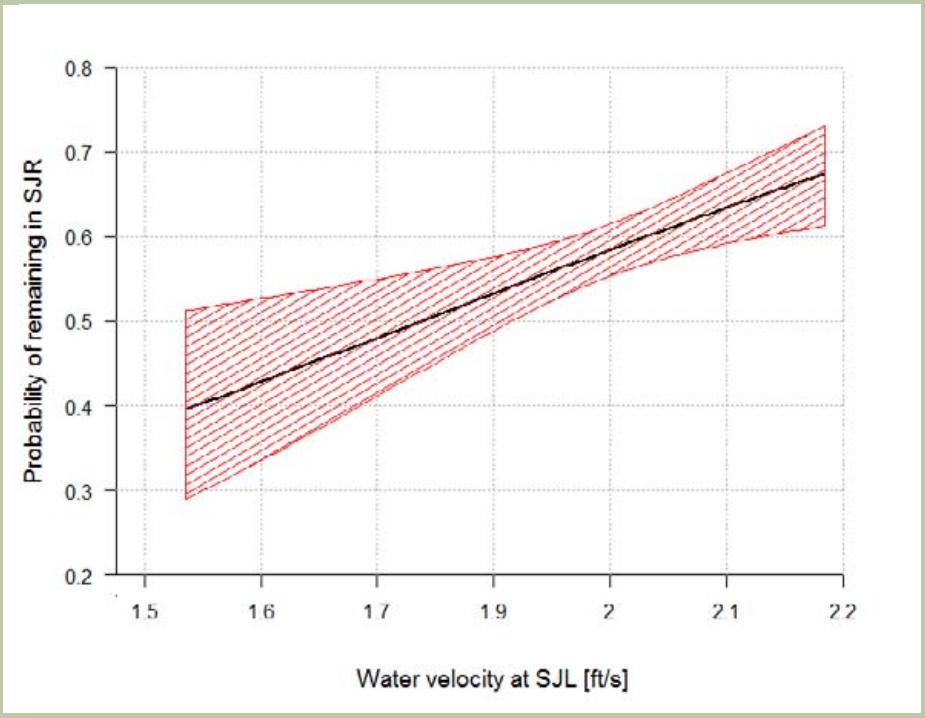


Figure 5-12
Approximate Last Known Location of Acoustic Tags Detected as Immobile in Grantline Canal Near the Tracy Boulevard Bridge Using Mobile Telemetry Monitoring During the 2011 Tagging Studies

Figure 5-13
Approximate Last Known Location of Acoustic Tags Detected as Immobile in the San Joaquin River Upstream of Turner Cut Using Mobile Telemetry Monitoring During the 2011 Tagging Studies

Figure 5-14
Approximate Last Known Location of Acoustic Chinook Tags Detected as Immobile Using Mobile Telemetry Monitoring During the 2011 Tagging Studies

Figure 5-15
Average Daily Densities of Unmarked Juvenile Chinook Salmon Caught in the Mossdale Kodiak Trawl in 2011 on the San Joaquin River

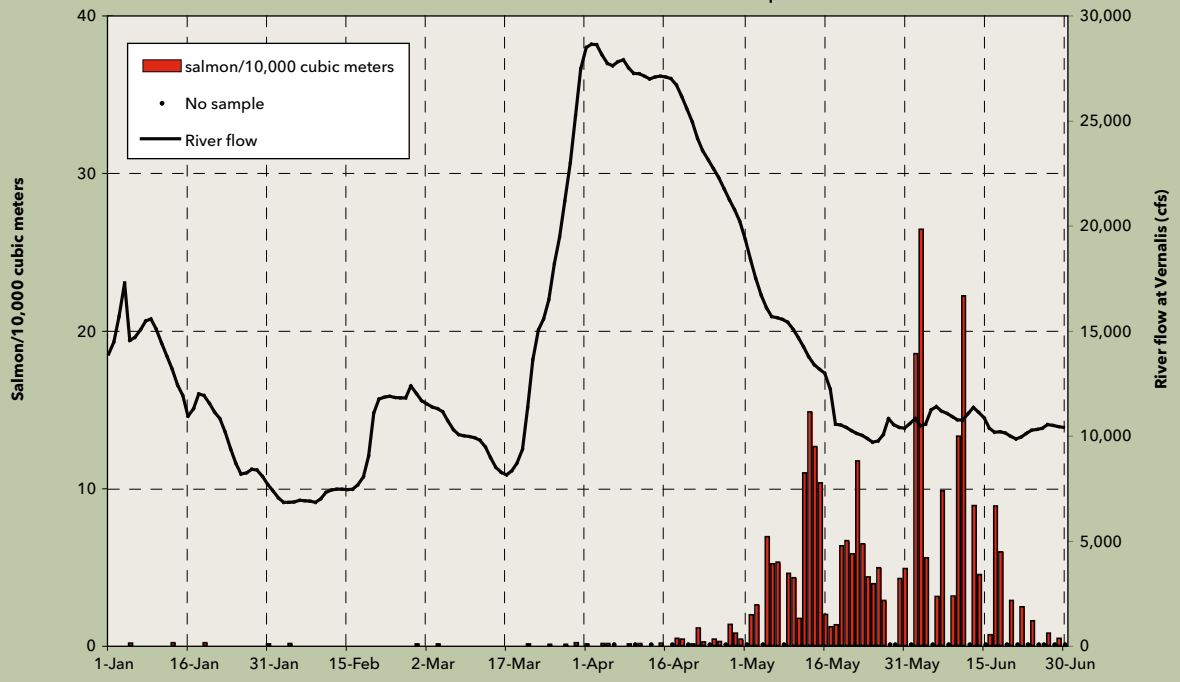


Figure 5-16
Individual Daily Forklengths (FL) in millimeters of Marked and Unmarked Juvenile Chinook Salmon from the Mossdale Kodiak Trawl on the San Joaquin River, January through June 2011

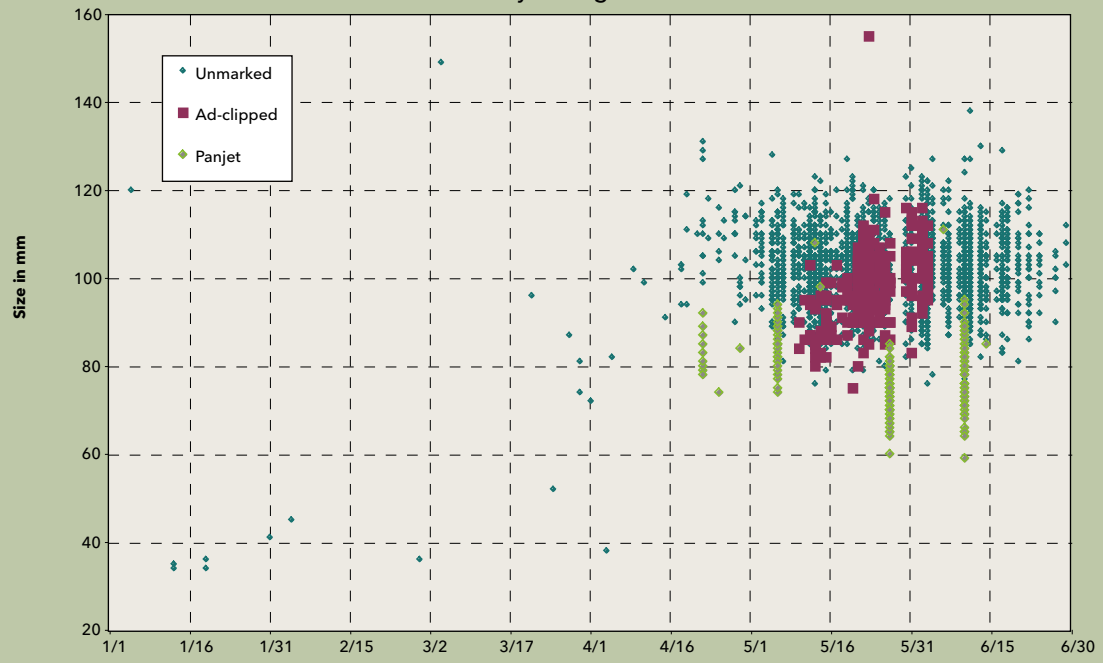


Figure 5-17
Weekly Average Export Rates from January through June 2011 from the State Water Project (SWP) & Central Valley Project (CVP) and Vernalis Flow in Cubic Feet per Second (cfs)

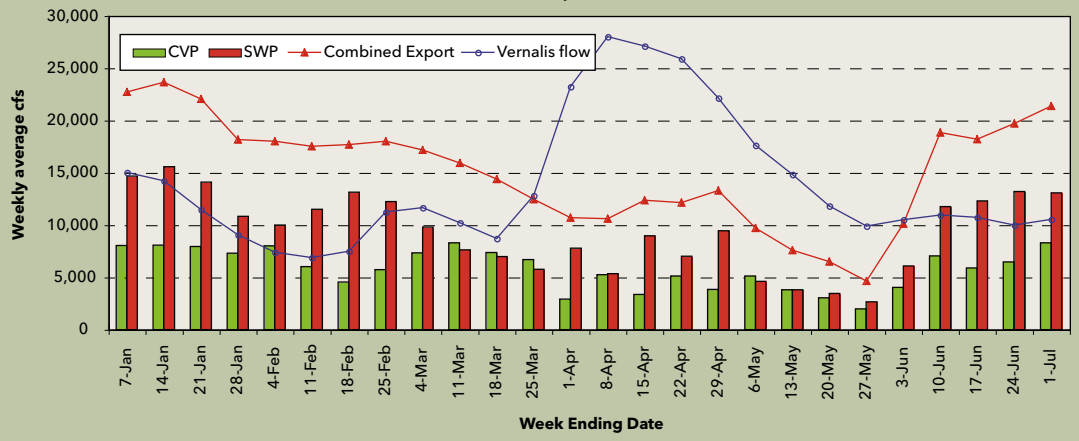


Figure 5-18
Central Valley Project (CVP) Estimated Juvenile Chinook Salmon Salvage and Loss from January through June 2011

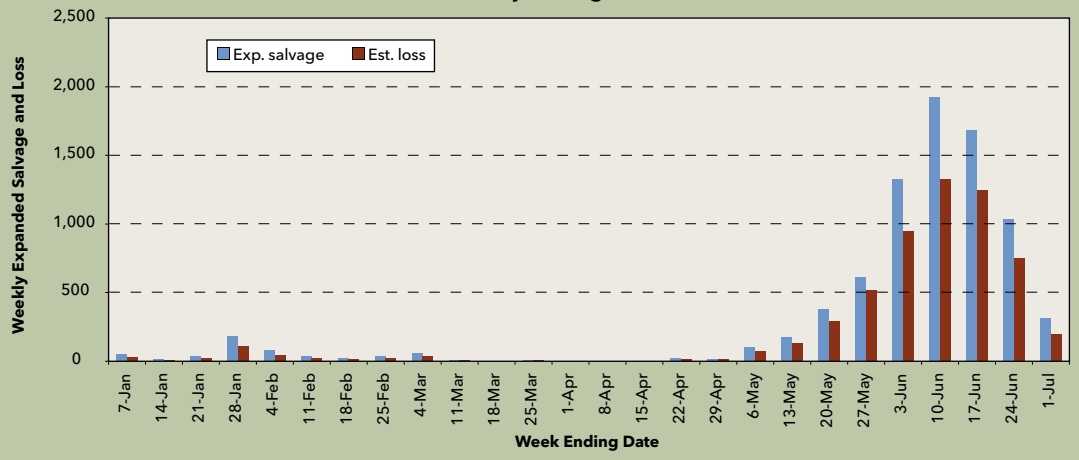


Figure 5-19
State Water Project (SWP) Estimated Juvenile Chinook Salmon Salvage and Loss from January through June 2011

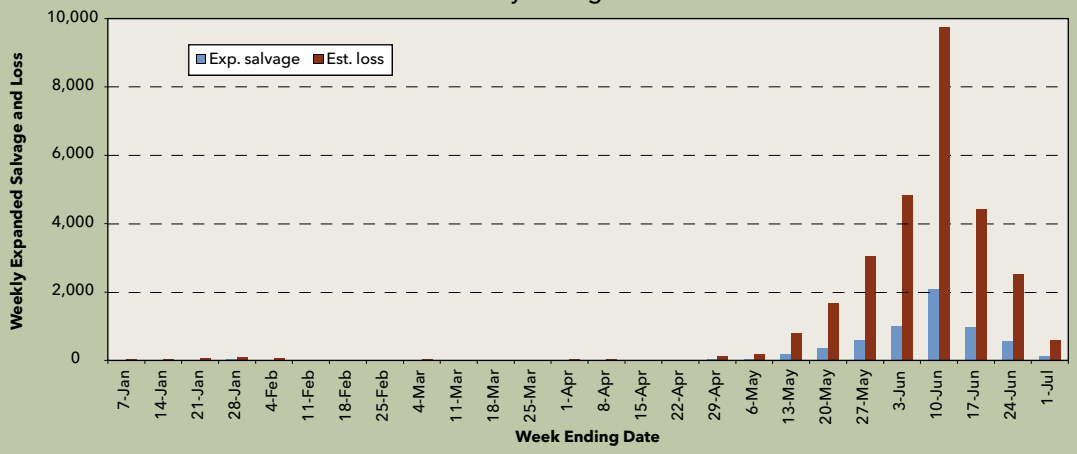


Figure 5-20
State Water Project (SWP) & Central Valley Project (CVP) Combined Juvenile Chinook Salmon Salvage and Loss Density Estimates per 1,000 Acre Feet of Export from January through June 2011

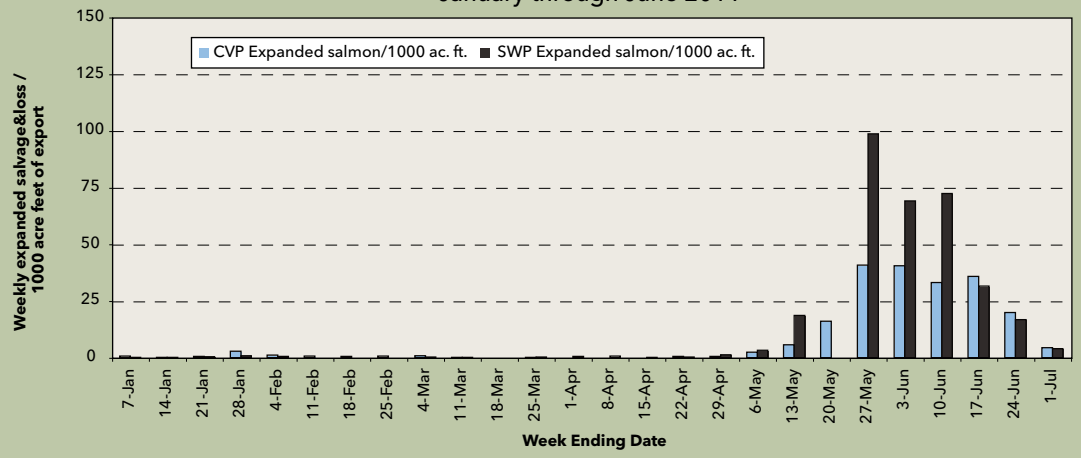
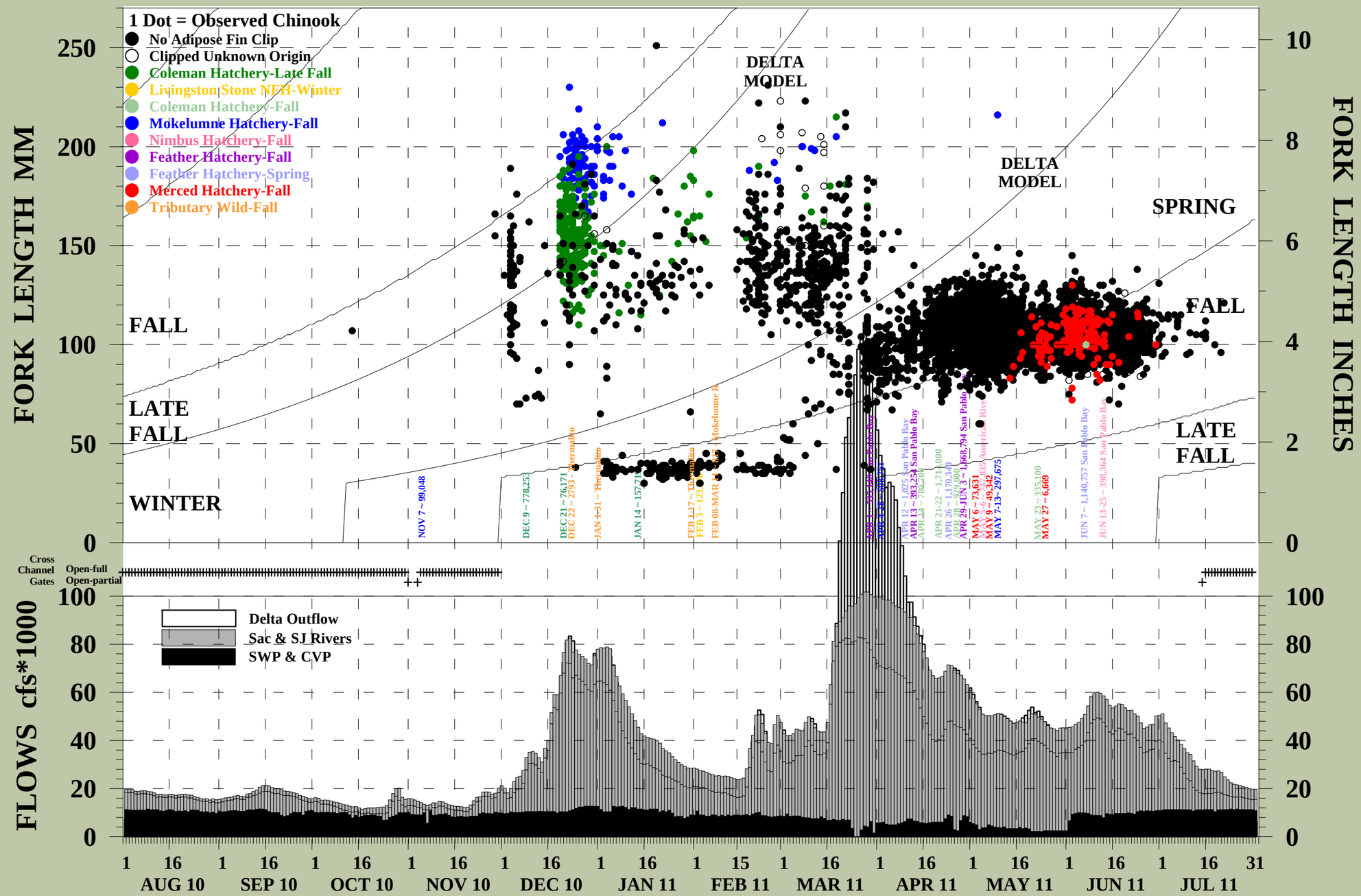


Figure 5-21
Observed Juvenile Chinook Salmon in Salvage at the State Water Project (SWP) & Central Valley Project (CVP) Delta Fish Facilities from 8/1/2009 Through 7/31/2010
(Source: A. Llaban, DWR)



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Preliminary, subject to revision

Island were used in the survival model, either using the reduced "smolt-only" data or using the full data set that included the predator-type detections. If all predator-type detections, including those mentioned here, had been included along with this detection, the overall estimate of survival to Chipps Island would still have been 0.02 for the entire study period and 0.01 during the VAMP Target Flow period.

Survival in 2011

Survival through the Delta was low in 2011. Although estimated survival was observed to be higher in the Old River route (0.04, $\widehat{SE}$ = 0.01) than the San Joaquin River route (0.01, $\widehat{SE}$ = 0.00), survival in both routes was very low both during and after the VAMP period. One benefit of using acoustic tags and estimating reach and route specific survival is that it allows us to identify areas of high relative mortality as the tagged fish migrate downstream. Evaluating survival by reach may help explain why survival through the Delta using either route was so low for tagged juvenile salmon used in these studies in 2011.

The four release groups of acoustic-tagged Chinook salmon analyzed for survival and route entrainment probabilities in 2011 consisted of two groups released during the latter half of the 2011 VAMP period and two groups released within three weeks after the end of the VAMP. While survival was generally low for all four release groups, overall estimated survival to Chipps Island was slightly higher for the post-VAMP release groups than for the VAMP release groups: 0.01 ($\widehat{SE}$ =0.004) during VAMP vs. 0.03 ($\widehat{SE}$ =0.007) after VAMP (P=0.0015). The small increase in survival after the end of VAMP came from an increase in the route-specific survival to Chipps Island via the Old River route: $\overline{\hat{S}}_B = 0.01$ ($\widehat{SE}$ =0.006) during VAMP vs. $\overline{\hat{S}}_B = 0.07$ ($\widehat{SE}$ =0.014) after VAMP (P=0.0002). The increase in survival was coincident with an increase in the water export rate throughout the Delta after the VAMP ended. However, despite the increase in estimated survival after the end of the VAMP, survival estimates from the period of higher export levels remained very low.

South Delta Survival in 2011

Estimated survival in 2011 through the Southern Delta region was relatively high at 0.56 ($\widehat{SE} \leq 0.03$; without predator-like detections) compared to survival through the entire Delta. The Southern Delta region started at Mossdale, with endpoints at: 1) the entrances to Clifton Court Forebay and the CVP; 2) Old River North and Middle River North receivers near Highway 4, and 3) the receivers in the San Joaquin River and in Turner Cut just downstream of the Turner Cut junction.

Overall survival through the Southern Delta region in the Old River route was estimated at 0.66 ($\widehat{SE}$ =0.02), with the majority of the mortality occurring after fish passed Old River South (ORS, site B2). For fish that survived to ORS, approximately 23% ($\widehat{SE}$ =2%) arrived at the CVP trashracks, and another 29% ($\widehat{SE}$ =0.02) arrived at the radial gates (RGU). Approximately 16% of ORS fish ($\widehat{SE}$ =0.01) made it past those sites to the Old River North (ORN) receivers near Highway 4. Combined over these ORN, CVP, and RGU, these results indicate a survival estimate of 0.68 ($\widehat{SE}$ =0.02) in the Southern Delta region between ORS and ORN, CVP, and RGU.

In contrast, the lowest survival estimate in the Southern Delta region in the San Joaquin River route was 0.59 ($\widehat{SE}$ =0.02) for the reach from the Navy Drive Bridge (STN) to the channel markers (A8) and Turner Cut (F1). The low survival estimate in this reach resulted in lower estimates of overall survival through the Southern Delta region for the San Joaquin River route fish ($\hat{S}_{A(SD)}$ =0.48, $\widehat{SE}$ =0.02) than for the Old River route fish ($\hat{S}_{B(SD)}$ =0.66, $\widehat{SE}$ =0.02) (Table 5-21).

Survival in Downstream Reaches of the Delta

Survival in the Delta downstream of the Southern Delta endpoints was generally much lower than upstream, and contributed to the low survival to Jersey Point and Chipps Island regardless of which pathway the juveniles took. One mechanism for the low survival in the San Joaquin River route may be diversion into the interior and south Delta as the tagged fish move downstream. Averaged over all releases (VAMP and non-VAMP), approximately 21% of the tagged fish that approached the Turner Cut junction on the San Joaquin River entered Turner Cut: 23% during the VAMP releases vs. 18% after VAMP. However, none of those tagged fish entering the interior Delta via Turner Cut were subsequently detected at Chipps Island. One of the tags detected at Turner Cut (from release 2 during the VAMP) that had previously been detected at the Navy Drive Bridge receiver (STN) was later detected at Middle River North (MRN) and then at the Clifton Court Radial Gates (RGU), but it did not survive to Chipps Island. This was not an isolated case of movement from the San Joaquin River to the interior Delta as eight other tags originating from the San Joaquin River were also detected at the MRN receivers (including predator-type detections), none of which were subsequently observed at Jersey Point or Chipps Island. The majority (6 of 8) of those tags detected entering the interior Delta from the San Joaquin River came from releases made after the end of the VAMP. These detection histories appear to support the hypothesis that tagged fish leaving the San Joaquin River via Turner Cut or other junctions move further into the Southern Delta towards the SWP or CVP, either

as a smolt or a predator. Only 1 fish of 17 detected at Middle River (MRN) survived to Chipps Island (by way of Clifton Court Forebay), suggesting that fish that have entered the interior Delta from the San Joaquin River tend not to re-enter the San Joaquin River, but rather move further into the south/southwestern Delta. It also suggests survival to Chipps Island is low for fish entering the interior Delta from the San Joaquin River. This is further supported by the low estimated joint probability of fish successfully moving from Old River north (ORN) to Jersey Point or False River ($\phi_{B3,GH}$ = 0.02, $\widehat{SE}$ =0.01, Table 2 and Table 3 in Appendix H).

Movement towards the interior and south Delta from the mainstem San Joaquin River may also account for the high mortality inferred by the low estimated transition probabilities between Medford Island (A10) and Jersey Point (G1). The average estimate of this transition probability ($\phi_{A10,GH}$) was 0.08, suggesting many of the fish that arrive at Medford are not successfully making it downstream to Jersey Point. Movement into the interior Delta via Old or Middle rivers or through Frank's Tract may contribute to this perceived mortality.

The estimated transition probability from the CVP trashracks to the holding tanks averaged 0.23 ($\widehat{SE}$ =0.03) over all release groups (0.15 during VAMP; 0.28 after VAMP). One mechanism for this low probability of reaching the holding tanks may be from predation between the trashracks and the holding tanks. This hypothesis is supported by the detection of 46 tags that were detected at the CVP trashracks that were later found elsewhere in the south Delta. Some of these tags were later detected back at the CVP, but none of them were detected at Chipps Island, all behavior suggesting the smolts were preyed upon between the CVP trashracks and the holding tank. In addition, some tags (14) were detected by the receiver located in the Delta Mendota Canal (DMC) and could account for some of the mortality between the CVP trashracks and the holding tanks. Furthermore, an additional seven tags were subsequently detected on the CVP trashrack receivers after being detected in the DMC, suggesting that tagged fish or predators are moving from inside the CVP to the DMC and back at a high rate. Predation was observed at the CVP with 37 tags classified as in a predator upon arrival at the CVP and 67 tags classified as predators upon departure from CVP. The mobile monitoring confirmed predation appeared to be high in front of the CVP, with a total of 37 acoustic tags detected near this location.

The joint probability of moving and surviving from the CVP holding tanks to Chipps Island was relatively high with an average estimate of 0.62 ($\widehat{SE}$ =0.08), averaged over all release groups. For the release groups during VAMP, the estimate was 0.50 ($\widehat{SE}$ =0.18); after VAMP, the estimate was 0.65 ($\widehat{SE}$ =0.09). This is in contrast to the survival through Clifton Court Forebay and the SWP, where the estimated transition probability from RGD to Chipps Island was low for all release groups (average = 0.02; $\widehat{SE}$ =0.01). This result seems consistent with previous studies (Clark et al., 2009; Gingras, 1997; SJRGA, 2011) that have identified high mortality for juvenile steelhead or salmon moving through Clifton Court Forebay and through the SWP. The VAMP team evaluated estimating the survival through the SWP more precisely, but sample sizes needed were estimated to be quite large (Appendix I).

The receivers at the radial gates inside the Clifton Court Forebay (RGD) had only one tag classified as in a predator on arrival, but 106 tags classified as in a predator on departure from RGD. The mobile tracking confirmed that several tags were found in the vicinity of the State and federal pumping facilities.

Comparison of 2011 Results to Past Years

Smolt survival through the Delta from Mossdale or Durham Ferry to Jersey Point has been extremely low over the past 10 years regardless of flow, exports, or operation of the HORB. Since 2003, at flows ranging from approximately 2,000 to 27,000 cfs, survival was consistently less than or equal to 12%. In contrast, survival between 1994 and 2001 was much higher and generally ranged between approximately 15 and 50% (Figure 5-1). These present survival levels will not produce a sustainable population. The reason for the change in survival in the last decade is unclear and more study is needed to better define what is happening.

Estimated survival in 2011 through the Southern Delta was consistent with the 2010 estimate (0.56, $\widehat{SE} \leq 0.03$ in both years) and considerably higher than the 2009 estimate (0.06, $\widehat{SE}$ =0.01) (without predator-like detections). Differences in survival between years may be due to flow, with 2009 a low-flow year and 2010 and 2011 above normal and wet flow years, respectively (Buchanan et al., 2013). However, differences between years, could also be due to differences in tag weight to body weight ratios as the minimum fish size criteria were not met in 2009; or due to differences in fish origin since Feather River Hatchery fish were used in 2009 while in 2010 and 2011 the smolts came from Merced River Hatchery. Any one or all of these factors may have contributed to the apparent differences in survival between 2009 and other years.

Between 1985 and 1991, CWT studies were conducted to estimate survival in the two main routes through the Delta; Old River and the San Joaquin River. The results of these studies indicated survival was generally higher for the fish released on the San Joaquin River at Dos Reis, downstream of Old River, than for fish released into