Element 1d - Salmon Smolt Survival Investigations[1] (2010)

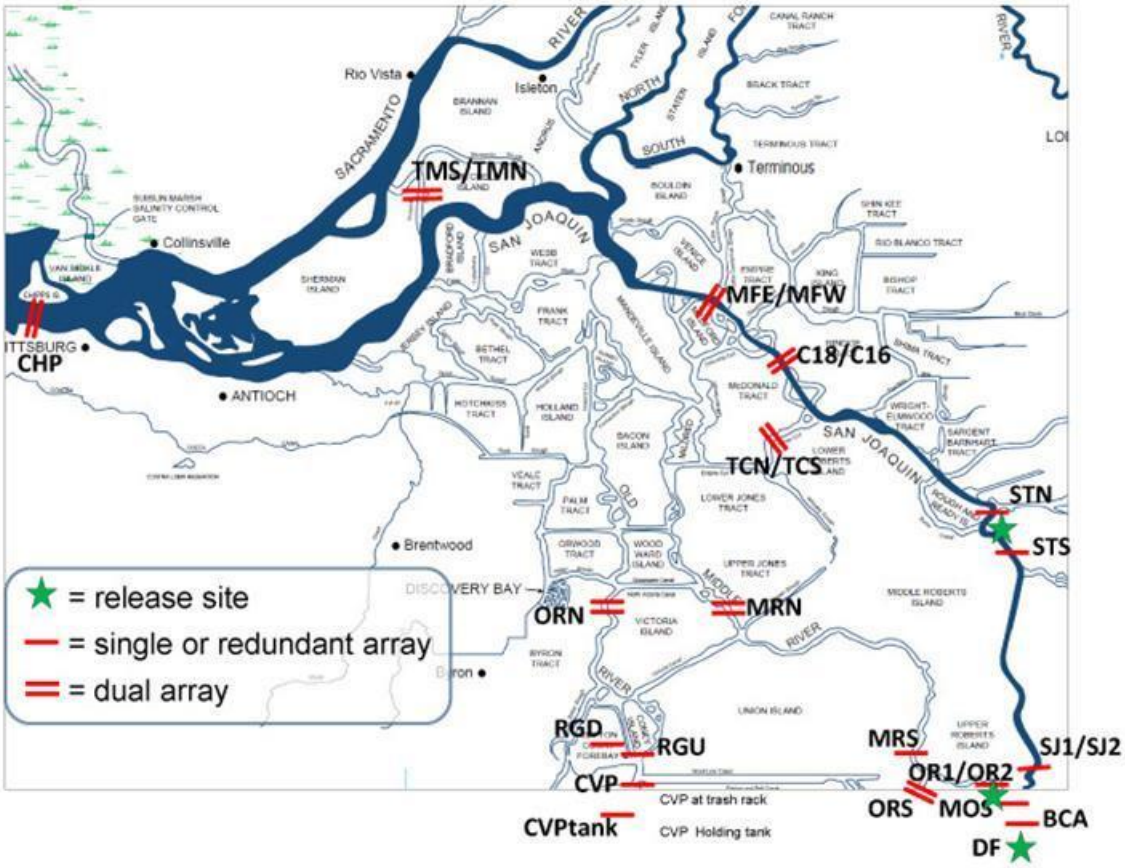
The lack of study fish from the Merced River Hatchery (MRH) in conjunction with the potential for interruptions in trawling at Chipps Island due to incidental catches of delta smelt prompted a transition away from use of coded wire tagged (CWT) salmon and toward acoustic telemetry methodologies starting in 2007. This transition continued with the biological investigations associated with the 2010 VAMP study. Compared to traditional mark-recapture techniques, acoustic telemetry provides greater temporal and spatial coverage of the outmigration process. Further, continuous, simultaneous monitoring at several locations allows estimation of distribution probabilities at junctions and reach-specific survival throughout the study region. Moreover, 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.

Introduction

During the 2010 study, Chinook salmon smolts were acoustically tagged with Hydroacoustic Technology, Incorporated (HTI) tags 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 (Figure 2-1). A total of twenty-one releases were made between April 27th and May 19th, with seven releases at each of the three separate sites. At Durham Ferry between 70 and 74 fish were released per release period, while at Old River and at Stockton, between 34 and 36 fish were released at each location per release period.

The study design was intended to provide estimates of survival to Chipps Island given that survival through the Delta was low. The releases at Old River and near Stockton were made to augment the numbers 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. In addition, the seven sets of releases at Durham Ferry were also used to meet the study needs of the joint California Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) evaluation of a non-physical barrier (NPB) at the head of Old River often called the Bio-Acoustical Fish Fence or BAFF. Each tagged fish 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 the survival estimates.

[1] This chapter is a republication of Chapter 5 Salmon Smolt Survival Investigations 2010 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP). Prepared by San Joaquin River Group Authority for the California Water Resources Control Board in compliance with D-1641. September 2011. See also appendixes A, B, and C at the back of this report, which are also replications of appendices E, F, and G, in original report.



(Figure compliments of University of Washington)

Figure 2-1. Locations of Acoustic Receivers and Release Sites Utilized for the 2010 VAMP Study including Locations of Acoustic Receivers the California Department of Water Resources Deployed for the South Delta Temporary Barriers Study

Study Design and Methods

Study Fish

All fish used in the VAMP 2010 study originated from Merced River Fish Hatchery (MRH). Approximately 1,750 juvenile fall run Chinook salmon were transferred by California Department of Fish and Game (CDFG) from MRH to the Tracy Fish Collection Facility (TFCF) on April 15th (n=500), April 22nd (n=500), April 29th (n=500), and May 6th (n=250). Fish were held at TFCF for 11-15 days prior to tagging to allow for acclimation to Delta water quality and temperature prior to release. During the first 7-11 days water temperature in the holding tanks at TFCF was held at approximately 14-15°C (57-59ºF) using a water chiller to reduce the temperature of ozonated Delta water. During the last 3-4 days prior to tagging, the water supply was switched to ozonated Delta water at ambient Delta water temperatures (i.e., not passed through the water chiller). Fish were not held at ambient temperatures for the duration of holding at TFCF because Proliferative Kidney Disease (PKD) is progressive at temperatures greater than 15°C (59ºF).

Transmitter Programming

HTI model 795 Lm microacoustic transmitters were programmed according to modified guidelines developed during the 2008 VAMP. Transmitters were programmed the day prior to tagging which was two days prior to the beginning of each release. Transmitters were soaked for approximately 24 hours prior to programming. Tag programming files were developed by HTI which provided the tag period and pulse width to be used for each tag in each release group. Tag periods used during the 2010 study ranged from 4 seconds to 10 seconds, with a pulse width of 2 milliseconds. The HTI tag programming software provided programming history files which contained the date, time, tag period, and pulse width for each tag that was programmed. On a datasheet the manufacturing lot was also recorded for each tag programmed.

After programming, tags were sniffed in a cup of water using a HTI sniffer and monitored through at least three transmission cycles. At most 5 attempts were made to program each tag. If the tag could not be programmed after 5 attempts, a new tag was selected, and the tag that would not program was returned to HTI. During the 2008 VAMP some tags that passed activation and sniffing could not be heard after fish tagging. To address this issue in 2009 and 2010, each activated tag was briefly listened to within a few hours after programming and prior to surgical implantation in study fish to confirm tag function and programming. A total of 36 tags failed to initialize and all programmed tags were heard during validation immediately after programming in 2010.

Transmitter Implantation and Validation

The 2010 training and tagging operations were conducted at the TFCF as was done in 2009. In 2007 and 2008 training occurred at the Mokelumne River Fish Hatchery and tagging occurred at Merced River Fish Hatchery (MRH). The TFCF was selected in 2009 as a preferred alternative to MRH for tagging due to the proximity and similar water temperature conditions to the release sites at Durham Ferry, Old River, and Stockton. Transit time to the release site and large differences in temperature between MRH and the release sites posed significant challenges to the study in previous years. Moving the tagging operations to a location in the Delta improved the study design by addressing these issues. The ability to conduct both training and tagging at a single site was an added benefit of moving to the TFCF.

Tagging operations occurred at the TFCF between April 26th and May 17th. 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 defined by Adams et al. 1998 and Martinelli et al. 1998. The HTI Model 795 Lm micro acoustic tag used for this study had an average weight of 0.65 g in air (range: 0.61 g to 0.73 g), was 16.4 mm long, with a diameter of 6.7 mm.

The challenges with fish size and tag weight that occurred during 2009 (San Joaquin River Group Authority, 2010) were not encountered during 2010. A minimum fish weight criterion of 12.1 g was used to ensure a maximum tag weight to body weight ratio of 5.4%. The same criteria was also used during 2008, but could not be achieved during 2009 (San Joaquin River Group Authority, 2010). All fish tagged and released during the 2010 VAMP met the minimum weight criterion of 12.1 g. Most fish had tag weight to body weight ratios of 3-4%, far below the 5.4% maximum criterion (Figure 2-2). Although the minimum weight criteria was met for all fish, 10 fish ranging in weight from 12.1 to 12.7 grams had a maximum tag weight to body weight ratio which slightly exceeded the 5.4% criteria (range 5.5-5.8%) due to tag weights ranging from 0.68 to 0.71 grams. These fish however represented less than 1% of the total number of fish tagged and released during the 2010 VAMP.

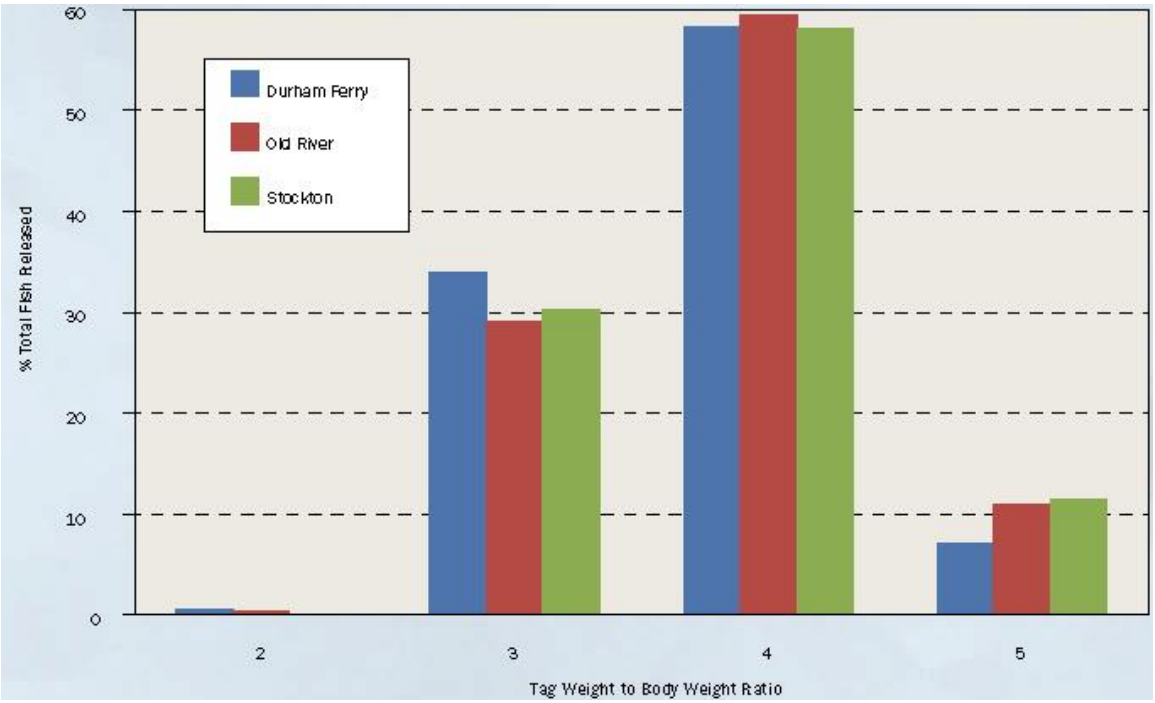


Figure 2-2. Frequency Distribution of Tag Weight to Body Weight (TW:BW) Ratio of Live Study Fish Released during the 2010 VAMP Study

Standard operating procedures (SOP) for tagging (Appendix A) were largely based on methods developed by the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS). The SOP 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 (MS-222) buffered with an equal concentration of sodium bicarbonate until they lost equilibrium. Fish were removed from anesthesia, fork length (FL) measured to nearest mm and weighed to nearest 0.1 g. 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) holding containers with high dissolved oxygen concentrations (110 – 130%) to recover from anesthesia effects. Holding containers were perforated, starting 15 cm from the bottom, to allow water exchange. The non-perforated section of the container held 7 L (1.8 gal) of water to allow transfer without complete dewatering. Each holding container was stocked with three tagged fish and covered with a snap-on lid. Holding containers were held in large round tanks until loaded for transport to the release site. Water levels were adjusted in these tanks to ensure that tagged fish had access to air to adjust their buoyancy and compensate for the weight of the transmitter. The dates and approximate times for each tagging session are listed in Table 2-1.

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. In the 21 separate releases, a total of 17 transmitters were found to be non-functional during this evaluation and these fish were removed from the study.

Table 2-1. Tagging, Transport, Holding, and Release Information for the Seven Sets of Fish Releases (released approximately every 6 hours over a 24-hour period) for VAMP in 2010

Durham Ferry												
				Release A		Release B		Release C		Release D		Fish Health
Tagging	Transport	Minimum Holding Time	Total released (A+B+C+D)	Date/Time	Number released	Date/Time	Number released	Date/Time	Number released	Date/time	Number released	Dummy tagged
Mon 4/26 0800 - 1252	Mon 4/26 1301 - 1340	4/26 1415 - 4/27 1400	74	4/27 1402, 1411	18	4/27 1954, 2001	18	4/28 0211	18	4/28 0809, 0812	20	10
Thurs 4/29 0800 - 1245	Thurs 4/29 1300 -1350	4/29 1415 - 4/30 1400	74	4/30 1407, 1408	18	4/30 1958, 1959	18	5/1 0200, 0201	18	5/1 0759, 0800	20	10
Mon 5/3 0800 - 1215	Mon 5/3 1230 -1315	5/3 1330 - 5/4 1400	73	5/4 1355, 1402	18	5/4 1958, 2004	18	5/5 0159, 0200	18	5/5 0759, 0800	19	10
Thurs 5/6 0800 - 1215	Thurs 5/6 1235 - 1315	5/6 1335 - 5/7 1400	70	5/7 1404, 1408	18	5/7 2004, 2005	18	5/8 0202, 0204	16	5/8 0802, 0803	18	10
Mon 5/10 0800- 1200	Mon 5/10 1215 -1258	5/10 1314 - 5/11 1400	70	5/11 1402	17	5/11 1959	17 *	5/12 0158, 0159	17	5/12 0759, 0801	19	10
Thurs 5/13 0800 - 1200	Thurs 5/13 1210 - 1255	5/13 1310 - 5/14 1400	73	5/14 1402	17	5/14 1959	18	5/15 0201, 0202	18	5/15 0759, 0801	20*	10
Mon 5/17 0800 - 1215	Mon 5/17 1225 - 1310	5/17 1330 - 5/18 1400	73	5/18 1401, 1402, 1403	17 (+3 intentional morts)	5/18 2000	18	5/19 0159, 0200	17	5/19 0759, 0801	18	10

* one mortality observed after transport but not included in the number released

Old River																
				Release A			Release B			Release C			Release D			Fish Health
Tagging	Transport	Minimum Holding Time	Total released (A+B+C+D)	Date/Time	Number released	Tidal condition at release	Date/ Time	Number released	Tidal condition at release	Date/Time	Number released	Tidal condition at release	Date/ Time	Number released	Tidal condition at release	Dummy tagged
Tues 4/27 0800 - 1115	Tues 4/27 1123 -1215	4/27 1249 - 4/28 1100	36	4/28 1103	9	slack before ebb	4/28 1703	9	slack before flood	4/28 2300	9	slack before ebb	4/29 0505	9	slack before flood	10
Fri 4/30 0800 - 1115	Fri 4/30 1130 - 1200	4/30 1239 - 5/1 1300	36	5/1 1305	9	slack before ebb	5/1 1903	9	slack before flood	5/2 0059	9	slack before ebb	5/2 0700	9	slack before flood	10
Tues 5/4 0800 - 1124	Tues 5/4 1140 - 1218	5/4 1237 - 5/5 1600	36	5/5 1603	9	slack before ebb	5/5 2207	9	slack before flood	5/6 0404	9	slack before ebb	5/6 0958	9	slack before flood	10
Fri 5/7 0800 - 1052	Fri 5/7 1109 - 1146	5/7 1204 - 5/8 1430	36	5/8 1434	9	slack before flood	5/8 2035	9	slack before ebb	5/9 0230	9	slack before flood	5/9 0830	9	slack before ebb	10
Tues 5/11 0800 - 1045	Tues 5/11 1105 - 1140	5/11 1157 - 5/12 1000	36	5/12 1002	9	slack before ebb	5/12 1559	9	slack before flood	5/12 2159	9	slack before ebb	5/13 0356	9	slack before flood	10
Fri 5/14 0800 - 1037	Fri 5/14 1045 - 1126	5/14 1138 - 5/15 1130	35	5/15 1135	9	slack before ebb	5/15 1733	9	slack before flood	5/15 2335	9	slack before ebb	5/16 0532	8	slack before flood	10
Tues 5/18 0800 - 1040	Tues 5/18 1100 - 1135	5/18 1200 - 5/19 1030	35	5/19 1027, 1028	9 (+3 intentional morts)	slack before flood	5/19 1629	9	slack before ebb	5/19 2239	8	slack before flood	5/20 0434	6	slack before ebb	10

Table 2-1 (cont.). Tagging, Transport, Holding, and Release Information for the Seven Sets of Fish Releases (released approximately every 6 hours over a 24-hour period) for VAMP in 2010

Stockton																
				Release A			Release B			Release C			Release D			
Tagging	Transport	Minimum Holding Time	Total released (A+B+C+D)	Date/Time	Number released	Tidal condition at release	Date/ Time	Number released	Tidal condition at release	Date/Time	Number released	Tidal condition at release	Date/ Time	Number released	Tidal condition at release	Fish Health Dummy tagged
Tues 4/27 1200 - 1345	Tues 4/27 1353 - 1455	4/27 1600 - 4/28 1500	36	4/28 1457	9	slack before flood	4/28 2102	9	slack before ebb	4/29 0311	9	slack before flood	4/29 0901	9	slack before ebb	10
Fri 4/30 1200 - 1345	Fri 4/30 1355 - 1450	4/30 1520 - 5/1 1630	36	5/1 1630	9	slack before flood	5/1 2232	9	slack before ebb	5/2 0432	9	slack before flood	5/2 1042	9	slack before ebb	10
Tues 5/4 1200 - 1340	Tues 5/4 1352 - 1445	5/4 1510 - 5/5 1400	35	5/5 1958	9	slack before ebb	5/6 0202	8	slack before flood	5/6 0801	9	slack before ebb	5/6 1401	9	slack before flood	10
Fri 5/7 1200 - 1325	Fri 5/7 1340 - 1430	5/7 1500 - 5/8 1800	36	5/8 1801	9	slack before ebb	5/8 0002	9	slack before flood	5/9 0600	9	slack before ebb	5/9 1200	9	slack before flood	10
Tues 5/11 1200 - 1421	Tues 5/11 1425 - 1524	5/11 1600 - 5/12 1400	35	5/12 1400	9	slack before flood	5/12 1953	9	slack before ebb	5/13 0206	8	slack before flood	5/13 0804	9	slack before ebb	10
Fri 5/14 1200 - 1347	Fri 5/14 1354 - 1445	5/14 1520 - 5/15 1600	34	5/15 1556	8	slack before flood	5/15 2159	9	slack before ebb	5/16 0415	9	slack before flood	5/16 1001	8	slack before ebb	10
Tues 5/18 1200 - 1303	Tues 5/18 1315- 1502	5/18 1522 - 5/19 1300	35	5/19 1253, 1254	9 (+3 intentional morts)	slack before ebb	5/19 1901	9	slack before flood	5/20 0102	9	slack before ebb	5/20 0701	5	slack before flood	10

Transportation to Release Sites

In order to minimize the stress associated with moving fish, specially designed transport tanks were used to move fish from TFCF to the release sites. The tanks were designed to securely hold a series of 19 L (5 gal) 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. Insulation was added to the exterior of the metal tanks to reduce water temperature fluctuations. Each transport tank was mounted on the bed of a flatbed truck that was equipped with an oxygen tank and hosing to deliver oxygen to the tanks during transport.

Buckets were removed from the holding tank at the TFCF and loaded into the transport tanks. Immediately prior to loading, all fish were visually inspected for mortalities or signs of poor recovery from tagging (e.g. erratic swimming behavior). Only one fish was removed for signs of poor recovery from the 21 release groups tagged at the TFCF. The approximate transport times are listed in Table 2-1. Temperature and dissolved oxygen (DO) in the transport tanks were recorded after loading buckets into transport tanks but before leaving the TFCF for the release site and at the release site prior to unloading (Table 2-2).

Table 2-2. Water Temperature and Dissolved Oxygen (DO) at the Tracy Fish Collection Facility Prior to Transport to the Three Release Sites, in the Transport Tank after Loading and after Transport, and in the River Immediately Prior to Placing the Fish in Holding Containers for Each of the Seven Release Groups and the Number of Mortalities after Transport, Just Prior to Release after the 24-hour Holding Period and the Dummy-tagged Fish after the 48-hour Holding Period

2010 VAMP Fish Releases into the San Joaquin River at Durham Ferry											
Transport Date	At Tracy Fish Collection Facility		Tank after loading		Tank after transport		# morts after transport	San Joaquin River at Durham Ferry			Dummy tag morts after 48 hrs
	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)		Temp (˚C)	DO (mg/L)	# morts just prior to release	
4/26/10	19.6	-	18.8	13.92	20.1	11.48	0	18.8	6.54	0	0
4/29/10	17.4	14.18	17.3	14.5	17.4	13.25	0	15.6	9.12	0	0
5/3/10	18.1	14.21	18.1	15.12	18.9	13.82	0	17.3	9.56	0	0
5/6/10	18.3	12.23	17.7	12	18.1	13.83	0	15.9	10.4	0	0
5/10/10	15.5	-	15	-	16.0	-	1	12*	-	0	0
5/13/10	17.5	11.34	17.7	15.35	18.3	15.33	1	16.0	11.5	0	0
5/17/10	18.4	8.5	16.5	12.27	16.5	14.11	0	16.8	9.8	0	0
Average	17.83	12.09	17.3	13.86	17.90	13.64		16.73	9.49		

2010 VAMP Fish Releases into Old River just Downstream of the Head of Old River											
Transport Date	At Tracy Fish Collection Facility		Tank after loading		Tank after transport		# morts after transport	Old River just Downstream of its Confluence with the Mainstem San Joaquin River			Dummy tag morts after 48 hrs
	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)		Temp (˚C)	DO (mg/L)	# morts just prior to release	
4/27/10	18.1	12.5	18	14.52	17.9	6.35	0	17.5	8.44	0	0
4/30/10	17	14.22	16.8	13.97	16.8	11.32	0	15.3	9.32	0	0
5/4/10	18.4	13.43	17.8	12.31	18.7	8.5	0	17.3	9.0	0	0
5/7/10	-	-	17.8	13.42	20.8	7.5	0	15.7	9.4	0	1
5/11/10	16.4	11.45	16.6	-	16.8	11.8	0	14.2	10.2	0	0
5/14/10	17.9	9.32	16.5	12.7	17.7	7.67	0	16.8	10.2	0	0
5/18/10	18.4	7.23	16.6	16	16.8	-	0	16.8	-	0	0
Average	17.70	11.36	17.16	13.82	17.93	8.86		16.23	9.43		

2010 VAMP Releases into the San Joaquin River near Stockton Waste Water Treatment Facility (STWWTF)											
Transport Date	At Fish Facility		Tank after loading		Tank after transport		# morts after transport	San Joaquin River near Stockton Wastewater Treatment Plant			Dummy tag morts after 48 hrs
	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)	Temp (˚C)	DO (mg/L)		Temp (˚C)	DO (mg/L)	# morts just prior to release	
4/27/10	18.2	13.72	18.2	14.6	18.3	10.89	0	18.1	7.49	0	0
4/30/10	18.4	13.17	18.1	12.9	18.7	14.07	0	16.8	9.39	0	0
5/4/10	19.3	13.38	17.9	13.24	18.2	14.07	0	18.3	7.74	0	0
5/7/10	18.4	14	16.9	13.84	18.1	15.2	0	17.2	9.67	0	0
5/11/10	18.1	8.41	17.5	15.35	17.8	12.63	0	15.6	8.94	0	0
5/14/10	18.7	10.3	17.2	15.19	17.9	12.04	0	18.1	10.50	0	0
5/18/10	19.2	6.9	18.1	11.29	18.8	9.35	0	18.5	8.52	0	0
Average	18.61	11.41	17.70	13.77	18.26	12.61		17.51	8.89		

* - Potentially an error in reading

Perforated buckets were removed from the transport tanks and carried to the river. For the releases at Old River, perforated buckets were placed into "sleeves" and transferred to a small boat for moving fish to the holding location. 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". Perforated buckets were carried to the river at the Durham Ferry site, usually without a "sleeve". The buckets were transferred from the truck at the Stockton release site using a similar procedure to that used at Old River; where they were placed in sleeves and transported by boat a short distance to the holding location. Water temperature and dissolved oxygen levels were measured in the river near the holding locations at each of the release sites prior to placing the fish into perforated plastic garbage cans in the river (see Table 2-2).

The tagged fish were transferred from buckets to 120 L (32 gal), perforated, plastic garbage cans for the 24-hour holding period. The perforated garbage cans had hole sizes of 0.95 or 0.64 cm. Three buckets, with usually three fish per bucket, were emptied into each trash can. Fish were held in the garbage cans for a minimum of 24 hours prior to release (see Table 2-1). Dummy tagged fish were treated similarly but were held for 48 hours. At least one person remained onsite for the duration of the holding period to ensure that study fish and equipment were not vandalized or otherwise tampered with.

During the holding and recovery period tagged fish were also monitored by a hydrophone installed at each of the release sites. This monitoring period allowed confirmation of the operational status of each transmitter prior to release. There were four tags not detected during the monitoring at the release sites; one from the 5th release into the San Joaquin River at Durham Ferry, one from the 6th release at Durham Ferry, one from the 1st release into the San Joaquin River near the Stockton Waste Water Treatment Facility (SWWTF) and one from the 7th release at the SWWTF. The undetected tags were noted in the database but were not used in the survival analysis (essentially removed from the release groups).

Releases

Seven releases were made between April 27th and May 19th at three separate sites; on the San Joaquin River at Durham Ferry (approximate river mile (RM) 66), Old River near its junction with the San Joaquin River (approximate RM 48) and on the San Joaquin River near the Stockton Wastewater Treatment Facility (SWWTF) (approximate RM 39) (see Figure 2-1). At Durham Ferry a total of approximately 74 fish were released per release period, while at Old River and San Joaquin River near the SWWTF, a total of approximately 36 fish were released per release period (see Table 2-1).

After the fish had been held for a 24 hour period, releases were done every six hours until all fish were released. Release times for Durham Ferry were set for 1400, 2000, 0200 and 0800 hours, while releases at Old River and SWWTF varied based on the tide (see Table 2-1). Releases at Old River and at the SWWTF were conducted three or nine hours after the high slack to release fish in the middle of the tide phase for each release. It was assumed that releasing fish during the middle of the tidal cycle would allow fish to move out of the release area before tides moved them too far upstream (flood tides) or downstream (ebb tides).

To assure the fish from the Durham Ferry releases did not experience mortality or differential mortality associated with potential operation of an agricultural pump located directly upstream of the release site and to minimize their exposure to predators that potentially congregated near the holding locations, a boat was used to transport tagged fish in the perforated 120 L (32 gal) containers downstream about 275 m (300 yds) before releasing them at RM 66. At the Old River and SWWTF release sites, boats were also used to move release groups downstream from the holding location prior to release; at the Old River release site the fish were moved downstream around the bend in Old River and the fish released near the Stockton WWTF were released about 60 m (200 ft) downstream of the

holding area. Prior to release, individual garbage cans were attached to the gunnel of the jon boat and transported to the center of the river channel. In addition, a sleeve (either another slightly larger un-perforated garbage can or a large plastic bag) was placed around the perforated garbage can to minimize the amount of water from within the perforated garbage can that seeped into the river as the can was being transported downstream to avoid having any potential predators, that had congregated near the holding area from following the cans downstream and eating the fish just moments after release. All releases were made in the center of each channel.

Once the release site was reached, the perforated garbage cans were lifted to the surface to allow most of the water to drain. This allowed the tagged fish to be observed just prior to release. Observations were conducted to determine if there was any mortality of tagged fish after the holding period and just prior to release. The time was noted for each release. Dead or impaired fish were collected and identified by tag period.

To determine the "behavior" of dead fish, a total of nine tagged salmon, three at each release location, were intentionally sacrificed immediately before release and released with the live study fish. The nine tagged salmon were euthanized by pithing the fish (inserting a dissecting probe through the top surface of the fish's head between and directly behind the eyes and pushing the probe back and forth) and using scissors to cut through all the gill arches on the left side of each fish. The intent of releasing dead fish with the live release groups was to evaluate how far downstream a dead fish could travel since detection of dead fish at a receiver would be perceived in the model as survival of a live fish. The shorter the distance that a dead fish travels, the less potential there is for the survival estimates to be biased by detection of dead fish

Dummy-Tagged Fish

In order to evaluate the effects of tagging, transportation, and release, several groups of fish were implanted with inactive, or dummy transmitters. Dummy tags were interspersed randomly into the tagging order for each release group. For each release, 10 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 48 hours, they were euthanized with MS-222, measured (FL to nearest mm) and examined qualitatively for percent scale loss, body color, fin hemorrhaging, eye quality, gill coloration and vigor (Table 2-3). Any mortality was also documented. Ten dummy-tagged fish from three groups (first, third and last) from each release location were examined for bacteriology, virology and gill ATPase.

Table 2-3. Characteristics Assessed for Chinook Salmon Smolt Condition

Character	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)

Receiver Deployment

The hydrophone receiver network shown in Figure 2-1 was developed as part of a series of VAMP biology group meetings involving SJRA partners along with agency representatives (NOAA, EPA, CDFG, USBR, DWR, USGS, etc.) and fishery modelers from the University of Washington. This also involved the other agencies conducting similar studies within the Lower San Joaquin River and Delta in an effort to maximize the data use between all groups. A hierarchy of study objectives was discussed in relation to the tradeoffs associated with a variety of different hydrophone placement scenarios. Principal objectives of the hydrophone layout for 2010 were to: (1) obtain fish survival estimates through the Delta from Durham Ferry and 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 and Turner Cut) (see Figure 2-1).

In past years VAMP relied on Natural Resource Scientists, Inc (NRS) to install and maintain the HTI acoustic equipment. However, in 2010, NRS could not provide this service so the United States Fish and Wildlife Service (USFWS), Stockton office took the primary responsibility for the installation and maintenance of the receivers with support from Normandeau and Associates (Stevenson, WA) and the United States Geological Survey (USGS) Columbia River Research Lab (CRRL). The USGS- Sacramento office installed and maintained the receivers located at Chipps Island during the 2010 VAMP study. Equipment at DWR and USBR facilities was installed and maintained by their own personnel.

As part of the 2010 VAMP program, twenty acoustic receivers were deployed at twelve locations within the San Joaquin River and Delta (see Figure 2-1). Sixteen of these receivers at ten locations were installed between March 21st and March 28th by USFWS staff. Three receivers were deployed by the USGS-Sacramento Office at Chipps Island (one location) and one receiver was deployed by the USBR in the holding tank at the Central Valley Project (CVP). There were an additional twelve receivers deployed at seven locations as part of the DWR temporary barriers study which were coordinated with the 2010 VAMP study in order to allow the use of the data from these receivers by both studies.

For the sixteen receivers deployed between March 21st and 28th, 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. Hydrophone locations were marked with an onboard GPS unit (Lowrance HDS-5). Each site contained a hydrophone, receiver, input/output box and 12V deep- cycle battery to power the equipment. All equipment was housed in a metal 'jobox' which was fabricated with a divider to facilitate holding the receiver in a water bath to eliminate overheating. The joboxes were modified using similar techniques to those described in Vogel (2010): 1) incorporating a water bath inside the joboxes, 2) cutting ventilation holes in the bottom and top for convection cooling, and 3) painting the exterior of the metal boxes with a ceramic heat-reflecting paint.

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. 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 activated on April 17th.

The location of some sites in 2010 differed slightly from 2009 to reduce noise observed in the data files at some locations in 2009. Sites that were moved for the 2010 VAMP study included San Joaquin River at Mossdale Bridge, San Joaquin River near Lathrop and San Joaquin River near Stockton Wastewater Treatment Facility. Additional sites were installed for 2010 VAMP study that were not part of the 2009 VAMP study. These included a single receiver in the San Joaquin River just downstream of the Banta Carbona intake structure and dual arrays at Medford Island and Threemile Slough. A dual

array at Chipps Island was also added in 2010. A listing of sites and their locations along with the site number assigned during data processing and survival modeling can be found in Table 2-4.

Table 2-4. Names and Description of Receivers and Hydrophones used in the 2010 VAMP Study, with Receiver Codes used in Figure 2-1, Survival Model (Figure 2-5), and in Data Processing at the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS) in Cook, Washington

Individual Receiver Name and Description	Hydrophone Location		Receiver Code shown in Figure 5-1	Survival Model Code Shown in Figure 5-5	Data Processing Code Used in Figures 5-3 and 5-4
	Latitude (°N)	Longitude (°W)			
San Joaquin River at Banta Carbona	37.72765	121.29860	BCA	A2	901
San Joaquin River at Mossdale	38.02502	121.46580	MOS	A3	902
San JoaquinRiver near Lathrop	37.82191	121.31868	SJ1	A4	903
San JoaquinRiver near Lathrop	37.82231	121.31734	SJ2	A4	904
San Joaquin River at Stockton USGS gauge	37.93341	121.32853	STS	A5	905
San Joaquin River at Stockton Navy Bridge	37.94656	121.33933	STN	A6	906
San Joaquin River at Shipping Channel Marker 18	38.02278	121.33490	C18	A7a	907
San Joaquin River at Shipping Channel Marker 16	38.02616	121.47000	C16	A7b	908
San Joaquin River at Medford Island, east	38.05221	121.51095	MFE	A8a	909
San Joaquin River at Medford Island, west	38.05318	121.51317	MFW	A8b	910
Old River near junction with San Joaquin River	37.81247	121.33541	OR1	B1	921
Old River near junction with San Joaquin River	37.81226	121.33532	OR2	B1	920
Old River South, upstream	37.82037	121.37796	ORSU	B2a	922
Old River South, downstream	37.81874	121.37992	ORSD	B2b	923
Old River North, upstream	37.89015	121.57244	ORNU	B3a	990
Old River North, downstream	37.89160	121.56845	ORND	B3b	991
Middle River South	37.83481	121.38370	MRS	C1	980
Middle River North, upstream	37.89002	121.48942	MRNU	C2a	983
Middle River North, downstream	37.89258	121.49063	MRND	C2b	984
Radial Gate at Clifton Court Forebay, upstream (in entrance channel to forebay)	37.82961	121.55695	RGU	D1	950
Radial Gate at Clifton Court Forebay, downstream (inside forebay) (2)	37.82987[a]	121.55767[a]	RGD	D2	951/952
Central Valley Project trashracks (2)	37.81682[a]	121.55856[a]	CVP	E1	961/962
Central Valley Project holding tank	37.81594	121.56140	CVPtank	E2	960
Turner Cut, northeast (upstream)	37.82187	121.31867	TCN	F1a	930
Turner Cut, southwest (downstream)	37.98997	121.46038	TCS	F1b	931
Chipps Island, east	38.04663[a]	121.89644[a]	CHPe	G1a	800
Chipps Island, west (2)	38.04609[a]	121.89644[a]	CHPw	G1b	810/915
Threemile Slough, south (not used in survival model)	38.09721	121.68549	TMS	T1a	940
Threemile Slough, north (not used in survival model)	38.11105	121.68351	TMN	T1b	941

[a] Average latitude and longitude given for sites with multiple hydrophones

Receiver Maintenance

Receiver sites were visited three days per week (Mon, Wed, Fri) from April 19th through June 15th. At each site, the receiver 'jobox' was opened and the battery was removed. Used batteries were recharged for use the following maintenance day. Maintenance of the receivers consisted of accessing the box, replacing the 12-volt battery with a fully charged battery, making sure the I/O box was functioning and determining if the beacon tag was present. Also, data already stored on the receivers was downloaded on each visit to a laptop using HTI software. For most of the sites, data were uploaded to a FTP site soon after collection.

Ten of the receivers (at six locations) were maintained by the USFWS, Stockton Office. These six locations were located on the San Joaquin River between Stockton and Threemile Slough. Five receivers (at three locations) were maintained by the CDFG, Region 4 office (Mossdale, Old River, and San Joaquin River near Lathrop). FISHBIO maintained the single receiver at Banta Carbona. Personnel from USGS, Sacramento Office deployed and maintained two four-port receivers and one single-port receiver near Chipps Island (3 receivers at one location). An additional twelve receivers at seven locations were maintained by DWR as part of their south Delta temporary barriers program and included receivers in (two receivers) and outside of Clifton Court Forebay (one receiver), Old (two receivers) and Middle River north (two receivers) and near the Old and Middle River confluence (three receivers at two locations) (see Figure 2-1 and Table 2-4). In addition, the two sites upstream and downstream of the trash rack (two receivers, one location) at the CVP were also maintained by personnel from DWR. An additional receiver was placed in the holding tank at the CVP Tracy Fish Facility and was maintained by USBR personnel.

Several of these sites required field crews to utilize boats to change batteries and retrieve data. Sites that were maintained using a boat were; San Joaquin River at Mossdale (MOS), Old River (OR1 and OR2), San Joaquin River at Lathrop (SJ1 and SJ2), Navy Drive Bridge (STN), Stockton (STS), channel markers 16 (C16) and 18 (C18), Medford Island ((MFE) and (MFW)) and Turner Cut ((TCS) and (TCN)). Three sites were accessible by vehicle. These sites included San Joaquin River at Banta Carbona (BCA), Threemile Slough south (TMS) and Threemile Slough north (TMN).

Temperature Monitoring

Water temperature was monitored during the 2010 VAMP 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 (Appendix B -Table 1 and Appendix B - Figure 1). Depth of the measurements varied from water surface level to approximately 4 feet below water surface level. As part of the 2010 VAMP monitoring program, additional temperature recorders were deployed in the south and central Delta to provide geographic coverage for characterizing water temperature conditions while juvenile salmon emigrate from the lower San Joaquin River through the Delta. Water temperature was recorded instantaneously at 24-minute intervals throughout the period of the 2010 VAMP investigations.

Two temperature recorders deployed as part of the 2010 VAMP temperature monitoring activities were vandalized making the data irretrievable. This resulted in missing temperature data for the Jersey Point USGS Gauging Station and Werner Cut temperature monitoring sites.

Tag Life Study

An in-tank tag life study was conducted to quantify the rate of tag extinction under the operating parameters used for the 2010 VAMP study following similar methods employed by the CRRL during the 2008 VAMP and FISHBIO during the 2009 VAMP (San Joaquin River Group Authority, 2010). A

stratified random sample of 55 tags was taken across 1,078 successfully programmed model 795 Lm tags acquired from HTI which were comprised of seven manufacturing lots. Tags were programmed with periods ranging from 4 to 10 seconds (sec), with a pulse width of 2 milliseconds (ms). The tag life study began May 26th and tags were programmed according to the same procedures used for the field study. Tags were secured to a PVC stand with hook and loop closure that was placed into the study tank immediately after programming.

Two independent detection systems were used to continuously monitor the tags. 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.

A recording thermograph was placed in the tank prior to tag initialization and temperature readings were logged every 60 minutes for the duration of the study.

Data Processing for Survival Analysis

Data collected at individual monitoring sites were transferred to the Columbia River Research Lab (CRRL) of the United States Geological Survey (USGS) 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's 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 a 30-day study with 20 receivers and 1000 tagged fish, visual inspection of each file using MarkTags would require 14.4 million (1000 tags in each of 24 hourly files for each of 30 days for each of 20 receivers) page-views in the MarkTags software. At an ambitious rate of 1 page viewed per second, it would require 4,000 hours of continuous, uninterrupted work to visually identify valid detections. The use of an automated process to identify fish detections clearly saved 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. If 100% accuracy must be achieved, then all the data must be processed manually. Manual processing of all the data was not an option for this study; however, the results of the automated processed files were compared to manually processed files for a limited number of sites to assess the accuracy of the auto processed files and to determine the need for manual processing in the future.

Two independent automated processes (hereafter referred to as automarking) were implemented to identify fish detections. Automarking utilizes algorithms to identify fish detections. For one of the automarking processes CRRL used modified algorithms and parameter settings within MarkTags. Over the past 15 years, USGS, CRRL has developed procedures to determine the optimal study-specific parameter specifications to optimize the use of MarkTags. The second automarking process (hereafter referred to as FishCount) used algorithms and parameters developed by USGS. During development of this new process, CRRL assessed the accuracy of finding fish detections by comparing the results against data that had been manually processed. While automarking greatly reduces the number of hours it takes to identify valid detections, the algorithms are complex, and the accuracy in identifying all possible valid detections in the data can vary. To ensure that the automated process was correctly identifying valid detections, all detections identified by MarkTags and all the detections identified by FishCount were manually verified, with the exception of the data collected at the five sites in the Clifton Court area (site numbers 950, 951, 952, 961, and 962 used in data processing1). Due to the nature of the data collected at the Clifton Court sites, the MarkTags process identified a relatively large number of false positive

detections (over 190,000). Since all false positive detections required manual verification, the number of false positive detections generated using MarkTags precluded manual verification of all of these detections. When the data from these sites were processed using the FishCount process, fewer false positives were identified (under 16,000). For the five sites in the Clifton Court area, FishCount was the only automated process used to identify valid detections, and all false positive detections were manual verified. Because two independent automated processes were used to identify detections in the data from all but 5 of the receiver sites, USGS conducted further analysis to compare the accuracy of the two processes. CRRL found that FishCount consistently found more valid detections (Figure 2-3) and fewer false positive detections than MarkTags (Figure 2-4).

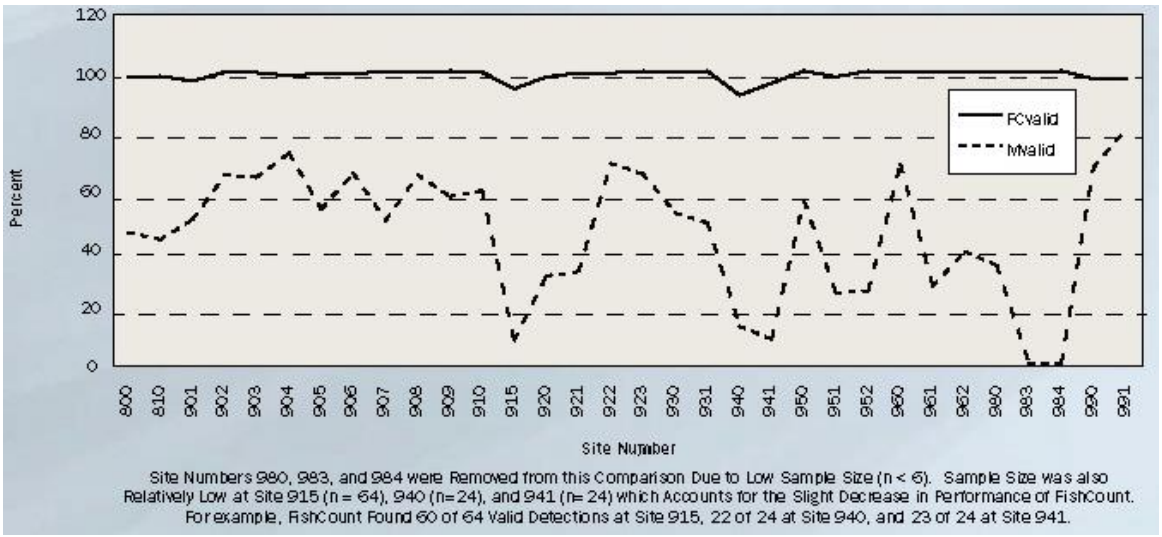


Fig 2-3 note: See Table 2-4 for comparison of site numbers with actual receiver site locations

Figure 2-3. Plot Showing the Percent (%) of Valid Detections Found by FishCount (solid line) and MarkTags (dashed line) for Each Receiver Site Number

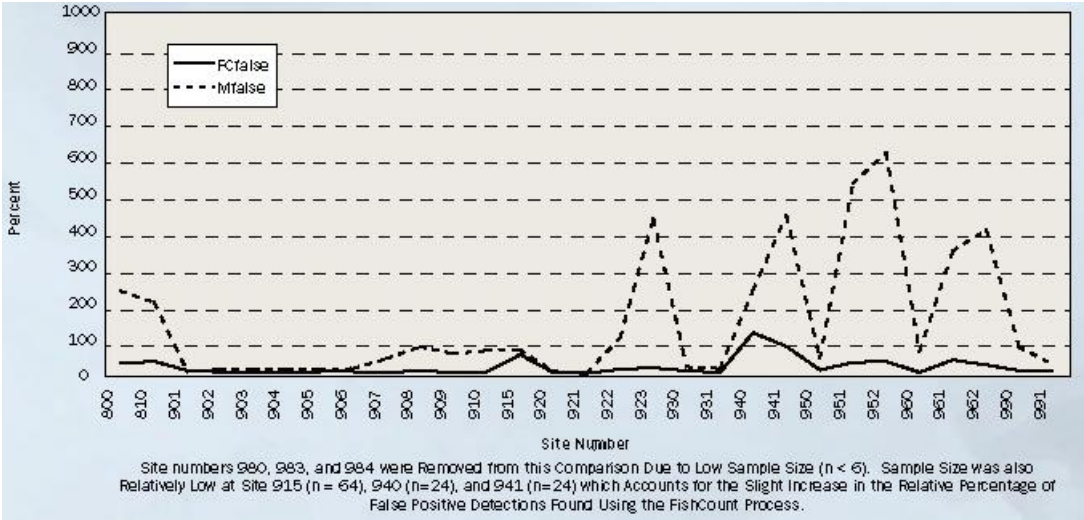


Fig 2-4 note: See Table 2-4 for comparison of site numbers with actual receiver site locations

Figure 2-4. Plot Showing the Percent (%) of False Detections Found by FishCount (solid line) and MarkTags (dashed line) for each Receiver Site Number

In addition to the autoprocessing, data from a subset of sites were manually processed: Old River (OR1 and OR2) (2 receivers), San Joaquin River at Lathrop (SJ1 and SJ2) (2 receivers), Chipps Island (CHPe and CHPw) (1 four port receiver and 1 single node) and San Joaquin River at Mossdale (MOS) (1 receiver). The objective of manually processing a subset of the stations was to; 1) determine differences in tag detections using autoprocessing versus manually processing to gauge the effectiveness of the autoprocessing, and 2) characterize the acoustic signal pattern of detections for use in classifying detections as salmon or predator detections (described below).

Tag code detections were compared between the manually processed and autoprocessed databases. Where differences in tag codes were apparent, tag codes were verified and these results were the basis of the comparisons at each receiver that was manually processed. Each method of processing was used to identify false negatives and false positives arising from the other processing method. While this provided some assessment of the error rate in both the autoprocessed and manually processed data, it did not identify errors made by both the autoprocessor and the manual processer. Other than at random, it is possible but unlikely both methods resulted in the same mistakes. Manual mistakes were also found in manual transcription but were counted as an error only if there was an error in the electronic database (bookmarks not properly constructed or erroneously constructed in database). Lastly, tag detections of the autoprocessed data were compared between redundant sets of receivers, taking into account any down time of the receivers.

The University of Washington received the primary database of autoprocessed detection data from the USGS- CRRL. 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 indicated 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 obvious invalid detections. In addition to the diagnostic comparisons between the two databases described above, the University of Washington identified potentially invalid detections based on unreasonable travel times or unlikely transitions between detections. The processor (USGS-CRRL or manual processor) then manually examined the raw data for the suspect detections to determine their validity. 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 period 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 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 positively 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, a decision process was used to classify detections as either likely to have come from live salmon smolts, or likely to have come from predatory fish. This decision process was applied to all detections of all tags. Two data sets were then constructed: the full data set included all detections, including those classified as coming from predators (i.e., "predator-type"), while the reduced data set was restricted to those detections classified as coming from live smolts (i.e., "smolt-type").

The survival model was fit to both data sets separately, and the resulting survival estimates were compared to assess the differences in survival between our best estimate of survival (without predator-type detections) and that using the uncorrected dataset.

The decision process used three levels of analysis: near-field, mid-field, and far-field (Vogel, 2010). The near-field analysis focused on movements of the tag within a short time period (no longer than one hour) within the detection range of the receiver. The mid-field analysis focused on movements of the tag among neighboring receivers and over a time scale of several hours to a day. Far-field analysis considered the movement of the tag throughout the study area. 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 2-5). Environmental data were downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/selectQuery.html) on January 4, 2011. River flow and water velocity were highly correlated at most environmental monitoring sites. All detections were considered when implementing the decision process, including detections from Threemile Slough that were otherwise excluded from the survival analysis, and detections at the Bio-Acoustical Fish Fence (BAFF) at the head of Old River.

Table 2-5. Environmental Monitoring Sites for River Flow, River Stage, and Water Velocity Used in Predator Decision Rule

Enivonmental Monitoring Site			Detection Site	Data Available		
Site Name	Latitude (°N)	Longitude (°W)		River Flow	Water Velocity	River Stage
OH1	37.8080	121.3290	OR1/OR2	Yes	Yes	Yes
OH4	37.8911	121.5692	ORN	Yes	Yes	Yes
OLD	37.8050	121.4490	ORS	No	No	Yes
ORI	37.8280	121.5526	CVP, RGU	Yes	Yes	No
MAL	38.0440	121.9190	CHP	No	No	Yes
MSD	37.7860	121.3060	MOS	Yes	Yes	Yes
PRI	38.0594	121.5572	C18/C16, MFE/ MFW	Yes	Yes	Yes
SJG	37.9350	121.3290	STS, STN	Yes	Yes	Yes
SJL	37.8100	121.3230	SJ1/SJ2	Yes	Yes	Yes
TRN	37.9928	121.4542	TCN/TCS	Yes	Yes	Yes
VNI	38.0500	121.4960	C18/C16	No	No	Yes

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 temporarily move upstream with the flow.

Movements and transitions between detection sites on the far-field scale were considered first. Tags that moved between sites quicker than a salmon were classified as predators upon arrival at the destination site. Conversely, tags were classified as predators upon arrival if they were observed moving very slowly between sites where most tags were observed to move quickly. The range of migration rates considered reasonable for a salmon smolt was selected based on conversations with Dave Vogel (Natural Resource Scientists, Inc.) and Brent Bridges (U.S. Bureau of Reclamation), and varied depending on location, water velocity, and flow volume (Table 2-6).

Table 2-6. Cutoff Values Used in the Predator Decision Rule

Release Site	Detection Site	Previous Site	Residence Time[a] (hr)	Travel Time (hr)		Migration Rate[b] (km/hr)		Flow at arrival[c] (cfs)	Comment
			Maximum	Minimum	Maximum	Minimum	Maximum		
DF	BCA	DF	1	3	20	0.5	3.5		
DF	MOS	BCA	1	3	33	0.3	3.5		
		DF	1	6	70	0.3	3.5		
DF	SJ1/SJ2	MOS	2	1.7	20	0.3	3.5		If not classified as predator at BAFF
		MOS	2	1.7	3	2	3.5	> 2800	If also classified as predator at BAFF
		MOS	2	2.5	20	0.3	2.5	< 2800	If also classified as predator at BAFF
		SJ1/SJ2	0	100[d]	0	100[d]	NA		
STK	SJ1/SJ2	STS	2	100[d]	0	100[d]	NA	> 50	
		SJ1/SJ2	0	100[d]	0	100[d]	NA		
DF	STS	SJ1/SJ2	2	NA	NA	NA	NA	> 3000	Flood tide after arrival: max residence time = 10
		SJ1/SJ2	NA	5	50	0.3	3		
		STS	NA	NA	NA	NA	NA		
STK	STS	STK	8.5	0	3.5	0.12	NA		STS is near STK
		STN	0	100[d]	0	100[d]	0		
DF	STN	STS	2	0.7	10	0.3	4		Flood tide after arrival: max residence time = 9
		STN	NA	NA	NA	NA	NA		
		SJ1/SJ2	2	10	60	0.3	4		
STK	STN	STK	10	0.5	9	0.3	3		Increasing tide after arrival: max residence time = 6
		STN	0	100[d]	0	20	0	> 500	
DF	C18/C16	C18/C16	0	100[d]	0	NA	NA		
		MFE/MFW	0	100[d]	0	NA	NA		
		STN	24	10	52	0.3	3.5		
		STS	24	12	61	0.3	3.5		
STK	C18/C16	STK	24	20	70	0.3	1		
		STN	24	7	52	0.3	2		
DF	MFE/MFW	C18/C16	24	NA	17	0.3	4		Maximum migration rate not firm cutoff
		MFE/MFW	0	100[d]	0	NA	NA		
STK	MFE/MFW	C18/C16	24	7	52	0.3	4		Maximum migration rate not firm cutoff
		MFE/MFW	0	100[d]	0	NA	NA		
DF	TCN/TCS	C18/C16	24	NA	NA	NA	NA	> 500	Positive flow = into San Joaquin
		STN	24	10	9	0.3	3.5	> 500	Positive flow = into San Joaquin
		STS	24	12	0	20	3.5	> 500	Positive flow = into San Joaquin
DF	TMN/TMS	MFE/MFW	10	NA	55	0.4	1		
STK		MFE/MFW	10	NA	55	0.4	1		
DF	OR1/OR2	MOS	0.5	1	4	1	4		Migration rate range depends on flow
		SJ1/SJ2	0.5	1	4	1	4		Migration rate range depends on flow
OR	OR1/OR2	OR	0.5	NA	1	0.4	NA		
		OR1/OR2	0	100[d]	0	100[d]	0		
		ORS	0	100[d]	0	100[d]	0		
DF	ORS	OR1/OR2	4	1.2	6	1	5		Lower migration rate ok if ebb changes to flood
		MOS	4	2	10	1	5		Lower migration rate ok if ebb changes to flood
OR	ORS	OR1/OR2	4	1.2	6	1	5		Lower migration rate ok if ebb changes to flood
		OR	4	2	7	1	5		Lower migration rate ok if ebb changes to flood
DF	MRN	TCN/TCS	5	NA	50	0.4	NA		
		MFE/MFW	0	100[d]	0	100[d]	0		Unlikely transition if migrating
		C18/C16	0	100[d]	0	100[d]	0		
STK	MRN	TCN/TCS	5	NA	50	0.4	NA		
		MFE/MFW	0	100[d]	0	100[d]	0		Unlikely transition if migrating
		C18/C16	0	100[d]	0	100[d]	0		
DF, OR	CVP	ORS	4[e]	NA	50	0.4	NA		
		ORN	4[e]	NA	24	0.4	NA		
		RGU	4[e]	NA	15	0.1	NA		
		CVP	0	100[d]	0	100[d]	0		
DF, OR	CVPtank	CVP	NA	NA	1	0.25	NA		
		ORS	NA	NA	53	0.3	NA		
		RGU	NA	NA	17	0.1	NA		
		ORN	NA	NA	30	0.3	NA		
DF, OR	ORN	ORS	24[e]	NA	85	0.3	NA		
		RGU	24[e]	NA	24	0.3	NA		
		ORN	48[e]	NA	NA	NA	NA		Regional residence time (multiple visits)
DF, OR	RGU	RGU	24[e]	NA	NA	NA	NA		Regional residence time (multiple visits)
		ORS	4[e]	NA	24	0.3-0.4	NA		
		ORN	4[e]	NA	12	0.6	NA		Expect transition on single tidal stage if pushed upriver
		CVP	4[e]	NA	15	0.1	NA		
DF, OR	RGD[f]	RGU	4	NA	5	NA	NA		
DF, STK	CHP	MFE/MFW	24[e]	20	150	0.3	2		
		C18/C16	24[e]	25	170	0.3	2		
DF, OR, STK	CHP	TMN/TMS	24[e]	14	95	0.3	2		
DF, OR	CHP	CVPtank	24[e]	5	NA	NA	NA		Lower travel time ok if with flow, smolt behavior
		ORN	24[e]	25	240	0.3	2		
DF, OR, STK	CHP	CHP	24[e]	NA	NA	NA	NA		Regional residence time (multiple visits)

a = residence time includes up to 12 hours missing between detections
b = Approximate migration rate was calculated on most direct pathway.
c = Flow condition, if any, must be exceeded for predator classification.
d = values of 100 were used as default cutoff values of minimum travel time and migration rate for transitions deemed unlikely for salmon smolts
e = look at raw observation data when interpreting residence time; was tag present continually, or moving with tide?
f = if concurrent detections at RGU and RGD, use migration rate to RGU and residence time at RGU to determine predation

Table 2-6 note: Values past the cutoff indicate a predator.

Abrupt changes in migration rate were also used to identify possible predator detections, if there was no alternative explanation for such a change (e.g., change in flow dynamics). A tag's regional residence time was considered, as well. For example, a tag that remained in the western Old River region, moving among the Central Valley Project Trash racks, Clifton Court Forebay access channel, and Old River at Highway 4 for more than one or two days would be classified as being in a predator upon one or more of those detections. The tag was first classified as a predator upon the first exhibition of predator-type behavior, with the acknowledged uncertainty that the salmon smolt may actually have been eaten sometime before the first obvious predator- type detection. River flow and water velocity were considered when assessing the tag migration rate and travel time for predator classification.

The mid-field analysis focused on the arrival and residence of a tag in the vicinity of a detection site, with all receivers comprising a dual or redundant array considered jointly. It was assumed that salmon would be more likely to be influenced by the river flow than predators, and less likely to move against the flow. Arrival timing at the San Joaquin River sites and some of the Old River sites was compared to the magnitude, direction, and rate of change of the river flow or water velocity measured every 15 minutes at the nearest monitoring site, if available. Tags that moved against the flow were classified as being in predators at the first detection after such a movement. An exception was made for tags that moved against low magnitude flow, or were observed to arrive or depart from a receiver immediately before or after a change in flow direction. Because of the complex hydrologic environment around the Central Valley Project Trash racks and the Clifton Court Forebay entrance, the flow patterns were not considered in assessing detections at these sites. Residence time at a site was also examined as part of the mid-field analysis, with very long residence times interpreted as indicative of predators. The prospect of a salmon being pushed back into range of a receiver by the flow, thus prolonging its perceived residence time at the site, was taken into account. On the other hand, a tag that was continuously within range of a receiver over a long period of time (e.g., multiple tidal cycles) was assumed to be in a predator upon departure from the receiver.

The near-field analysis focused on the movements of the tag in the vicinity of a single receiver. These movements were identified by the pattern of the acoustic signal, with signals characterized using the following coding scheme:

1 = Inverted signal < 30 minutes
  12 = Wavy signal < 30 minutes
  13 = Flat line signal < 30 minutes
2 = Inverted signal > 30 minutes
3 = Wavy signal > 30 minutes
4 = Combination of wavy and flat line signal > 30 minutes
5 = Flat line signal > 30 minutes
6 = Unknown

Codes 1 and 2 were interpreted as consistent with the directed behavior of a migrating salmon. Codes 4 and 5 were interpreted as consistent with the hovering or circling behavior of a predatory fish (e.g., striped bass) or a defecated tag that would indicate predation. A wavy signal (codes 12, 3) may indicate predator behavior, especially in a high flow setting, or smolt behavior in a low flow setting. Likewise, a short flat line signal (code 13) was deemed more likely to indicate a predator than a smolt. Near-field signal characteristics were considered in cases where classifications from the mid-field and far-field scales were uncertain. Near-field analysis using these codes was restricted to manually processed data from the Mossdale (MOS), Old River (OR1/OR2), and Chipps Island (CHPe/CHPw) receivers.

Additional near-field analysis was available for tags detected at the BAFF located at the head of Old River. As part of the non-physical barrier study, tags detected on the eight receivers located at the BAFF at the head of Old River were categorized as being in either salmon or predators upon leaving the barrier based on 2-dimensional tag tracks within the barrier region (similar to the near- field analysis described

above), and on tag detections downstream of the barrier region. These designations were considered in conjunction with flow magnitude and direction measured on the stream flow gauges at OH1 and SJL, tag migration rate through the reach including the non-physical barrier (i.e., Mossdale to either Lathrop or Old River sites OR1/OR2), and detections of the tag elsewhere in the study area. A tag with an especially low migration rate through the HORB area during a period of high flow, and classified as a predator in the non- physical barrier study, was classified as a predator for the survival study upon arrival at the downstream end of the reach. Conversely, a tag with an especially high migration rate through that area during a period of low flow and classified as a predator in the non-physical barrier study, was also classified as a predator upon arrival downstream for the survival analysis.

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 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, and not 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.

All detections on the receivers in the western part of the Delta (CVP, RGU/RGD, ORNU/ORND, MRNU/MRND, MRS), at Threemile Slough (TMS), and at Chipps Island were examined in detail. Detections at ORS, OR1/OR2, and the San Joaquin receivers were examined only if the travel time or residence time was markedly different from the majority of detections at those sites. Criteria used as cutoff values for travel times, migration rates, and residence times for salmon smolts (see Table 2-6) were determined based on conversations with Dave Vogel of Natural Resource Scientists and Brent Bridges of the U.S. Bureau of Reclamation.

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. 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 two receivers located near Lathrop in the San Joaquin River (SJ1 and SJ2), from the two receivers located at the head of Old River (OR1 and OR2), from the two receivers located at the Central Valley Project trash racks (CVP), and from the two receivers located inside the Clifton Court Forebay outside the State Water Project (RGD).

Survival Model

A multi-state statistical release-recapture model was developed and used to estimate salmon smolt survival and migration route parameters throughout the study area. The release-recapture model was similar to the model developed by Perry et al. (2010) and the model developed for the 2009 VAMP study (San Joaquin River Group Authority, 2010). Figure 2-5 shows the layout of the receivers with the labels used in the survival model (Table 2-4)[2]. The survival model represented movement and survival throughout the study area to a single exit point at Chipps Island (Figure 2-6). Individual receivers comprising dual arrays were identified separately, with “a” representing the upstream receiver and “b” representing the downstream receiver. Fish moving through the Delta toward Chipps Island may use any of several routes. The simplest route followed the San Joaquin River until it joins the Sacramento River just upstream of Chipps Island (Route A). An alternative route used Old River, from its head on the San

[2] Various site identities were used during the 2010 VAMP study for receiver placement, data storage, data analysis and survival modeling. A listing of all identifiers used during the 2010 VAMP study is shown in Table 2-4.

Joaquin River just upstream of Lathrop to its confluence with the San Joaquin River just downstream of Mandeville Island (Route B). Route C entered Middle River from Old River. Two possible routes used the water export facilities off of Old River; fish entering either the State Water Project (Route D) or the Central Valley Project (Route E) had the possibility of being trucked from those sites and released just upstream of Chipps Island. Finally, fish that remained in the San Joaquin River past Stockton may have entered Turner Cut and maneuvered to Chipps Island through the interior of the Delta (Route F). Fish in routes B, C, and F all had multiple unmonitored pathways available for passing through the Delta toward Chipps Island. The survival model named detection sites (receivers) according to route, with Chipps Island assigned its own route name (G). An additional set of receivers located in Threemile Slough (Route T) was not used in the survival model. The routes and the study area exit point 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 = Chipps Island; exit point
T = Threemile Slough: not used in survival model

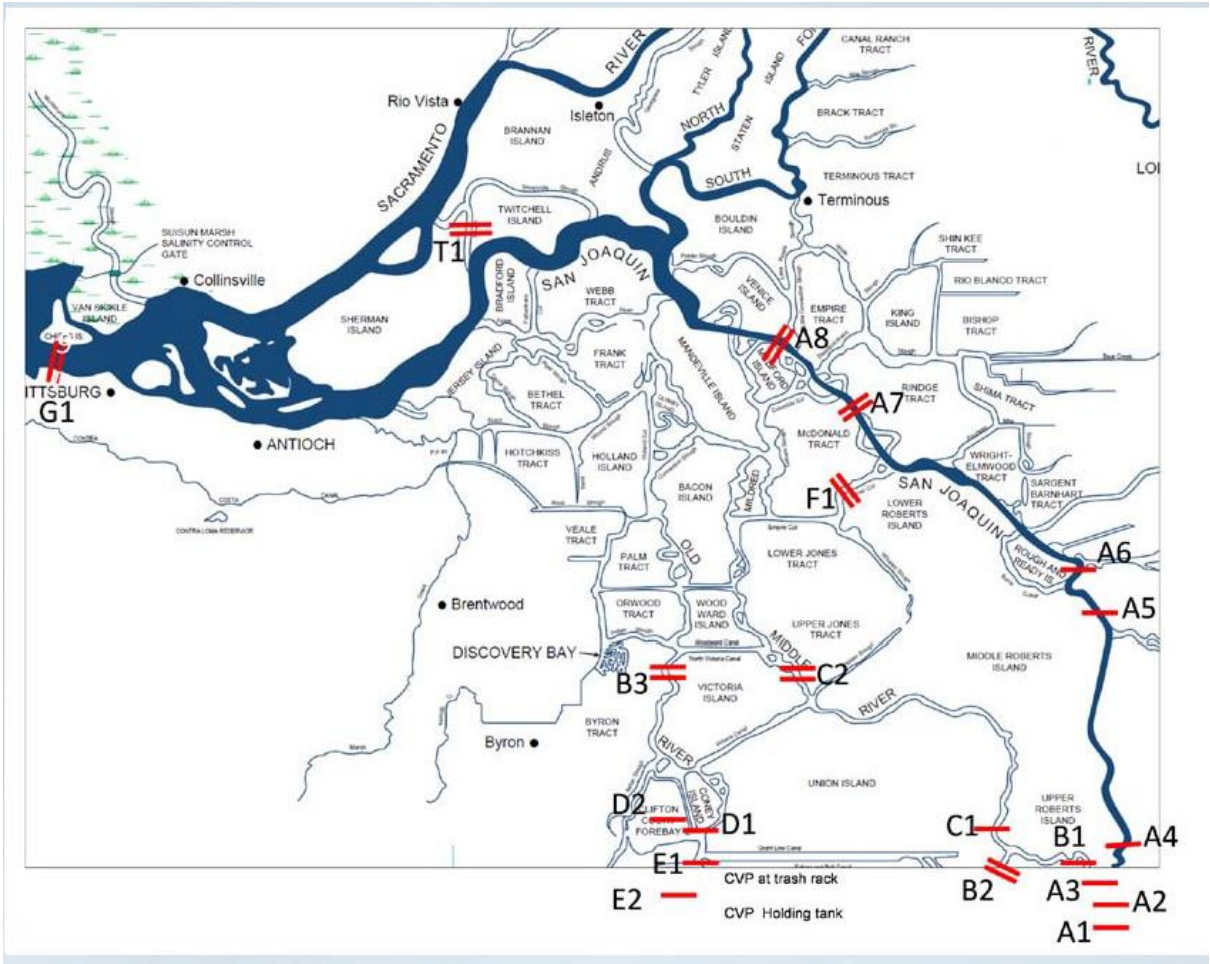


Fig 2-5 note: Site A1 is the release site at Durham Ferry. Site T1 was excluded from the survival model. (See Table 2-4 for a complete listing of codes used in the survival model.)

Figure 2-5. Locations of Acoustic Receivers ("Detection Sites") Used in the Statistical Survival Model for the 2010 VAMP Study including Locations of Acoustic Receivers Installed and Maintained by the California Department of Water Resources for the South Delta Temporary Barriers Study

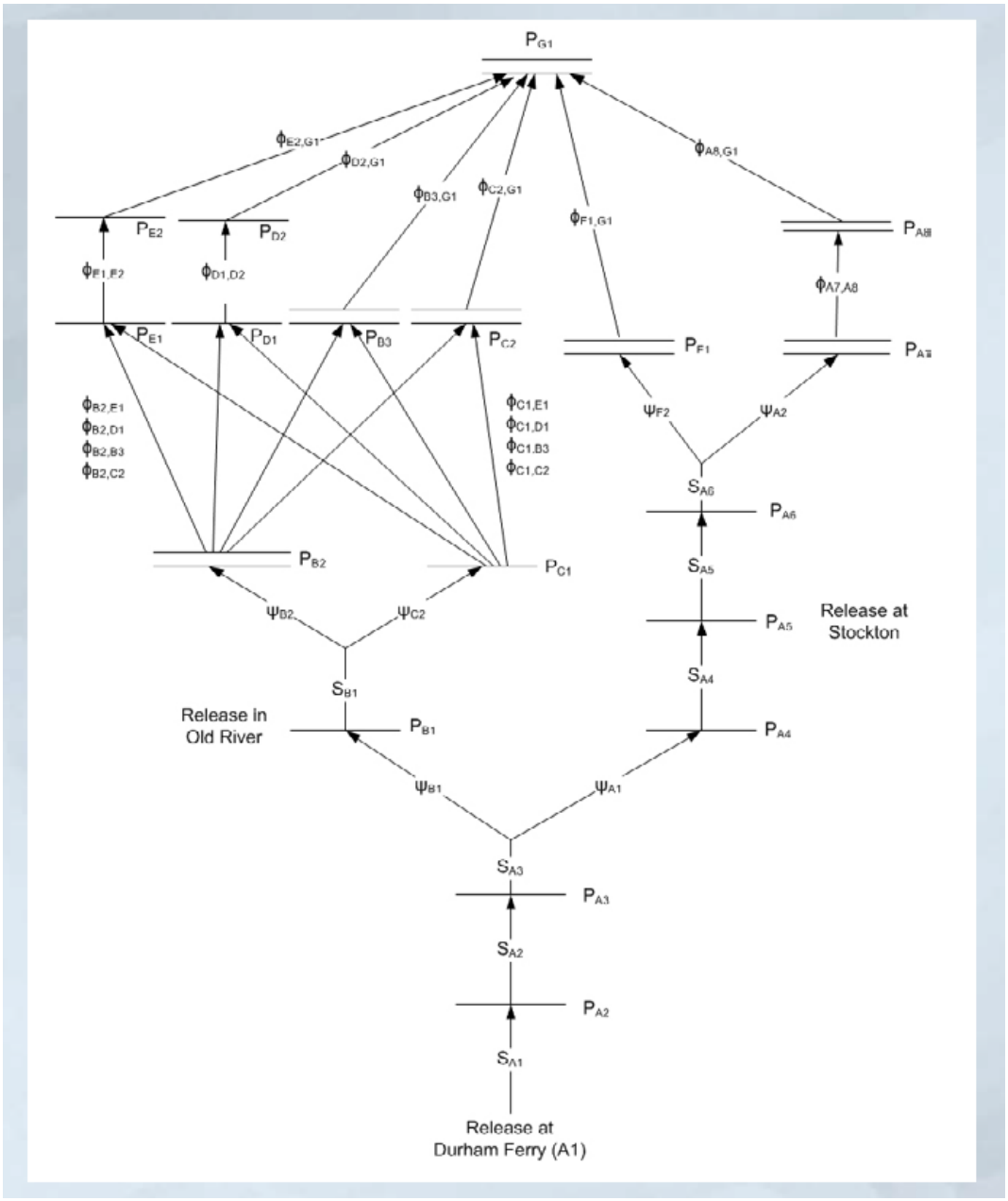


Fig 2-6 note: Parameters include Probabilities of Survival (S_{hi}), Route Entrainment (Ψ_{hi}), Transition ($\varphi_{kj,hi}$), Detection (P_{hi}). Single lines denote single-array telemetry stations, and double lines denote dual-array telemetry stations. Names of telemetry stations correspond to site labels in Figure 2-5. Parameters $\varphi_{B2,D1}$, $\varphi_{C1,D1}$, P_{D1} and $\varphi_{D1,D2}$ were estimated separately for arrival at D1 when the redial gates were open versus closed.

Figure 2-6. Schematic of Mark-Recapture Model Showing Estimable Parameters for Acoustically Tagged Juvenile Chinook Salmon Tagged and Released in the 2010 VAMP, Using the Layout of Telemetry Stations in Figure 2-5

The release-recapture model used parameters that denoted 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 ($\varphi_{kj,hi}$) (see Figure 2-6, and Appendix C-Table 1). 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 113 parameters for each release occasion: 44 detection probabilities, 8 survival probabilities, 18 route entrainment probabilities, and 43 transition probabilities.

The model parameters were:

P_{hi} = probability of detection at telemetry station i within route *h*, conditional on surviving to station i; for a dual array, *i = ia, ib* for the upstream, downstream receivers in the 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), conditional on fish surviving to junction *l*.

$\varphi_{kj,hi}$ = 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 transition and detection parameters involving the receiver 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), they could linger in the area until the gates opened, and many appeared to do so. Thus, parameters $\varphi_{B2,D10}$ $\varphi_{C1,D10}$ $\varphi_{D10,D2}$ and P_{D10} represented transition to and from site D1 and detection at D1 when the gates were open, and parameters $\varphi_{B2,D1C}$ $\varphi_{C1,D1C}$ $\varphi_{D1C,D2}$ and P_{D1C} represented transition to and from D1 and detection at D1 when the gates were closed. It was not possible to estimate unique detection probabilities for the open and closed status, so only a single detection probability was estimated for site D1, regardless of gate status: $P_{D10} = P_{D1C} = P_{D1}$. Additionally, it was assumed that the detection probability was 100% at both RGD (the radial gate receivers inside Clifton Court Forebay; $P_{D2} = 1$) and CVPtank (the receiver in the holding tank at the Central Valley Project; $P_{E2} = 1$). These assumptions were necessary in the absence of receivers located downstream of those detection sites and unique to those routes.

In some cases, it was not possible to separately estimate the transition or survival probability to a site and the detection probability at the site. This occurred for CVP (Trash rack receiver at the Central Valley Project, site E1) when no tags were detected at both CVP and CVPtank (site E2), and for RGU (outside the radial gates in the entrance channel to the Clifton Court Forebay, site D1) when no tags were detected at both RGU and RGD (site D2). In these cases, a "last reach" parameter was estimated in place of $\varphi_{kj,hi}$ and P_{hi}:

$\lambda_{kj,hi}$ = last reach parameter: joint probability of migration and survival from site *j* in route *k* to site *i* in route *h*, and detection at site *i* in route *h*.

In addition to the basic model parameters, derived performance metrics measuring migration route probabilities and survival were estimated as functions of the model parameters. The probability of taking the San Joaquin River route (Route A) was $\psi_A = \psi_{A1}$. The probability of using the Old River route (Route B) was $\psi_B = \psi_{B1}\,\psi_{B2}$. The probability of using the Middle River route (Route C) was $\psi_C = \psi_{B1}\,\psi_{C2}$. The probability of surviving from the entrance of the Delta (site A3, MOS) through an entire migration pathway to Chipps Island was estimated as the product of survival probabilities that trace each pathway:

$$S_A = S_{A3}\,S_{A4}\,S_{A5}\,S_{A6,G1}$$
$$S_B = S_{A3}\,S_{B1}\,S_{B2}$$
$$S_C = S_{A3}\,S_{B1}\,S_{C1}$$

The survival probability $S_{A6,G1}$ represented the overall survival from site A6 (STN) on the San Joaquin River to Chipps Island (CHP, site G1). Fish at site A6 either remained in the San Joaquin River at the flow split with Turner Cut with probability ψ_{A2}, or entered Turner Cut with probability $\psi_{F2} = 1-\psi_{A2}$ (see Figure 2-5, Figure 2-6). Thus, the overall probability of surviving from A6 to Chipps Island was defined as

$$S_{A6,G1} = S_{A6}(\psi_{A2}S_{A7,G1} + \psi_{F2}\varphi_{F1,G1}).$$

There were multiple migration routes between site A7 (C16/C18) and Chipps Island, and most of these routes were unmonitored. Thus, it was not possible to estimate route selection and route-specific survival along each individual route. However, it was possible to estimate the overall survival from site A7 to Chipps Island ($S_{A7,G1}$), and this survival probability was used to define $S_{A6,G1}$ above. Site A8 (Medford Island) on the San Joaquin River provided estimation of the joint probability of remaining in the San Joaquin River after site A7, and surviving to Chipps Island: $S_{A7,G1} = \varphi_{A7,A8}\varphi_{A8,G1}$.

Survival probabilities S_{B2} and S_{C1} represented survival of fish that remained in Old River at B2 (ORS), or entered 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) (see Figure 2-5, Figure 2-6). Each of these routes leads eventually to Chipps Island (G1). 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 $\varphi_{kj,hi}$ parameters defined above and in Figure 2-6). However, the overall survival from B2 (S_{B2}) or C1 (S_{C1}) to Chipps Island could be defined by summing products of the $\varphi_{kj,hi}$ parameters:

$$S_{B2} = (\varphi_{B2,D10}\varphi_{D10,D2} + \varphi_{B2,D1C}\varphi_{D1C,D2})\varphi_{D2,G1} + \varphi_{B2,E1}\varphi_{E1,E2}\varphi_{E2,G1} + \varphi_{B2,B3}\varphi_{B3,G1} + \varphi_{B2,C2}\varphi_{C2,G1}$$

$$S_{C1} = (\varphi_{C1,D10}\varphi_{D10,D2} + \varphi_{C1,D1C}\varphi_{D1C,D2})\varphi_{D2,G1} + \varphi_{C1,E1}\varphi_{E1,E2}\varphi_{E2,G1} + \varphi_{C1,B3}\varphi_{B3,G1} + \varphi_{C1,C2}\varphi_{C2,G1}$$

For fish that reached the interior receivers at the State Water Project (D2) or the Central Valley Project (E2), the parameters $\varphi_{D2,G1}$ and $\varphi_{E2,G1}$, respectively, represented the joint probability of migrating and surviving to Chipps Island, including survival during and after collection and transport.

Using the estimated migration-route probabilities and route-specific survival for these three routes (A, B, and C), survival of the population from A3 (Mossdale) to Chipps Island was estimated as:

$$S_{total} = \psi_A S_A + \psi_B S_B + \psi_C S_C.$$

In order to compare 2010 VAMP study results with results from the 2009 VAMP study, when no detections were available from Chipps Island, "regional" survival was also estimated through the southern portion of the Delta, both within each route and overall:

$$S_{A(region)} = S_{A3}S_{A4}S_{A5}S_{A6}$$
$$S_{B(region)} = S_{A3SB1}(\varphi_{B2,B3}+\varphi_{B2,D10}+\varphi_{B2,D1C}+\varphi_{B2,E1}+\varphi_{B2,C2})$$
$$S_{C(region)} = S_{A3}S_{B1}(\varphi_{C1,B3}+\varphi_{C1,D10)}+\varphi_{c1,d1c}+\varphi_{C1,E1}+\varphi_{C1,C2})$$
$$S_{total} = \Psi_A S_{A(region)}+\Psi_B S_{B(region)}+\Psi_C S_{C(region)}$$

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 A3 A4 A5 A7ab A8b0 G1a0 represented a tag that was released at Durham Ferry and detected at Mossdale (MOS, site A3), and then

moved through the San Joaquin River to Chipps Island with detections on the receivers at Lathrop (SJ1/SJ2, A4), the USGS gauge in Stockton (STS, A5), the shipping channel markers in the San Joaquin River just downstream of the junction with Turner Cut (C16/C18, sites A7a and A7b), and the Medford Island west receiver (MFW, A8b). The tag was finally detected on the eastern string of receivers at Chipps Island (G1a). This tag evaded detection at some receivers, namely Banta Carbona (BCA, site A2), the receiver at the Navy Bridge in Stockton (STN, A6), the eastern receiver at Medford Island (MFE, A8a), and the western receiver at Chipps Island (CHPw, G1b). The probability of having this detection history was

$$S_{A1}(1-P_{A2})S_{A2}P_{A3}S_{A3}\Psi_{A1}P_{A4}S_{A4}P_{A5}S_{A5}(1-P_{A6})S_{A6},\Psi_{A2}P_{A7a}P_{A7b}$$
$$\times\ \varphi_{A7,A8}(1-P_{A8a})P_{A8b}\varphi_{A8,G1}P_{G1a}(1-P_{G1b})$$

A second example is the detection history STK A6 F1ab. This detection history represented a tag that was released in a supplemental release at Stockton, and detected on the Navy Bridge receiver in Stockton (STN, A6) and on both receivers in Turner Cut (TCN and TCS, F1a and F1b). This tag was not detected again after detection in Turner Cut. The next available detection site after Turner Cut was Chipps Island, and the tag was not detected there either because it did not reach Chipps Island (mortality), or because it evaded detection as it passed Chipps Island (imperfect detection). Thus, this detection history has probability

$$\varphi_{STK,A6}P_{A6}S_{A6}(1-\Psi_{A2})P_{Fla,Flb}[1-\varphi_{F1,G1},+\varphi_{Fl,G1}(1-P_{G1a})(1-P_{G1b})$$

A third example is the detection history OR B1 B2a0 E1 E2 G1ab. This tag was released in a supplemental release in Old River, and was observed moving past receivers in the Old River route to Chipps Island. The tag was detected at the receivers just downstream from the head of Old River (OR1/OR2, site B1), the upstream receiver of the pair located in Old River just past the junction with Middle River (ORSU, B2a), the receivers at both the Central Valley Project trash rack (CVP, E1) and the Central Valley Project holding tank (CVPtank, E2), and finally at both receivers at Chipps Island (G1a, G1b). The tag was not detected on the downstream receiver at the ORS station (site B2b), but was assumed to be present there because of detection on the upstream receiver. This detection history has probability

$$\varphi_{OR,B1}P_{B1}S_{B1}\Psi_{B2}P_{B2a}(1-P_{B2b})\varphi_{B2,E1}P_{E1}\varphi_{E1,E2}\varphi_{E2,G1}P_{G1a}P_{G1b}$$

A final example of a detection history is DF A2 A3 C1 D1O D2. This tag was released at Durham Ferry and detected at both Banta Carbona (A2) and Mossdale (A3) before entering Old River, moving to Middle River (C1), and finally being detected on the receivers both outside and inside the radial gates at the Clifton Court Forebay (D1 and D2). The tag arrived at the outside receiver when the gate was open, denoted by D1O in the capture history. The tag evaded detection at the Old River receivers just downstream of the head of the river (B1), but was assumed to have passed those receivers because it was detected both upstream and downstream. This detection history has probability

$$S_{A1}P_{A2}S_{A2}P_{A3}(1-\Psi_{A1})1-P_{B1})S_{B1}(1-\Psi_{B2})P_{C1}\varphi_{C1,D10}P_{D1}\varphi_{D10,D2}$$
$$\times\ [1-\varphi_{D2,G1}+\varphi_{D2,G1}(1-P_{Gla})(1-P_{G1b})$$

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

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, developed at the University of Washington (Lady et al., 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). Sparse data meant that some parameters could not be estimated for some release strata. 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 occasion, consisting of the initial release at Durham Ferry and the associated supplemental releases at Stockton and in Old River. For each release occasion, the complete data set that included possible detections from predatory fish was analyzed separately from the reduced data set that was restricted to detections classified as salmon smolt detections.

Several steps were used to find the most parsimonious model that sufficiently represented the observed data. In all steps, the Akaike Information Criterion (AIC) was used to select between competing models, with a difference of $\Delta AIC \geq 2$ used to indicate a significant difference in model fit (Burnham and Anderson, 2002). First, the significance of the radial gates status on arrival at the outside receiver (RGU, site D1) was tested for all release groups pooled, with supplemental releases modeled separately from Durham Ferry releases. If the effect of the gates was found to be insignificant ($\alpha = 0.05$), then a simplified model was used for parameter estimation in which $\varphi_{B2,D1O} = \varphi_{B2,D1C}$, , $\varphi_{C1,D1O} = \varphi_{C1,D1C}$, and $\varphi_{D1O,D2} = \varphi_{D1C,D2}$.

Subsequent analysis focused on unique release occasions, with the Durham Ferry, Old River, and Stockton releases from a single release occasion analyzed jointly. A unique sequence of models was fit for each release occasion:

Model 1: The supplemental releases at Old River and Stockton were modeled with unique parameters compared to the initial release at Durham Ferry.

Model 2a: Unique parameters were used to model the supplemental releases, with the exception that the Stockton supplemental release group and the Durham Ferry release group were modeled with common detection probabilities at common detection sites.

Model 2b: Either Model 1 or Model 2a, as selected by AIC, was modified to use common detection probabilities for the Durham Ferry release group and the Old River supplemental release group.

Model 3a[i]: The model selected by AIC among the above models was modified sequentially to use common survival, route entrainment, and transition probabilities for parameter i for the Durham Ferry release and the Stockton supplemental release group, starting with downstream parameters and sequentially working back upstream. For example, Model 3a[$\varphi_{A8,G1}$] used unique survival, route entrainment, and transition probabilities for all parameters except for $\varphi_{A8,G1}$, which was equated between the Durham Ferry release group and the Stockton supplemental release group. If Model 3a[$\varphi_{A8,G1}$] was selected, then Model 3a[$\varphi_{A7,A8}$] was tested, in which the transition parameter $\varphi_{A7,A8}$ was equated for the Durham Ferry and Stockton releases. If Model 3a[$\varphi_{A8,G1}$] was not selected by AIC, then Model 3a[$\varphi_{A7,A8}$] was not tested, under the assumption that differences in survival in a downstream reach imply differences in survival in all upstream reaches. All survival, route entrainment, and transition probabilities were sequentially tested working upstream until either a significant difference was found or until the parameter S_{A6} was tested.

Model 3b[i]: The model selected from the sequence of 3a[i] models was modified sequentially to use common survival, route entrainment, and transition probabilities among reaches for the Durham Ferry release and the Old River supplemental release group. Again, downstream reaches were tested first, with upstream reaches tested only if models equating downstream parameters were selected over models with unique parameters. The farthest upstream parameters to be tested were

$\varphi_{B2,i}$ and $\varphi_{C1,i}$, for i = B3, C2, D1O, D1C, and E1. The parameters S_{B1} and ψ_{B2} were not tested because the reach between B1 and the B2/C1 receivers was very close to the site of the Old River supplemental release.

Final estimation of the parameters used the result of the model sequence described above, with AIC used in model selection. For each model, goodness-of-fit was assessed visually using Anscombe residuals (McCullagh and Nelder, 1989). For each release occasion, derived parameters $S_{A6,G1}$, S_{B2}, and S_{C1} were estimated for the supplemental releases and for the Durham Ferry release separately using the selected model, and then combined in a weighted average over the initial and supplemental releases. In particular, if $\hat{\theta}_i$ is the estimate of the measure θ for release group i (i = DF or STK) for a specific release occasion, then the occasion-specific measure was estimated as

$$\hat{\theta} = w_{DF}\hat{\theta}_{DF} + w_{STK}\hat{\theta}_{STK}$$

where w_i is the proportion of all fish estimated to have arrived at site A6, that came from release i (i = DF or STK). Similarly, if $\hat{\theta}_i$ is the estimate of measure θ for release group i (i = DF or OR) for a release occasion, then the occasion-specific measure was estimated as

$$\hat{\theta} = w_{DF}\hat{\theta}_{DF} + w_{OR}\hat{\theta}_{OR}$$

where w_i is the proportion of all fish estimated to have arrived at site B1 that came from release i (i = DF or OR). Standard errors were estimated using the delta method (Seber, 2002: 7-9). Population-level estimates of parameters and performance measures were estimated as a weighted average of the release-occasion estimates, with weights proportional to total release size for a given occasion (i.e., total of Durham Ferry, Old River, and Stockton releases).

For each release group, the effect of 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

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

The parameter V was estimated using Program USER. It was also tested whether tagged Durham Ferry fish 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:

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

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

Analysis of Tag Failure

The estimated survival and transition probabilities were adjusted for premature tag failure using methods adapted from Townsend et al. (2006). Tag survival was modeled using the 4-parameter vitality

curve (Li and Anderson, 2009) together with results from the tag-life study. Two tags in the tag-life study were observed to die within 25 hours of tag activation (see tag life study results in a later section). Because these deaths occurred within the recovery period allowed for the tagged fish between tagging, tag activation, and release to the river, all tagged salmon smolts that were released were known to have tags that had survived this initial period of premature tag death. Thus, these two tags were omitted from the tag-life data when fitting the tag-survival model. Additionally, because all detection events of tagged fish in the study area began before Day 40, the final 5 tag death times were omitted from the tag-life study because they reduced the fit of the tag survival model (see tag life study results in a later section).

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 (i.e., San Joaquin route [A] and Old River route [B]), travel time and the probability of tag survival to Chipps Island were estimated separately for the two routes. 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 is expected to be small.

Analysis of Tagger Effects

Tagger effects were analyzed by fitting the release- recapture model to the detection data from each tagger separately, pooling over release occasion. The significance of the tagger effect on model fit was assessed using a Likelihood Ratio Test (α=0.05) (Sokal and Rohlf, 1995). Additionally, estimates of cumulative survival throughout the study area were compared visually among taggers. The reduced data set (without predator detections) 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 arithmetic mean was used to summarize travel times.

Comparison of NPB Fate Assignment and VAMP Detections

Salmon tags that were released at Durham Ferry were available to pass both the non-physical barrier (NPB) at the head of Old River (sometimes called the Bio-Acoustical Fish Fence (BAFF)) and either the Lathrop receivers (SJ1/SJ2) in the San Joaquin River or the Old River receivers OR1/OR2. Detections of these tags at the Lathrop and Old River receivers were compared to the fate classification given to each fish observed in the NPB study at the Old River Barrier (ORB) area. Both the NPB study and the 2010 VAMP study independently identified route selection (San Joaquin River or Old River) at the head of Old River for all fish detected passing through this area; these independent route assignments were compared. Additionally, the survival model assumes 100% survival from the head of Old River to the receivers at Lathrop and Old River (OR1/ OR2), or alternatively equal survival in each route to the detection sites. This assumption was also assessed using detections from the NPB study and the VAMP receivers downstream of the HORB area. Differences in predator classification were taken into account for these comparisons. The assessment of survival focused only on those tags classified as both entering the HORB

area in smolts (based on VAMP classifications) and also leaving the HORB area in smolts (based on NPB classifications).

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 CCFB, and (3) the San Joaquin River from Old River downstream to Turner Cut (see Figure 2-1). Weekly surveys were conducted in each reach between May 3rd and June 3rd with the exception that the reach between Banta Carbona and Old River was not surveyed during the week of May 3rd due to the reported high survival rates down to the non-physical barrier at Old River. The reach of the San Joaquin River between Durham Ferry and Banta Carbona was surveyed on May 24th after all tagged fish had been released.

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, anchor 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 manually processed to identify tag detections.

Study Results and Discussion

Transportation

Average water temperature in the transport tank, after buckets were loaded and prior to transport, was approximately 17 °C (range between 15 and 18.8 °C) and dissolved oxygen was approximately 13 mg/l (range between 11.3 and 15.4 ºC). Over the course of the 45-60 minute drive from TFCF to the release sites, water temperatures in the transport tanks changed by -0.1 to 1.3 °C (see Table 2-2).

Water temperatures in the river were about 17 °C and ranged between 12.0 and 18.8 °C (see Table 2-2). The temperature reading of the 12.0 ºC recorded during the Durham Ferry 5th release was much lower than other temperatures and the reading may have been faulty; although the 5th release for all three release locations had the lowest river temperatures recorded during the release periods. The dissolved oxygen levels were between 6 and 11 mg/L in the river at all the release sites.

There were two fish identified as mortalities after transport. One was from the transport on May 10th to the Durham Ferry release site and one was from the transport on May 13th to the Durham Ferry release site. These mortalities were likely due to poor recovery from tagging. There were no dead fish observed after the holding period prior to the release, with the exception of one of the dummy-tagged fish.

Intentional Mortalities

Of the nine intentional mortalities released, none were detected at fixed receiver stations and five were detected during mobile tracking surveys. All tags detected during the mobile monitoring had moved less than 0.25 miles downstream of the release sites indicting a low probability of bias in the survival estimates due to potential misclassification of drifting mortalities as survivors to a given point.

Dummy-Tagged Fish

One fish was found dead of the 210 dummy-tagged fish evaluated after 48 hours (Table 2-7). The fish was from the group of dummy-tagged fish examined on May 9th from the Old River release group. Only two fish had abnormal body color or light colored gill filaments. The fish observed with the faded-body color was examined on May 20th at the Stockton release location. The fish with the light-red colored gill filaments was examined on May 2nd at Old River. All remaining fish were found swimming vigorously, had normal gill coloration, normal eye quality, normal body coloration and no fin hemorrhaging. Mean scale loss for all fish assessed ranged from 1.0 to 3.0%. Roughly 1% of the examined fish had loose sutures or slight hemorrhaging around the sutures (Figure 2-7). Mean fork length (FL) of fish ranged from 104.9 to 114.4mm. Short-term survival was 99% within the trashcan containers. These data indicate that the fish used for the VAMP in 2010 were in generally good condition (Table 2-7). A general pathogen and physiological screening was conducted on dummy-tagged fish from three of the seven 2010 VAMP release (tagged) groups and cohorts of release groups remaining at Merced River Hatchery (MRH) (see Chapter 6 for a discussion of the fish health evaluation[3]).

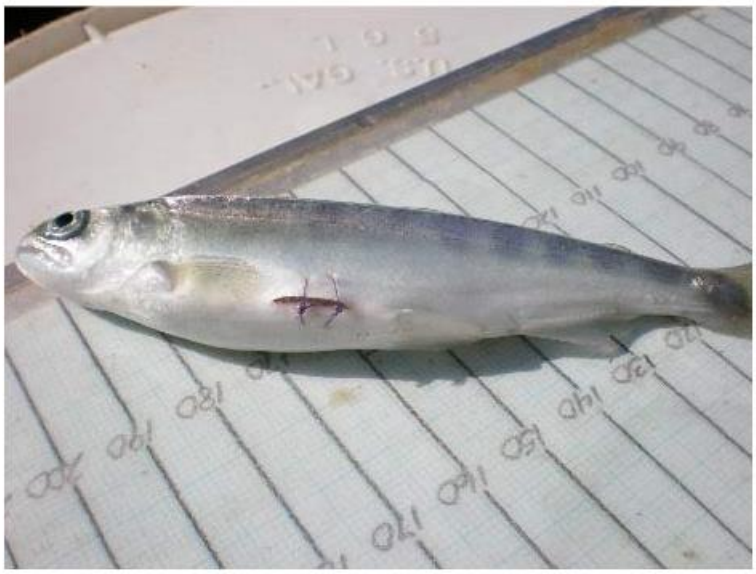


Figure 2-7. Loose Sutures on a Dummy-tagged Fish from the Durham Ferry Release Site during the 2010 VAMP Study

[3] Chapter 6 of the 2010 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP), prepared by the San Joaquin River Group Authority. 2011.

Table 2-7. Results of Dummy Tagged Juvenile Chinook Salmon Evaluated after Being Held for 48 Hours at the Release Sites as Part of the 2010 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	4/28/10, 0810	109.7 (1.9)	0/10	1.9 (0.8)	10/10	10/10	10/10	10/10
Old River	4/29/10, 0528	106.8 (1.8)	0/10	1.0 (0.0)	10/10	10/10	10/10	10/10
Stockton	4/29/10, 0908	104.9 (2.6)	0/10	1.0 (0.0)	10/10	10/10	10/10	10/10
Durham Ferry	5/01/10, 0810	110.1 (2.4)	0/10	2.1 (0.3)	10/10	10/10	10/10	10/10
Old River	5/02/10, 0710	108.2 (2.4)	0/10	2.4 (1.3)	10/10	10/10	10/10	9/10
Stockton	5/02/10, 1052	108.9 (2.5)	0/10	1.4 (0.5)	10/10	10/10	10/10	10/10
Durham Ferry	5/05/10, 0800	107.7 (4.1)	0/10	3.0 (2.4)	10/10	10/10	10/10	10/10
Old River	5/06/10, 1018	107.8 (2.6)	0/10	2.3 (1.1)	10/10	10/10	10/10	10/10
Stockton	5/06/10, 1416	107.7 (2.6)	0/10	2.2 (0.9)	10/10	10/10	10/10	10/10
Durham Ferry	5/08/10, 0823	111.0 (3.8)	0/10	2.1 (1.2)	10/10	10/10	10/10	10/10
Old River	5/09/10, 0830	109.3 (4.3)	1/10	2.9 (2.5)	9/9	9/9	9/9	9/9
Stockton	5/09/10, 1205	107.4 (3.7)	0/10	1.2 (0.4)	10/10	10/10	10/10	10/10
Durham Ferry	5/12/10, 0825	111.2 (3.1)	0/10	2.6 (0.7)	10/10	10/10	10/10	10/10
Old River	5/13/10, 0410	108.2 (5.1)	0/10	1.5 (0.7)	10/10	10/10	10/10	10/10
Stockton	5/13/10, 0816	108.7 (4.7)	0/10	1.6 (0.7)	10/10	10/10	10/10	10/10
Durham Ferry	5/15/10, 0816	111.6 (4.0)	0/10	2.0 (0.8)	10/10	10/10	10/10	10/10
Old River	5/16/10, 0550	113.5 (5.1)	0/10	2.1 (1.2)	10/10	10/10	10/10	10/10
Stockton	5/16/10, 1011	112.4 (3.7)	0/10	2.0 (1.2)	10/10	10/10	10/10	10/10
Durham Ferry	5/19/10, 0830	112.6 (3.4)*	0/10	2.8 (0.9)	10/10	10/10	10/10	10/10
Old River	5/20/10, 0453	114.4 (3.3)	0/10	1.5 (0.7)	10/10	10/10	10/10	10/10
Stockton	5/20/10, 0712	112.6 (4.1)	0/10	2.0 (1.2)	9/10	10/10	10/10	9/10

*Mean and SD was based on 7 fish

Receiver Performance

Receiver performance was much improved in 2010 over receiver performance in 2009. The use of modified 'joboxes' was continued because it seemed to eliminate the suspected overheating problems that occurred in previous years (Vogel, 2010). There were additional problems that occurred in 2009 that were eliminated in 2010. Several receivers in 2009 had periods during the study where the acoustic receiver did not function properly (SJRGA, 2010). The longest time periods were in the beginning of the study at Mossdale (SJO(s)) and Stockton USGS gage station (STP(s)) due to AC grounding issues in 2009. For VAMP 2010, these sites were moved to avoid both grounding and noise interference issues as suggested by NRS (Vogel, 2010).

While most of the issues from 2009 were eliminated, there were a few sites that had periods of non-operation in 2010. Most of the sites that had non-operation periods were due to pre-mature battery failure. A number of batteries that were used in 2010 had been used in 2009 and while all batteries were load tested and fully charged during the project, some batteries did not maintain an adequate charge and caused the loss of a limited number of files (Table 2-8). The use of a redundant receiver at Old River provided data from a second receiver when the other receiver was down.

The only other issue that was encountered regarding loss of files seems to have been related to when the '.RAT' files were downloaded. Files were to be downloaded during the time between 10 minutes after the top of the hour to 10 minutes before the hour. This was done to allow the receiver time to download all files. While this was done the majority of the time, there were a limited number of single files that were not retrieved due to downloading within the restricted time period. A number of files from sites maintained by DWR had a substantial number of '.RAT' files missing. Most of the failures were due to batteries losing voltage sooner than expected or for unknown causes.

Table 2-8. Periods of Non-operation of Acoustic Receivers during the 2010 VAMP Study

Table 2-8 note: Refer to Figure 2-2 for receiver locations

Site Name		Receiver Location	Start Down Time	End Down Time	Reason for down time
BCA		Banta Carbona	4/28/10 0300 hrs	4/28/10 1400 hrs	Downloaded data too close to the hour
MOS		Mossdale	5/27/10 0600 hrs	5/27/10 1400 hrs	Premature battery failure
OR1		Old River	6/5/10 1900 hrs	6/5/10 2000 hrs	Downloaded data too close to the hour
OR2		Old River	4/28/10 1000 hrs	4/30/10 1300 hrs	Premature battery failure
MFW		Medford Island	5/3/10 0800 hrs	5/3/10 0900 hrs	Was not written due to datalogger switch
MRNU		Middle River North Upstream	5/3/10 1100 hrs	5/4/10 0500 hrs	Unknown. Receiver light flashing
MRND		Middle River North Downstream	5/31/10 1900 hrs	6/1/10 1000 hrs	Low voltage problem; too long between battery changes
RGU		Radial Gates Upstream	3/30/10 1100 hrs	3/31/10 0900 hrs	Not able to log into node. Node was swapped out
RGU		Radial Gates Upstream	4/16/10 1000 hrs	4/18/10 0900 hrs	Possible improper settings change
RGU		Radial Gates Upstream	5/10/10 0600 hrs	5/10/10 0900 hrs	Unknown. No receiver check that day
RGU		Radial Gates Upstream	5/13/10 0000 hrs	5/14/10 1114 hrs	Unknown. No receiver check that day
RGU		Radial Gates Upstream	5/24/10 1400 hrs	5/25/10 0900 hrs	Low voltage problem; too long between battery changes
CHP	S810	Chipps Island	4/26/10 1200 hrs	4/26/10 1542 hrs	mechanical problem with receiver
CHP		Chipps Island	4/27/10 1600 hrs	4/27/10 2041 hrs	mechanical problem with receiver
CHP		Chipps Island	5/4/10 1300 hrs	5/5/10 0852 hrs	software problem
CHP	S915	Chipps Island	5/9/10 0900 hrs	5/9/10 1100 hrs	equipment failure
CHP		Chipps Island	5/19/10 1300 hrs	5/19/10 1500 hrs	equipment failure
CHP		Chipps Island	5/29/10 1800 hrs	5/29/10 2000 hrs	equipment failure
CHP		Chipps Island	6/8/10 2200 hrs	6/8/10 0000 hrs	equipment failure

Fish Health

No viral or bacterial pathogens were detected in the release groups. The most significant health problem observed was *Tetracapsuloides bryosalmonae* infection, with majority of salmon examined exhibiting early stages of clinical Proliferative Kidney Disease (PKD). No mortality or evidence of physiological impairment was observed in either the tagged or MRH groups (Nichols, 2010) (see Chapter 6 for an in-depth discussion of the fish health evaluation[4]).

Temperature Monitoring

Results of water temperature monitoring at Durham Ferry, Old River at HORB, and CCF Radial Gates during the April-June fall-run Chinook salmon smolt emigration from the San Joaquin River through the Delta are shown in Appendix B-, Figures 4, 6 and 19, respectively. Water temperatures measured within the lower San Joaquin River and Delta are shown in Appendix B, with a description of the monitoring sites shown in Appendix B- Figure 1 and Table 1 with data plots for 19 sites within the River and Delta shown in Appendix B- Figures 2 through 21. The plots in Appendix B show that all sites in the mainstem San Joaquin River (e.g., Durham Ferry, Mossdale, and Old River at HORB) were within a range considered to be suitable (typically < 20º C; 68º F) during April and May of the 2010 VAMP.

[4] Chapter 6 of the 2010 Annual Technical Report: On Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP), prepared by the San Joaquin River Group Authority. 2011.

Temperatures were slightly higher, but still usually under 20º C (68º F) further downstream within the Delta (e.g., Old River/Indian Slough Confluence, CCF Radial Gates). Results of the 2010 water temperature monitoring showed a longitudinal gradient of temperatures that generally increased as a function of distance downstream within the mainstem San Joaquin 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 2010 VAMP investigations. However, temperatures during early June were within the range considered to be stressful for juvenile Chinook salmon.

Tag Life Study

A stratified random sample of 55 tags was taken across 1,078 successfully programmed HTI model 795 Lm tags acquired in seven manufacturing lots from Hydroacoustic Technology, Inc (HTI) in Seattle, Washington. Results from the tag life study demonstrated that the tags used this year were reliable and none of the challenges with tag performance encountered during 2008 were identified in 2010. However, tag life during 2010 was more variable than in 2009, with a shorter minimum observed tag life and longer maximum observed tag life (San Joaquin River Group Authority, 2010). Most of this difference is likely due to the wider range of tag periods used in 2010 (4-10 seconds) than in 2009 (5-7 seconds). Tag life in 2009 ranged from 21 days to 29 days, whereas tag life in 2010 ranged from 12 hours to 60 days, with 96% of tags lasting 10 days or more (Figure 2-8). By the 20th day in 2010, 82% of the tags remained viable. In 2009, as soon as tags began to fail after the 20th day, the rate of attrition was high and all tags were dead by the end of the 29th day following initialization. In 2010 almost 40% of the tags were still viable on the 29th day. There were no clear differences in tag life between manufacturing lots (Figure 2-9).

As expected, tag life generally increased as the interval between pulse transmissions, the tag period, increased (see Figure 2-9). Longer intervals between pulse transmissions result in fewer pulses, and reduced energy consumption which increases the expected life of the tag.

About 16% of the 2010 tags (n=9) used in the tag-life study intermittently transmitted signals for 1 to 12 hours after the initial failure, whereas intermittent transmission was observed in approximately one-third of the tags used in the 2009 tag life study.

Water temperature in the tag-testing tank averaged 17 °C during the 60-day 2010 study, and generally ranged between 11°C and 18°C which was similar to river conditions during the 2010 survival experiment. However, water temperatures ranged between 24°C and 34°C during days 16 through 20 due to failure of the water chiller which controlled temperatures in the tank. At the time of this temperature spike, 82-90% of the tags were still functioning and potentially affected. Since tags are expected to last longer under higher water temperatures, tag life may have been slightly extended due to this event.

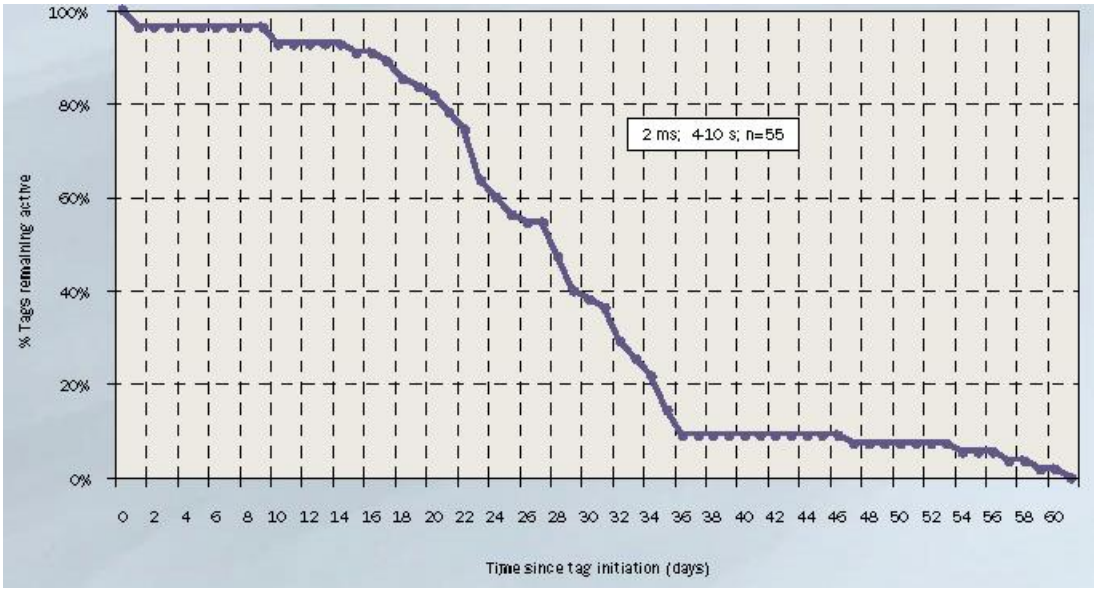


Figure 2-8. Acoustic Tag Extinction Rate for the Hydroacoustic Technology, Inc. Model 795Lm Tag Evaluated during the 2010 VAMP Study

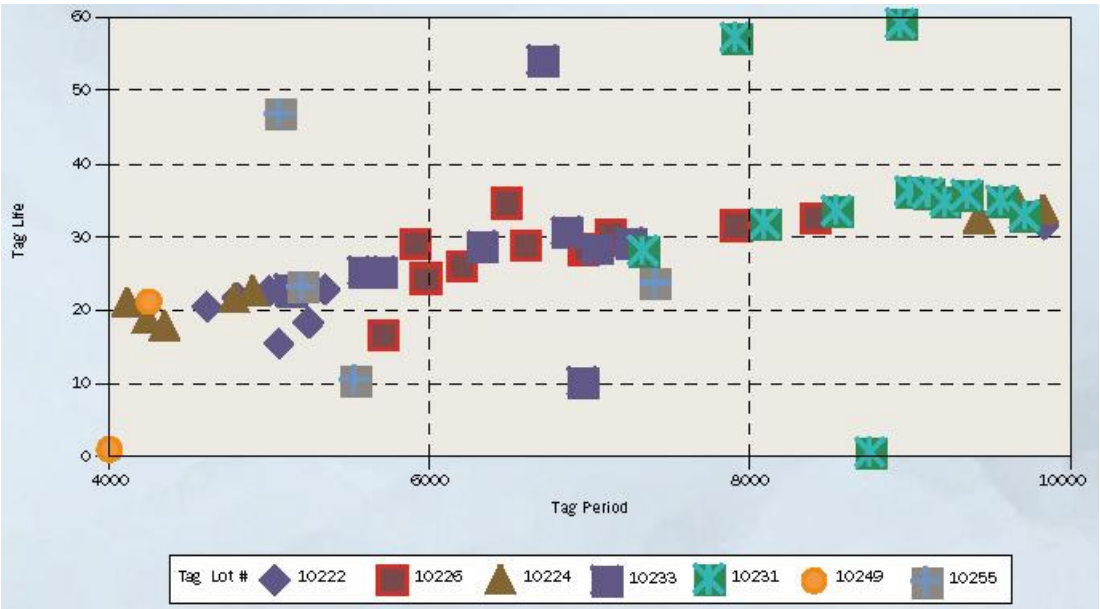


Figure 2-9. Acoustic Tag Extinction Rate for the Hydroacoustic Technology, Inc. Model 795Lm Tag Evaluated in Relationship to Manufacturing Lot and Tag Period Used for the 2010 VAMP Study

Table 2-9. Comparison of Data Processing Errors between Using Auto-processed and Manually-processed Data for Seven Acoustic Receivers Stations during the 2010 VAMP

Receiver	Autoprocessed					Manually Processed				
	Missed Detection	Tag Misread	Duplicated Detection	Fractional Read	False Positive	Missed Detection	Tag Misread	Fractional Read	False Positive	Unclear
OR 1	21	0	1	0	0	26	4	11	0	1
OR 2	10	1	2	0	0	16	1	0	1	1
Chipps 915	10	1	0	0	0	10	2	0	0	0
SJ1	0	0	0	1	0	56	0	2	0	0
SJ2	6	1	4	0	0	27	1	2	0	3
Chipps 800	16	1	3	0	1	0	3	1	0	1
Mossdale	2	0	0	0	0	27	0	4	0	0

Data Processing

Data from all fixed receiver sites were processed using two automarking algorithms: FishCount, an algorithm developed by Aaron Blake and Scott Brewer of CRRL of the USGS; and MarkTags, an algorithm developed by HTI and modified by CRRL of the USGS (Noah Adams, USGS-CRRL, Personal Communication).

Table 2-10. Summary of Auto-processing Errors Identified Independent of the Manual Data Processing

Receiver	Tag Misread	Duplicate Read	Fractional	False Positive
BCA	0	0	0	4
MOS	0	0	0	1
SJ2	1	0	0	0
STN	1	1	0	0
C16	0	1	0	4
C18	0	1	0	1
MFW	0	1	0	0
OR1	0	0	0	2
ORS	0	1	0	1
ORN	2	8	0	3
RGD	2	2	0	6
RGU	0	0	0	3
CVP	4	5	0	26
TMS	0	1	0	0
CHP-800	0	0	0	1
CHP-810	0	0	0	2

The manually processed data identified some tags that were missed in the autoprocessing. In addition, the autoprocessor picked up detections that the manual processing missed. The subset of sites that were manually processed were Old River (OR1/OR2) (2 receivers), Lathrop (SJ1/SJ2) (2 receivers), Chipps Island (CHP) (1 four port receiver and 1 single node) and Mossdale (MOS) (1 receiver). For the receiver at Old River (OR1), the autoprocessor missed 21 detections, the manual processing missed 26 detections (Table 2-9). In addition, 4 detections were manually misidentified and 11 additional detections were in error because they were fractionals of true tag codes. A fractional is a tag code displayed at the nth root of its primary signal or a fraction of its actual assignment. The autoprocessor duplicated one detection and gave it an incorrect code. One auto-processed detection could not be confirmed through manual processing. For the second receiver in Old River (OR2), fewer errors were identified both in the auto-processed and manual-processed data, but again with most of the errors being missed detections for both the manual and auto-processed data. Examination of the auto-processed detections independent of the manual processed data identified additional errors (Table 2-10). The largest number of errors occurred on the Central Valley Project trash rack receivers (CVP), with 4 misread tags, 5 duplicate reads, and 26 false positives. The large number of detections at this site complicated any type of data processing, making impractical both manual processing and in-depth comparisons between the two auto-processing algorithms (FishCount and MarkTags). These additional errors were only those that were obvious when comparing the medium and

far-field movement throughout the Delta for the tagged fish. It is likely there are additional errors in the data that were not identified with the processes used.

In some respects, missed detections are less of a problem than tags that are misread, fractionals, duplicated detections, or false positives. The model is designed to determine the probability of detection and is robust enough to correct for missed detections at most receivers. Where 100% probability of detection is desired or necessary, missed detections are also problematic. In some ways missed detections are addressed using redundant receivers at key locations (Old River (OR1 and OR2) and San Joaquin at Lathrop (SJ1 and SJ2)) as it is unlikely that the same fish would be missed at both receivers within a redundant array. Although the receivers at Old River each had down times in 2010, there was at least one receiver operating there at all times, so it is unlikely that any fish were missed at that site. For the redundant San Joaquin River receivers, there was no down time.

Detections of Acoustic-Tagged Fish

Of the 504 tags released in juvenile Chinook salmon at Durham Ferry, 500 were detected on one or more receivers downstream of the release site (Table 2-11), including the predator-type detections. In general, the number of tags detected at each site in the San Joaquin route declined with distance from Durham Ferry, with 477 tags detected at Mossdale, 232 tags detected at Lathrop, 188 tags detected at the Navy Bridge in Stockton, and 69 tags detected at Medford Island. Only 19 tags were detected at Turner Cut (Table 2-12). Approximately an equal number of tags were detected in the Old River route as in the San Joaquin route, with 245 tags detected on the Old River receivers located near the head of the river. Only one tagged fish was observed to use the Middle River (MRS) route rather than the Old River route at the head of Middle River. Because detection probability could not be estimated based on a single tag, the detection history for this tag was censored at its previous detection (at OR1/OR2), and the MRS site was not included in the survival model. Without the MRS site, it was no longer possible to separately estimate the survival probability from the first Old River receivers (OR1/OR2) to the head of Middle River (SB1) and the route entrainment probability at the head of Old River ($\psi B2$). Instead, the joint probability of migrating from OR1/OR2 toward the Old River South receivers (ORS) and surviving through that reach was estimated as:

$$\varphi_{B1,B2} = S_{B1}\psi_{B2}.$$

Table 2-11. Number of Tags from Each Release Group Detected Downstream of the Release Site in 2010, including Predator-type Detections

Durham Ferry Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	74	74	73	70	70	73	70	504
Total Number Detected	72	74	72	70	70	73	69	500
Old River Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	36	36	36	36	36	35	32	247
Total Number Detected	36	36	36	36	36	35	32	247
Stockton Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	35	36	35	36	35	34	31	242
Total Number Detected	34	35	34	34	35	33	30	235

Many tags were observed moving among the receivers at the Central Valley Project Trash rack (CVP), radial gates at the Clifton Court Forebay (RGU), and Old River North receivers (ORN). Among these three sites, the route with the final tag detection was used in the survival model. Approximately equal numbers of tags were detected finally moving from Old River South (ORS) to the Central Valley Project as to the radial gates at the Clifton Court Forebay, with fewer moving to the Old River North receivers (Table 2-12). Data gaps at the Central Valley Project trash rack receivers (CVP) prevented estimation of the detection probability at that site for the 4th Durham Ferry release group, so those receivers were omitted from the survival model for that release group. No tags were observed at the Middle River North sites (MRNU, MRND) after passing the southern Old River receivers. Thus, all Middle River receivers were omitted from the survival model for the Durham Ferry release groups. Of the 504 tags released in juvenile Chinook salmon at Durham Ferry, 59 were eventually detected at Chipps Island, including detections of tags classified as being in predators.

All 247 of the tags released in salmon in the Old River supplemental release groups were detected on one or more receivers downstream of the release site, including predator-type detections (see Table 2-11). None of these tags was detected using the Middle River route, so the Middle River receivers were omitted from the survival model for the Old River releases. As with the Durham Ferry release groups, more tags released at Old River were finally detected at the Central Valley Project trash racks and the Clifton Court Forebay radial gates than at the Old River North receivers. Data gaps at the Central Valley Project trash rack receivers (CVP) prevented estimation of the detection probability at that site for the 4th Old River release group, so those receivers were omitted from the survival model for that release group. Of the 247 tags released at Old River, 28 were detected at Chipps Island, including predator-type detections (see Table 2-12).

Of the 242 tags released in salmon in the Stockton supplemental release groups, 235 were detected on one or more receivers downstream of the release site, including predator-type detections (see Table 2-11). The majority of the detections downstream of the Stockton Navy Bridge (STN) were detected in the San Joaquin River, with 128 detected at one or the other, or both of the channel markers (C18/C16); only 17 tags were detected in Turner Cut, none of which was detected at Chipps Island (see Table 2-12). Twenty-seven tags from the Stockton release groups were detected at Chipps Island, all of which migrated past the shipping channel markers and Medford Island (see Table 2-12). All predator-type detections were included in these detections.

Some tag detections were not used in the survival analysis, either because the tags were assigned to a different migration route, or because the receivers where they were detected were not intended to be included in the survival model. For example, tag 8305.02 (period and subcode) was detected at the Middle River South receiver (MRS). However, because this tag was later detected at an Old River South receiver (ORS), it was assigned to the Old River route rather than to the Middle River route, and so the MRS detection was omitted. A total of eight tags were detected on the Middle River North receivers (MRN) throughout the study period, with four coming from the Durham Ferry releases and four from the Stockton supplemental releases. Three of these eight tags were last seen at Turner Cut before being detected at Middle River North, one was last detected at Medford Island, and four were last detected at the channel markers in the San Joaquin shipping channel (site C18/C16). Thus, all eight of these tags were assigned the San Joaquin River route rather than the Old River route, and so the Middle River North detections were not used in the survival analysis. Twenty tags were detected at the Threemile Slough receivers (TMN, TMS): ten tags from Durham Ferry, nine from the Stockton supplemental releases, and one from the Old River supplemental releases. Of these 20 tags detected at Threemile Slough, 11 were eventually detected at Chipps Island. However, some of these detections were classified as coming from predators. Threemile Slough was not included in the survival model.

Table 2-12. Number of Tags Observed from Each Release Group at Each Detection Site in 2010 and Release Location and Used in the Survival Analysis, including Predator-type Detections

Detection Site	Site Code	Survival Model Code	Durham Ferry Release Group							
			1	2	3	4	5	6	7	Total
Banta Carbona	BCA	A2	70	65	64	65	68	70	66	468
Mossdale	MOS	A3	68	74	68	67	68	72	60	477
Lathrop	SJ1/SJ2	A4	34	32	26	37	32	35	36	232
Stockton USGS Gauge	STS	A5	33	28	24	33	30	31	27	206
Stockton Navy Bridge	STN	A6	24	29	22	30	29	30	24	188
Shipping Channel Marker 18	C18	A7a	17	18	12	17	20	10	17	111
Shipping Channel Marker 16	C16	A7b	18	22	13	17	19	10	19	118
Medford Island East	MFE	A8a	11	8	8	11	14	6	10	68
Medford Island West	MFW	A8b	12	8	8	11	14	6	10	69
Turner Cut Northeast	TCN	F1a	2	1	1	6	5	2	1	18
Turner Cut Southwest	TCS	F1b	3	1	1	6	5	2	1	19
Old River	OR1/OR2	B1	34	42	42	31	36	36	24	245
Old River South Upstream	ORSU	B2a	31	41	38	28	36	37	23	234
Old River South Downstream	ORSD	B2b	0	41	37	20	14	0	0	112
Middle River South	MRS	C1	0	0	1*	0	0	0	0	1*
Old River North Upstream	ORNU	B3a	8	11	4	2	6	7	1	39
Old River North Downstream	ORND	B3b	8	12	3	1	5	6	1	36
Middle River North Upstream	MRNU	C2a	0	0	0	0	0	0	0	0
Middle River North Downstream	MRND	C2b	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	12	13	15	15	10	6	0	71
Radial Gates Downstream	RGD	D2	11	10	12	9	8	5	0	55
Central Valley Project trashrack	CVP	E1	11	16	12	5*	11	9	10	74
Central Valley Project tank	CVPtank	E2	2	3	3	4	10	8	5	35
Chipps Island East	CHPe	G1a	6	2	4	7	15	14	11	59
Chipps Island West	CHPw	G1b	6	2	4	7	14	12	11	56
Detection Site	**Site Code**	**Survival Model Code**	**Old River Release Group**							
			1	2	3	4	5	6	7	Total
Old River	OR1/OR2	B1	35	35	36	36	36	35	32	245
Old River South Upstream	ORSU	B2a	36	35	34	35	30	35	32	237
Old River South Downstream	ORSD	B2b	1	28	35	9	9	0	0	82
Middle River South	MRS	C1	0	0	0	0	0	0	0	0
Old River North Upstream	ORNU	B3a	13	3	7	5	5	7	1	41
Old River North Downstream	ORND	B3b	13	6	9	3	5	7	1	44
Middle River North Upstream	MRNU	C2a	0	0	0	0	0	0	0	0
Middle River North Downstream	MRND	C2b	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	12	15	12	7	6	11	0	63
Radial Gates Downstream	RGD	D2	10	13	11	4	8	9	0	55
Central Valley Project trashrack	CVP	E1	6	10	14	11*	7	5	19	72
Central Valley Project tank	CVPtank	E2	1	5	4	8	4	0	8	30
Chipps Island East	CHPe	G1a	1	6	3	8	3	0	7	28
Chipps Island West	CHPw	G1b	1	6	3	7	3	0	6	26
Detection Site	**Site Code**	**Survival Model Code**	**Stockton Release Group**							
			1	2	3	4	5	6	7	Total
Stockton Navy Bridge	STN	A6	27	30	33	34	35	33	30	222
Shipping Channel Marker 18	C18	A7a	21	22	14	16	21	7	17	118
Shipping Channel Marker 16	C16	A7b	21	23	15	17	24	8	18	126
Medford Island East	MFE	A8a	13	16	13	11	13	6	8	80
Medford Island West	MFW	A8b	13	17	13	11	13	6	8	81
Turner Cut Northeast	TCN	F1a	4	0	1	4	3	1	3	16
Turner Cut Southwest	TCS	F1b	4	0	1	4	3	2	3	17
Chipps Island East	CHPe	G1a	3	1	5	6	5	2	3	25
Chipps Island West	CHPw	G1b	4	0	5	6	6	2	3	26

*=not used in survival model.

The decision process used to distinguish between detections of Chinook salmon smolts and detections of predatory fish that had eaten the tagged smolts classified 602 of the 993 tags (61%) released as being detected in a predator at some point during the study (Table 2-13). Of the 504 tags released in juvenile Chinook salmon at Durham Ferry, 312 were classified as being detected in a predator at some point. The detection site with the largest number of first-time predator-type detections was the shipping channel markers in the San Joaquin downstream of Stockton (site C18/C16), where 42 tags released at Durham Ferry were first labeled as predators upon arrival at the receivers, and 16 were first classified as predators upon departure from the receivers. Being classified as a predator upon arrival was usually the result of unusual travel time or migration rate, while being classified as a predator only upon departure was usually the result of long residence time at a site. The Central Valley Project trash rack receivers (CVP) had the next largest number of first-time predator classifications, with 18 tags first classified as being in predators upon arrival at the site, and 31 tags classified as predators upon departure from the site. Among the Old River releases, a total of 162 tags were eventually classified as coming from a predator rather than a smolt, with the majority (88%) of such classifications occurring at the receivers at the Central Valley Project trash racks (CVP), the radial gates at the entrance to Clifton Court Forebay (RGU, RGD), and the Old River North site (ORN) (Table 2-13). A total of 128 tags that were released in salmon smolts in the Stockton supplemental releases were classified as being in predators at some point (Table 2-13). The Stockton release site was located between the receiver at the USGS gauge (STS) and the receiver near the Navy Bridge (STN) in Stockton. Thus, some tags released at Stockton were observed at the USGS gauge receiver (STS), and a few as far upstream as Lathrop (SJ1/SJ2). Several of these detections (6 of 37; 16%) were classified as coming from predators, based on travel time and travel in relation to river flow. Most of the first-time predator classifications occurred at the channel markers in the shipping channel downstream of Stockton (site C18/C16) (Table 2-13). None of the Stockton tags were observed at the eastern or southern receivers in the Old River route (i.e., OR1/OR2 and ORS). However, several Stockton tags were observed in the central Delta, at one or more of the Middle River, radial gate, and Central Valley Project receivers. These tags were generally classified as predators upon arrival at those sites based on long transition times. Even if they had not been classified as predators, they would not have contributed to the survival analysis because they were all previously assigned to the San Joaquin River route for survival analysis. One Stockton tag was classified as a predator upon arrival at the receivers in Threemile Slough (see Table 2-13).

Table 2-13. Number of Tags from Each Release Group and Release Location First Classified as in a Predator at Each Detection Site in 2010 as a Result of the Predator-Smolt Decision Process

Detection Site and Codes			Durham Ferry Release Groups															
			Classified as predator on arrival at site								Classified as predator on departure from site							
			1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	Total
Detection Site	Site Code	Survival Model Code																
Banta Carbona	BCA	A2	4	0	2	0	0	0	2	8	0	0	0	0	0	0	0	0
Mossdale	MOS	A3	1	0	0	0	0	1	2	4	0	1	0	0	0	1	0	2
Lathrop	SJ1/SJ2	A4	3	0	2	8	3	6	4	26	0	0	2	0	0	2	0	4
Stockton USGS Gauge	STS	A5	1	0	1	3	0	1	0	6	0	1	1	1	0	0	1	4
Stockton Navy Bridge	STN	A6	0	0	0	0	0	1	2	3	1	1	0	0	4	2	0	8
Shipping Channel Marker	C18/C16	A7	5	13	8	6	5	3	2	42	1	0	2	5	4	1	3	16
Medford Island	MFE/MFW	A8	5	1	0	0	1	0	0	7	1	0	1	0	1	1	0	4
Turner Cut	TCN/TCS	F1	1	0	0	3	3	1	0	8	0	0	0	0	0	0	0	0
Old River	OR1/OR2	B1	3	1	4	3	0	1	1	13	0	0	0	0	0	0	1	1
Old River South	ORS	B2	2	1	2	2	2	5	0	14	1	0	0	0	0	0	0	1
Middle River South	MRS	C1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Old River North	ORN	B3	3	3	2	1	1	3	1	14	2	5	2	0	4	3	0	16
Middle River North	MRN	C2	0	0	0	0	0	0	2	2	0	0	0	0	0	1	0	1
Radial Gates Upstream	RGU	D1	1	2	5	1	1	2	0	12	5	4	3	5	3	0	1	21
Radial Gates Downstream	RGD	D2	1	1	1	0	2	0	0	5	4	1	2	5	3	0	0	15
Central Valley Project trashrack	CVP	E1	2	2	0	2	3	5	4	18	5	9	8	1	1	1	6	31
Central Valley Project tank	CVPtank	E2	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Chipps Island	CHP	G1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3	3
Threemile Slough	TMS/TMN		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Tags			32	24	27	30	22	29	21	185	20	22	21	17	20	12	15	127

Detection Site and Codes			Old River Release Groups															
			Classified as predator on arrival at site								Classified as predator on departure from site							
			1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	Total
Detection Site	Site Code	Survival Model Code																
Old River	OR1/OR2	B1	0	0	0	1	2	1	1	5	0	0	0	0	1	0	0	1
Old River South	ORS	B2	0	1	1	0	0	1	1	4	1	0	0	0	0	0	0	1
Middle River South	MRS	C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Old River North	ORN	B3	2	0	0	5	1	4	0	12	4	4	3	0	2	5	3	21
Middle River North	MRN	C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	2	0	3	3	0	2	0	10	10	5	6	4	0	1	2	28
Radial Gates Downstream	RGD	D2	0	2	1	0	1	2	0	6	5	8	5	2	6	2	0	28
Central Valley Project trashrack	CVP	E1	0	1	2	5	4	2	8	22	2	4	5	0	2	1	2	16
Central Valley Project tank	CVPtank	E2	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chipps Island	CHP	G1	0	1	1	3	0	0	1	6	0	0	0	1	0	0	0	1
Threemile Slough	TMS/TMN		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Tags			4	6	8	17	8	12	11	66	22	21	19	7	11	9	7	96

Detection Site and Codes			Stockton Release Groups															
			Classified as predator on arrival at site								Classified as predator on departure from site							
			1	2	3	4	5	6	7	Total	1	2	3	4	5	6	7	Total
Detection Site	Site Code	Survival Model Code																
Lathrop	SJ1/SJ2	A4	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Stockton USGS Gauge	STS	A5	1	1	0	1	0	2	0	5	0	1	0	0	0	2	0	3
Stockton Navy Bridge	STN	A6	1	2	5	1	1	2	4	16	2	1	1	1	1	4	2	12
Shipping Channel Marker	C18/C16	A7	5	6	9	6	10	4	4	44	2	1	0	4	3	1	2	13
Medford Island	MFE/MFW	A8	1	1	0	2	1	0	0	5	1	2	2	1	2	0	1	9
Turner Cut	TCN/TCS	F1	2	0	2	2	1	1	1	9	0	1	0	0	1	1	0	3
Middle River South	MRS	C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Old River North	ORN	B3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Middle River North	MRN	C2	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radial Gates Downstream	RGD	D2	0	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0
Central Valley Project trashrack	CVP	E1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Central Valley Project tank	CVPtank	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chipps Island	CHP	G1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1
Threemile Slough	TMS/TMN		0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Total Tags			11	12	17	13	14	9	11	87	5	6	3	6	8	8	5	41

When the detections classified as coming from predators were removed from the detection data, fewer detections were available for the survival analysis (Table 2-14 and Table 2-15). Nevertheless, a large proportion of the tags released were detected at least once, suggesting high initial survival. Of the 504 tags released in juvenile Chinook salmon at Durham Ferry, 496 were detected on downriver receivers with smolt-type detections (see Table 2-14). Of these 496 tags, 202 were detected using the San Joaquin River route, and 229 were detected using the Old River route. Only six smolts were detected at Turner Cut, and none of these smolts was subsequently detected at Chipps Island. Only one tag was detected using the Middle River route; because this was too few detections for use in the survival model, the Middle River route was not included in the survival model for Durham Ferry releases. With predator-type detections omitted, approximately equal numbers of fish were observed to eventually move to the Old River North receivers (ORN) as to the Central Valley Project and Clifton Court Forebay receivers (Table 2-15). A total of 29 tags were detected at Chipps Island with only smolt- type detections, with 19 of these tags previously detected at the Central Valley Project and only 9 previously detected in the San Joaquin River at Lathrop or farther downstream.

Even without the predator-type detections, nearly all (245) of the 247 tags released in the Old River supplemental releases were detected on downriver receivers (see Table 2-14). The close proximity of the Old River release site to the first Old River receivers (OR1/ OR2) may explain the high proportion of tags detected. No tag from the Old River releases was detected using the Middle River route, so that route was omitted from the survival model for the Old River release groups. More salmon were detected using the Clifton Court Forebay route (sites RGU, RGD) than the Old River North route (site ORN) or the Central Valley Project route (sites CVP, CVPtank), although most fish detected on the receiver located outside the radial gate (RGU) were not subsequently detected on the receivers inside the gate (RGD) (see Table 2-15). Of the 247 tags released at Old River, only 16 were eventually detected at Chipps Island and classified as in salmon smolts (see Table 2-15).

Of the 242 tags released in salmon in the Stockton supplemental release groups, 218 were detected on downriver receivers with salmon-type detections. Most of these tags were last detected at the Stockton Navy Bridge (STN), with only 78 tags detected at the channel markers (sites C18 and C16) or downstream, and only 8 detected at Turner Cut (see Table 2-15). Twelve of the 242 tags released were detected at Chipps Island, classified as in salmon smolts (see Table 2-15).

Table 2-14. Number of Tags from Each Release Group at the Three Release Locations Detected Downstream during the 2010 VAMP, without Predator-type Detections

Durham Ferry Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	74	74	73	70	70	73	70	504
Total Number Detected	71	74	70	70	70	73	68	496
Old River Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	36	36	36	36	36	35	32	247
Total Number Detected	36	36	36	36	36	34	31	245
Stockton Releases								
Release Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number Released	35	36	35	36	35	34	31	242
Total Number Detected	32	31	33	33	35	29	25	218

Table 2-15. Number of Tags from Each Release Group at the Three Release Locations Observed at Each Detection Site in 2010 and Used in the Survival Analysis, without Predator-type Detections

Detection Site	Site Code	Survival Model Code	Durham Ferry Release Group							
			1	2	3	4	5	6	7	Total
Banta Carbona	BCA	A2	68	65	62	65	68	70	65	463
Mossdale	MOS	A3	65	74	67	67	68	71	60	472
Lathrop	SJ1/SJ2	A4	29	32	24	29	29	27	32	202
Stockton USGS Gauge	STS	A5	27	28	19	24	27	22	22	169
Stockton Navy Bridge	STN	A6	20	28	17	21	26	20	20	152
Shipping Channel Marker 18	C18	A7a	14	16	6	9	12	4	14	75
Shipping Channel Marker 16	C16	A7b	13	16	5	8	10	4	14	70
Medford Island East	MFE	A8a	10	5	3	2	2	2	4	28
Medford Island West	MFW	A8b	10	5	2	2	1	2	4	26
Turner Cut Northeast	TCN	F1a	1	0	0	0	3	1	1	6
Turner Cut Southwest	TCS	F1b	1	0	0	0	3	1	1	6
Old River	OR1/OR2	B1	31	40	37	27	36	35	22	228
Old River South Upstream	ORSU	B2a	27	39	33	22	34	31	20	206
Old River South Downstream	ORSD	B2b	0	39	33	18	14	0	0	104
Middle River South	MRS	C1	0	0	0	1*	0	0	0	1*
Old River North Upstream	ORNU	B3a	11	13	10	0	11	9	3	57
Old River North Downstream	ORND	B3b	10	14	6	0	7	2	2	41
Middle River North Upstream	MRNU	C2a	0	0	0	0	0	0	0	0
Middle River North Downstream	MRND	C2b	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	9	9	8	12	11	1	1	51
Radial Gates Downstream	RGD	D2	5	3	2	5	4	0	0	19
Central Valley Project trashrack	CVP	E1	7	16	11	3	7	2	7	53
Central Valley Project tank	CVPtank	E2	0	3	1	3	6	7	3	23
Chipps Island East	CHPe	G1a	3	2	0	2	7	8	7	29
Chipps Island West	CHPw	G1b	3	2	0	2	6	6	7	26
Detection Site	**Site Code**	**Survival Model Code**	**Old River Release Group**							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Old River	OR1/OR2	B1	35	35	36	36	36	34	31	243
Old River South Upstream	ORSU	B2a	36	34	33	35	29	33	30	230
Old River South Downstream	ORSD	B2b	0	27	34	9	9	0	0	79
Middle River South	MRS	C1	0	0	0	0	0	0	0	0
Old River North Upstream	ORNU	B3a	10	6	8	2	10	11	6	53
Old River North Downstream	ORND	B3b	9	7	8	2	7	6	4	43
Middle River North Upstream	MRNU	C2a	0	0	0	0	0	0	0	0
Middle River North Downstream	MRND	C2b	0	0	0	0	0	0	0	0
Radial Gates Upstream	RGU	D1	20	17	14	14	7	7	3	82
Radial Gates Downstream	RGD	D2	9	8	6	2	6	2	0	33
Central Valley Project trashrack	CVP	E1	3	5	11	2	4	2	8	35
Central Valley Project tank	CVPtank	E2	0	1	4	7	2	0	7	21
Chipps Island East	CHPe	G1a	0	0	1	7	2	0	6	16
Chipps Island West	CHPw	G1b	0	0	1	7	2	0	6	16
Detection Site	**Site Code**	**Survival Model Code**	**Stockton Release Group**							
			1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Stockton Navy Bridge	STN	A6	26	27	33	33	35	29	25	208
Shipping Channel Marker 18	C18	A7a	17	13	6	11	17	2	12	78
Shipping Channel Marker 16	C16	A7b	17	12	6	11	15	1	12	74
Medford Island East	MFE	A8a	10	8	5	5	7	0	8	43
Medford Island West	MFW	A8b	10	8	5	5	7	0	7	42
Turner Cut Northeast	TCN	F1a	2	1	0	1	2	1	1	8
Turner Cut Southwest	TCS	F1b	2	1	0	1	2	1	1	8
Chipps Island East	CHPe	G1a	2	1	1	2	4	0	2	12
Chipps Island West	CHPw	G1b	2	1	1	2	4	0	2	12

Table 2-16. Number of Juvenile Chinook Salmon Tagged by Tagger in Each Release Group and Release Location during the 2010 VAMP Study

Durham Ferry Release Group	Tagger			Total Tags
	A	B	C	
1	24	25	25	74
2	25	25	24	74
3	24	24	25	73
4	24	24	22	70
5	23	24	23	70
6	25	24	24	73
7	0	47	23	70
Total Durham Ferry Tags	145	193	166	504
Old River Release Group	**Tagger**			**Total Tags**
	A	B	C	
1	12	12	12	36
2	12	12	12	36
3	12	12	12	36
4	12	12	12	36
5	12	12	12	36
6	12	12	11	35
7	10	10	12	32
Total Old River Tags	82	82	83	247
Stockton Release Group	**Tagger**			**Total Tags**
	A	B	C	
1	12	11	12	35
2	12	12	12	36
3	11	12	12	35
4	12	12	12	36
5	12	12	11	35
6	10	12	12	34
7	11	11	9	31
Total Stockton Tags	80	82	80	242
Total Tags	307	357	329	993

Survival Effect of Tagger

Fish in the release groups were evenly distributed across separate fish taggers (Table 2-16). A chi-squared test found good distribution of taggers across all Durham Ferry release groups (P=1.0), and across all supplemental releases at both Old River and Stockton (P=1.0 in each case).

A likelihood ratio test found no significant effect of tagger on model fit to data from all release occasions pooled (P=0.9702). Additionally, estimated smolt survival through each river reach showed no consistent evidence of a tagger effect on survival (Table 2-17). Cumulative survival to Chipps Island via the San Joaquin route (Figure 2-10) and via the Old River route (Figure 2-11) also showed no consistent evidence of a tagger effect on survival. Consequently, detection data were pooled across taggers within each release group.

Tag Life Adjustment

Two of the 55 tags in the tag life study died within 25 hours of tag activation, and 5 tags survived more than 45 days (see Figure 2-8). The initial two tag deaths were omitted from the tag survival analysis because all tagged juvenile salmon released to the river were observed to have live tags more than 25 hours after tag activation. The tag life data were truncated at 40 days because all detections of tagged fish were observed prior to Day 40, and the tag survival model fit better without the last 5 tag failures (Figure 2-12).

The complete set of detection data, including the detections classified as coming from predators, included many detections that occurred well after the tags began dying in the tag life study (Figure 2-13, Figure 2-14).

A sizeable number of late detections occurred at the Channel Markers in the San Joaquin River just past the junction with Turner Cut, and at the Lathrop receivers just downstream of the junction with Old River (Figure 2-13). In the Old River route, the trash rack at the Central Valley Project had the largest proportion of late detections (Figure 2-14). 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 before most of the tag failure observed in the tag life study (Figure 2-15, Figure 2-16). Tag life corrections were made to survival estimates for both sets of detections (with and without detections classified as predators). Because of the prolonged detections observed in the complete data set, the tag-life adjustments to survival estimates were more extreme for the detection set that included the predator detections.

Table 2-17. Estimates (and Standard Errors) of Survival Probabilities (S_{A1}) and Transition Probabilities ($\varphi_{kj,hi}$) by Tagger for the VAMP 2010 study

Parameter	Tagger A	Tagger B	Tagger C
S_{A1}	0.99 (0.01)	1.00 (0.01)	0.99 (0.01)
S_{A2}	0.93 (0.02)	0.95 (0.02)	0.96 (0.02)
S_{A3}	0.93 (0.02)	0.89 (0.02)	0.92 (0.02)
S_{A4}	0.79 (0.05)	0.84 (0.04)	0.91 (0.04)
S_{A5}	1.01 (0.05)	0.93 (0.04)	0.98 (0.05)
S_{A6}	0.43 (0.05)	0.38 (0.04)	0.43 (0.04)
$\phi_{A7,A8}$	0.55 (0.07)	0.46 (0.08)	0.47 (0.06)
$\phi_{A8,G1}$	0.19 (0.08)	0.44 (0.11)	0.26 (0.09)
$\phi_{F1,G1}$	0.00 (0)	0.00 (0)	0.00 (0)
$\phi_{B1,B2}$	0.89 (0.03)	0.90 (0.03)	0.93 (0.03)
$\phi_{B2,B3}$	0.27 (0.04)	0.23 (0.04)	0.29 (0.04)
$\phi_{B3,G1}$	0.00 (0)	0.03 (0.03)	0.00 (0)
$\phi_{B2,D1O}$	0.21 (0.03)	0.22 (0.04)	0.21 (0.04)
$\phi_{B2,D1C}$	0.11 (0.02)	0.13 (0.03)	0.10 (0.03)
$\phi_{D1O,D2}$	0.35 (0.09)	0.45 (0.11)	0.38 (0.09)
$\phi_{D1C,D2}$	0.34 (0.13)	0.38 (0.12)	0.23 (0.11)
$\phi_{D2,G1}$	0.00 (0)	0.00 (0)	0.00 (0)
$\phi_{B2,E1}$	0.30 (0.06)	0.52 (0.15)	0.44 (0.17)
$\phi_{E1,E2}$	0.38 (0.11)	0.21 (0.08)	0.26 (0.08)
$\phi_{E2,G1}$	0.78 (0.10)	0.79 (0.11)	0.85 (0.09)

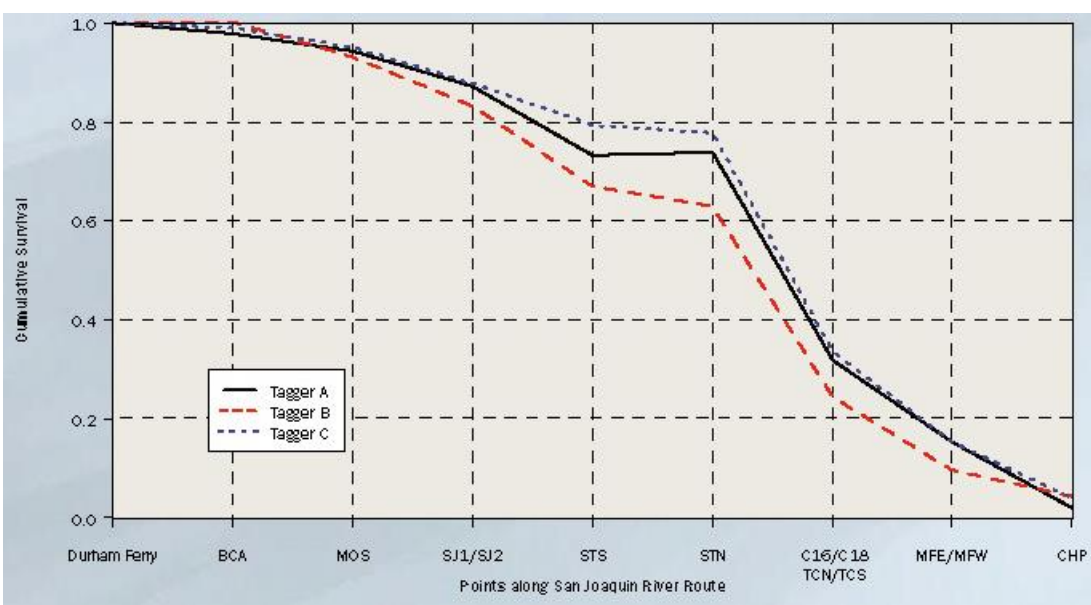


Figure 2-10. Estimated Cumulative Survival from the Release at Durham Ferry to Chipps Island along the San Joaquin River Route, by Tagger during the 2010 VAMP Study

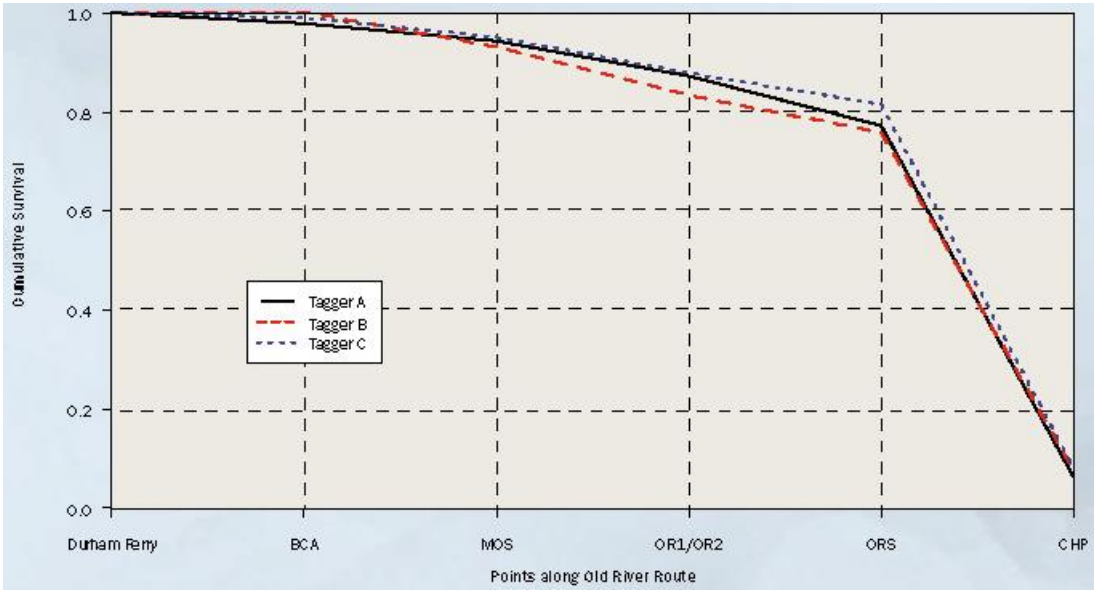


Figure 2-11. Estimated Cumulative Survival from the Release at Durham Ferry to Chipps Island along the Old River Route, by Tagger during the 2010 VAMP Study

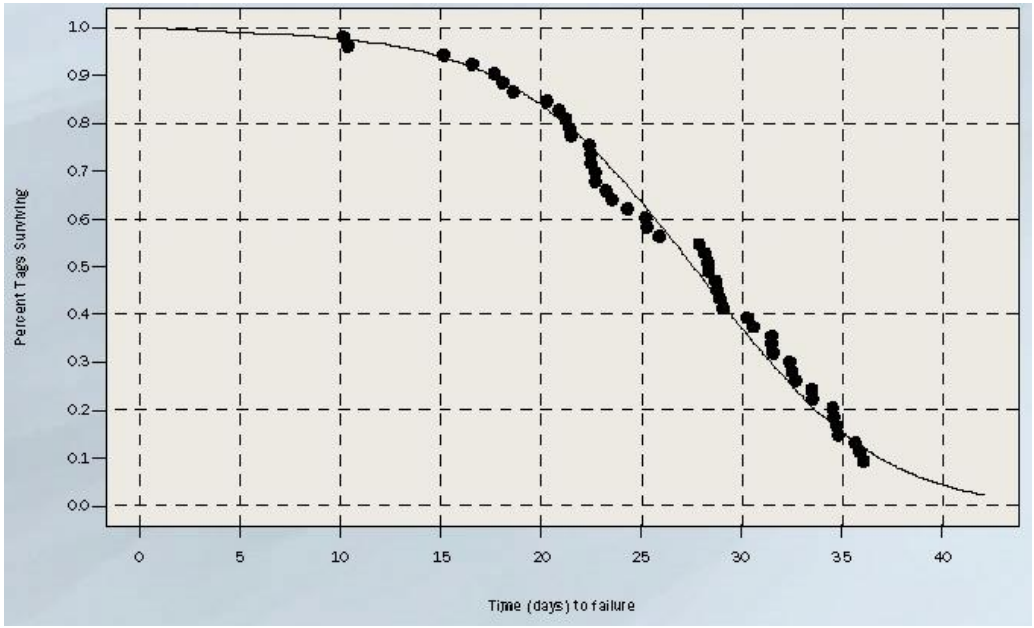


Fig 2-12 note: The first 2 and the last 5 tag failures were omitted.

Figure 2-12. Observed Tag Failure Times from the 2010 Tag-life Study, and Fitted Four-Parameter Vitality Curve

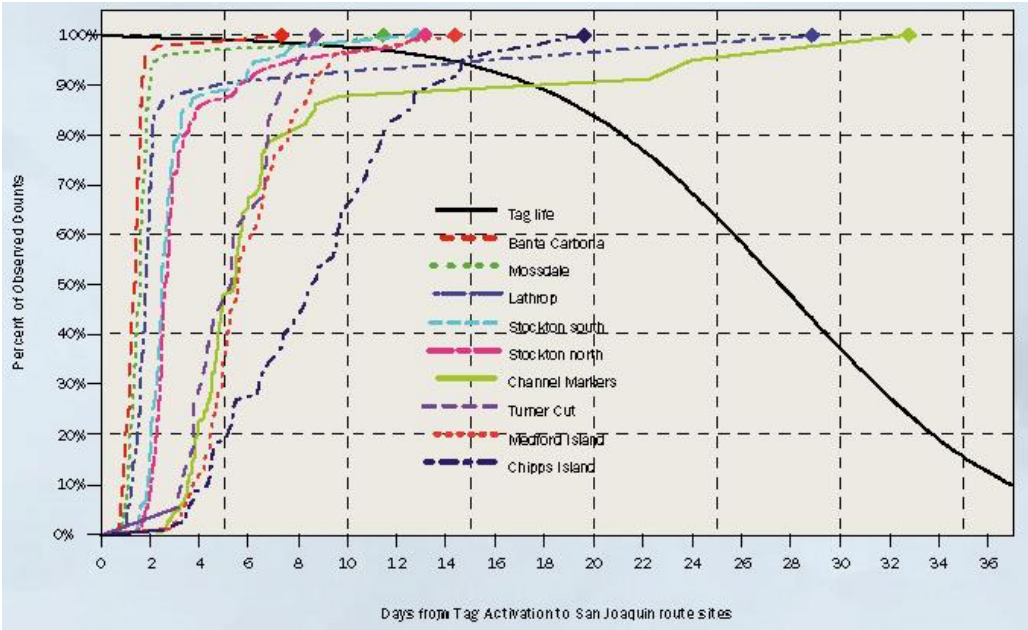


Fig 2-13 note: Only tags released at Durham Ferry are shown, including detections classified as predator detections

Figure 2-13. Four-Parameter Vitality Curve Survivorship Curve for Tag Life, and the Timing of Detections of Acoustic-tagged Chinook Salmon Smolts at Receivers Located in the San Joaquin River Route to Chipps Island

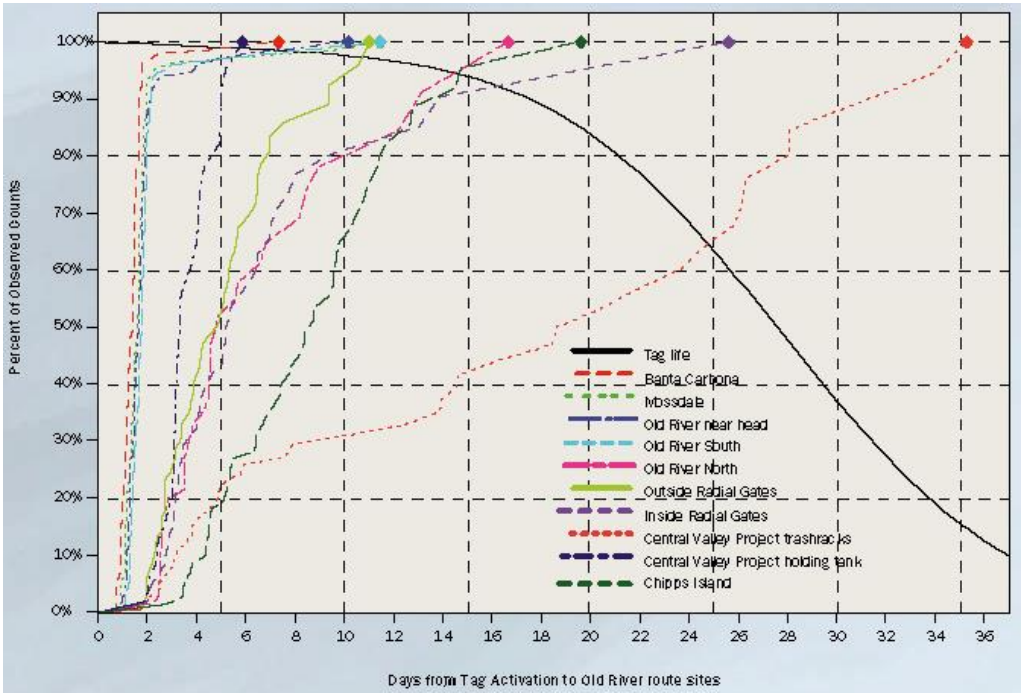


Fig 2-14 note: Only tags released at Durham Ferry are shown, including detections classified as predator detections

Figure 2-14. Four-Parameter Vitality Curve Survivorship Curve for Tag Life, and the Timing of Detections of Acoustic-tagged Chinook Salmon Smolts at Receivers Located in the Old River Route to Chipps Island

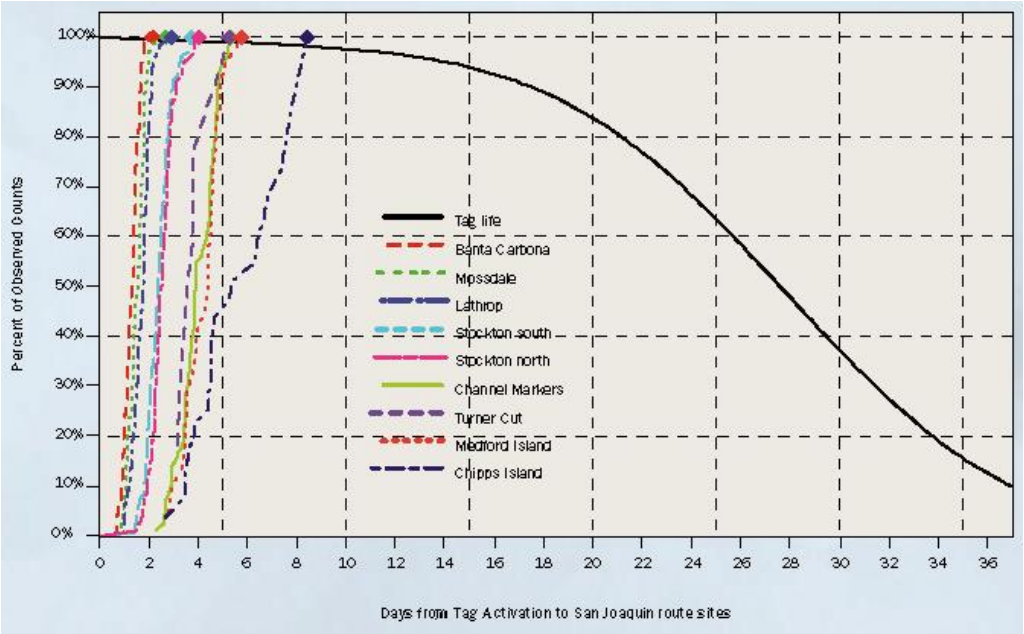


Fig 2-15 note: Only tags released at Durham Ferry are shown, omitting detections classified as predator detections

Figure 2-15. Four-Parameter Vitality Curve Survivorship Curve for Tag Life, and the Timing of Detections of Acoustic-tagged Chinook Salmon Smolts at Receivers Located in the San Joaquin River Route to Chipps Island

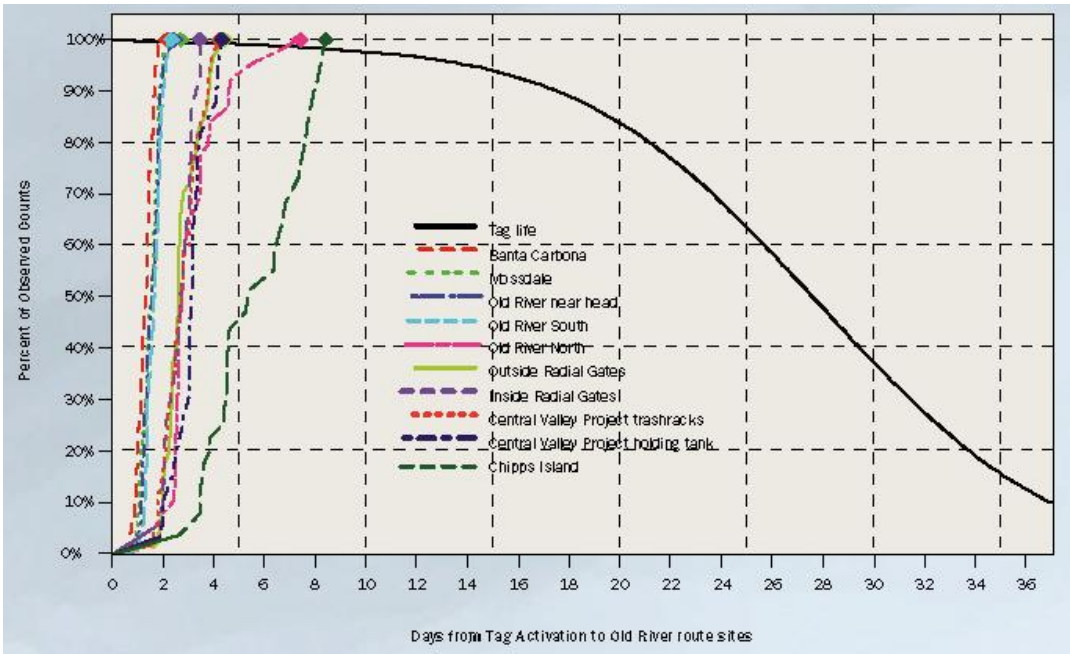


Fig 2-16 note: Only tags released at Durham Ferry are shown, omitting detections classified as predator detections

Figure 2-16. Four-Parameter Vitality Curve Survivorship Curve for Tag Life, and the Timing of Detections of Acoustic-tagged Chinook Salmon Smolts at Receivers Located in the San Joaquin River Route to Chipps Island

Survival and Route Entrainment Probabilities

The model selection process identified the most parsimonious model that adequately fit the data, based on AIC and visual analysis of the Anscombe residuals. For the reduced data set that excluded detections classified as coming from predators, estimating unique transition parameters to and from the radial gates at the Clifton Court Forebay (RGU, RGD) based on gate status (open and closed) significantly improved the fit of the model (ΔAIC = 6.755), so all models fit to the reduced data set used unique parameters based on gate status. However, for the full data set that included detections classified as coming from predators, the simpler model without a gate effect fit the model nearly as well as the model using unique gate parameters (ΔAIC =0.283). Thus, the models fit to the full data set used the simpler model that did not distinguish between open and closed gate states.

For most release occasions, the selected model used common detection, survival, route entrainment, and transition probabilities among the primary release group at Durham Ferry and the supplemental releases at Old River and Stockton (Table 2-18, Appendix C – Tables 2 and 3). All models considered used unique values of $\varphi_{B1,B2}$ for the Durham Ferry and Old River releases, because of the close proximity of the Old River release site to the OR1/OR2 receivers. Some parameters were unable to be estimated for certain release groups or release occasions because of sparse data. For example, without the predator-type detections, no information was available on the transition probability between the receivers at the radial gates at Clifton Court Forebay (RGU, RGD) and Chipps Island ($\varphi_{D2,G1}$) because no non- predator type detections on the radial gate receivers were used in the survival analysis. Also without the predator- type detections, it was not possible to separately estimate $\varphi_{B2,E1}$ and P_{E1} for the first release occasion (both Durham Ferry and Old River release groups) because no tags were observed at site E2 (CVPtank). For the 7th release occasion, it was not possible to separately estimate $\varphi_{B2,D1C}$ and P_{D1} because no tags were observed at site D2 (RGD) (both Durham Ferry and Old River release groups).

Table 2-18. Results of Model Selection Process for Detection Data, with and without Predator-type Detections. Release Occasion Consists of Primary Release Group at Durham Ferry and Supplemental Release Groups at both Old River and Stockton

With Predators	Release Occasion	Final Model Unique Parameters		Log-Likelihood	N_{par}	AIC
		DF vs. OR	DF vs. STK			
Yes	1	[none]	[none]	-69.74429	44	227.4886
Yes	2	P_{B2b}, P_{B3a}	P_{A6} P_{G1b} $\phi_{A7, A8}$ ψ_{A2} S_{A6}	-69.74230	50	239.4846
Yes	3	[none]	[none]	-65.42396	44	218.8479
Yes	4	P_{B2b}	[none]	-76.61694	43	239.2339
Yes	5	[none]	P_{A7a} P_{A7b}	-91.67242	45	273.3446
Yes	6	$\phi_{E1,E2}$	[none]	-61.41989	44	210.8398
Yes	7	[none]	[none]	-57.08281	40	194.1656
No	1	[none]	[none]	-62.10735	44	212.2147
No	2	P_{B2b} $\phi_{B2,D1C}$ $\phi_{B2,E1}$	P_{A6}	-67.23123	47	228.4625
No	3	[none]	P_{B3b}	-57.11298	44	202.2260
No	4	$\phi_{B2,E1}$ $\phi_{E1,E2}$ $\phi_{E2,G1}$	P_{B2b}	-68.73799	50	237.4760
No	5	[none]	[none]	-92.77070	46	277.5414
No	6	$\phi_{B2,D1C}$ $\phi_{B2,E1}$ $\phi_{E1,E2}$	[none]	-48.70236	49	195.4047
No	7	[none]	S_{A6} ψ_{A2} $\phi_{A7,A8}$ $\phi_{A8,G1}$	-55.50728	49	209.0146

Table 2-18 note: Final model description: Unique parameters are identified among release sites. DF = Durham Ferry, OR = Old River, and STK = Stockton. All models estimated unique value of $\varphi_{B1,B2}$ for the DF and OR release sites. N par = number of unique parameters estimated.

In these cases, the joint probability of transition and detection were estimated as: $\lambda_{B2,E1} = \varphi_{B2,E1}P_{E1}$ and $\lambda_{B2,D1C} = \varphi_{B2,D1C}P_{D1}$, respectively. If the detection probability was less than 1.0, then $\lambda_{ij} < \varphi_{ij}$, and the survival probability from the Old River South receivers (ORS) to the water export facilities (CVP, RGU) and Old River North (ORN) would be underestimated. However, the overall probability of survival to Chipps Island through the Old River Route (S_B) would not be affected by the detection probability at sites E1 (CVP) and D1 (RGU), because the estimated transition probabilities from those sites onward was zero in each case.

Using only those detections classified as coming from 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 Release 3 to 0.10 ($\widehat{SE}$ = 0.03) for both Release 5 and Release 7, with a population estimate of 0.05 ($\widehat{SE}$ =0.01) (Table 2-19; Appendix C - Table 2). Estimates of the probability of remaining in the San Joaquin River at the junction with Old River (ψ_A) ranged from 0.39 ($\widehat{SE}$ =0.06) for Release 3 to 0.59 ($\widehat{SE}$ =0.07) for Release 7, with a population-level estimate of 0.47 ($\widehat{SE}$ =0.02). The only significant preference for either route was observed in Release 3, where the Old River route was used more than the San Joaquin River route (Ψ=0.39, $\widehat{SE}$ = 0.06; P=0.0443). Estimates of survival from Mossdale to Chipps Island through the San Joaquin River route (S_A) ranged from 0.01 ($\widehat{SE}$ =0.01) for releases 2, 3, and 6 to 0.07 ($\widehat{SE}$ =0.04) for releases 1 and 7, with an average estimate of 0.04 ($\widehat{SE}$ =0.01) over all releases (see Table 2-19). Estimates of survival from Mossdale to Chipps Island through the Old River route (S_B) ranged from 0.00 ($\widehat{SE}$ =0.00) for Release 1 to 0.15 ($\widehat{SE}$ =0.05) for Release 7, with an average of 0.07 ($\widehat{SE}$ =0.01) (see Table 2-19). 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 San Joaquin route (P=0.0100). Lack of significance for other releases may be a result of low statistical power. Pooled over all release groups, however, 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).

Table 2-19. Performance Metric Estimates (standard error in parentheses) for Tagged Juvenile Chinook Salmon Released in the 2010 VAMP Study, Omitting the Predator-type Detections (Release Occasion includes Primary Release at Durham Ferry and Supplemental Releases at Old River and Stockton.)

Parameter	Release Occasion							Population Estimate
	1	2	3	4	5	6	7	
S_A	0.07[a] (0.03)	0.01 (0.01)	0.01 (0.01)	0.04 (0.02)	0.06 (0.03)	0.01 (0.01)	0.07 (0.03)	0.04[a] (0.01)
S_B	0.00[a] (0.00)	0.03 (0.02)	0.01 (0.01)	0.10 (0.03)	0.13 (0.04)	0.07 (0.02)	0.15 (0.05)	0.07[a] (0.01)
ψ_A	0.48 (0.06)	0.44 (0.06)	0.39[a] (0.06)	0.52 (0.07)	0.45 (0.06)	0.43 (0.06)	0.59 (0.07)	0.47 (0.02)
ψ_B	0.52 (0.06)	0.56 (0.06)	0.61[a] (0.06)	0.48 (0.07)	0.55 (0.06)	0.57 (0.06)	0.41 (0.07)	0.53 (0.02)
S_{Total}	0.03 (0.02)	0.02 (0.01)	0.01 (0.01)	0.06 (0.02)	0.10 (0.03)	0.05 (0.02)	0.10 (0.03)	0.05 (0.01)
$S_{A(region)}$	0.47[a] (0.07)	0.40[a] (0.06)	0.16[a] (0.04)	0.24[a] (0.05)	0.49[a] (0.06)	0.11[a] (0.04)	0.35[a] (0.06)	0.32[a] (0.02)
$S_{B(region)}$	0.78[a] (0.06)	0.90[a] (0.04)	0.75[a] (0.06)	0.56[a] (0.09)	0.88[a] (0.08)	0.68[a] (0.29)	0.83[a] (0.21)	0.77[a] (0.05)
$S_{Total(region)}$	0.63 (0.05)	0.68 (0.05)	0.52 (0.06)	0.39 (0.06)	0.71 (0.06)	0.43 (0.17)	0.55 (0.10)	0.56 (0.03)

[a] = significant difference between route A and route B estimate (α=0.05).

Table 2-19 note: "Regional" survival extended to the Shipping Channel markers and Turn Cut in Route A, and the Central Valley Project Trash Rack, Exterior Radial Gate Receiver at Clifton Court Forebay and Old River North Receivers in Route B. (Population-level estimates are weighted averages of release group estimates.)

Survival was also estimated through the portion of the study area that matched the 2009 study area. Estimates of survival in the San Joaquin River route from Mossdale to the Shipping Channel Markers (C18/C16) or Turner Cut (TCN/TCS) ($SA_{(region)}$) ranged from 0.11 ($\widehat{SE}$ =0.04) for Release 6 to 0.49 ($\widehat{SE}$ =0.06) for Release 5 (population-level average = 0.32; $\widehat{SE}$ =0.02) (see Table 2-19). Estimates of survival from Mossdale to the entrances of the water export facilities (CVP, RGU) or the northern Old River receivers at Highway 4 (ORN) ($SB_{(region)}$) ranged from 0.56 ($\widehat{SE}$ =0.09) for Release 4 to 0.90 ($\widehat{SE}$ =0.04) for Release 2 (population-level average=0.77 ($\widehat{SE}$ =0.05)) (see Table 2-19). Overall survival through the southern region of the Delta (comparable to the study region in the 2009 study) was estimated to range from 0.39 ($\widehat{SE}$ =0.06) for Release 4 to 0.71 ($\widehat{SE}$ =0.05) for Release 5 (average = 0.56; $\widehat{SE}$ =0.03) (see Table 2-19). These survival estimates were considerably higher than comparable estimates from the 2009 VAMP study, where average survival through this region (both routes) was estimated to be 0.06 ($\widehat{SE}$ =0.01) (without predator- type detections), with survival in the San Joaquin River route estimated at 0.05 ($\widehat{SE}$= 0.02), and survival through the Old River route estimated at 0.08 ($\widehat{SE}$= 0.02) (SJRGA, 2010).

When predator-type detections were included in the analysis, estimates of total survival from Mossdale to Chipps Island (S_{Total}) ranged from 0.06 ($\widehat{SE}$. =0.02) for Release 2 to 0.18 ($\widehat{SE}$ =0.03) for Release 5, with a population-level average estimate of 0.11 ($\widehat{SE}$ =0.01) (Table 2-20; Appendix C - Table 3). Using the full data set with the predator-type detections, estimates of the route entrainment probability into the San Joaquin River route (ψ_A) ranged from 0.38 ($\widehat{SE}$ =0.06) for Release 3 to 0.60 ($\widehat{SE}$ =0.06) for Release 7 (average = 0.49; $\widehat{SE}$ =0.02). As with the reduced data set, only Release 3 showed a statistically significant route preference (P=0.0229), with $\hat{\psi}_A$= 0.38 ($\widehat{SE}$ = 0.06) for that release group. Route-specific survival estimates from Mossdale to Chipps Island through the San Joaquin River route (S_A), including predator-type detections, ranged from 0.01 ($\widehat{SE}$ =0.03) for Release 2 to 0.18 ($\widehat{SE}$=0.05) for Release 5, with a population-level average of 0.11 ($\widehat{SE}$ =0.01) (see Table 2-20). Survival to Chipps Island through the Old River route (S_B) had estimates ranging from 0.04 ($\widehat{SE}$ =0.02) for Release 1 to 0.21 ($\widehat{SE}$=0.05) for Release 7 with a population-level average of 0.12; ($\widehat{SE}$ =0.01) (see Table 2-20). There was a statistically significant (α=0.05) difference in estimated survival between the two routes only for Release 2, for which the Old River route had a significantly higher probability of survival to Chipps Island than the San Joaquin River route (P =. 0.0289).

Table 2-20. Performance Metric Estimates (standard error in parentheses) for Tagged Juvenile Chinook Salmon Released in the 2010 VAMP Study, Including the Predator-type Detections (Release Occasion includes Primary Release at Durham Ferry and Supplemental Releases at Old River and Stockton.)

Parameter	Release Occasion							Population Estimate
	1	2	3	4	5	6	7	
S_A	0.11 (0.04)	0.01[a] (0.03)	0.12 (0.04)	0.15 (0.04)	0.18 (0.05)	0.10 (0.03)	0.12 (0.04)	0.11 (0.01)
S_B	0.04 (0.02)	0.10[a] (0.03)	0.06 (0.03)	0.15 (0.04)	0.18 (0.05)	0.11 (0.03)	0.21 (0.05)	0.12 (0.01)
ψ_A	0.50 (0.06)	0.43 (0.06)	0.38[a] (0.06)	0.55 (0.06)	0.47 (0.06)	0.49 (0.06)	0.60 (0.06)	0.49 (0.02)
ψ_B	0.50 (0.06)	0.57 (0.06)	0.62[a] (0.06)	0.45 (0.06)	0.53 (0.06)	0.51 (0.06)	0.40 (0.06)	0.51 (0.02)
S_{Total}	0.07 (0.02)	0.06 (0.02)	0.08 (0.02)	0.15 (0.03)	0.18 (0.03)	0.10 (0.02)	0.16 (0.03)	0.11 (0.01)
$S_{A(region)}$	0.64[a] (0.07)	0.63[a] (0.07)	0.49[a] (0.07)	0.59 (0.06)	0.77[a] (0.06)	0.30[a] (0.05)	0.54[a] (0.07)	0.57[a] (0.02)
$S_{B(region)}$	0.93[a] (0.05)	0.98[a] (0.02)	0.93[a] (0.07)	0.52[b] (0.06)	1.09[a] (0.10)	1.43[a] (0.57)	1.11[a] (0.25)	1.00[a] (0.09)
$S_{Total(region)}$	0.79 (0.04)	0.83 (0.04)	0.76 (0.06)	0.56[b] (0.05)	0.94 (0.06)	0.88 (0.30)	0.77 (0.11)	0.79 (0.05)

[a] = significant difference between route A and route B estimate (a=0.05).
[b] = survival to Central Valley Project trashracks not included.

Table 2-20 note: "Regional" 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 the Old River north receivers in Route B. (Population estimates are weighted averages of release group estimates.)

Including the predator-type detections, estimates of regional survival in the San Joaquin River route from Mossdale to the Shipping Channel Markers (C18/C16) or Turner Cut (TCN/TCS) ($SA_{(region)}$) ranged from 0.30 ($\widehat{SE}$ =0.05) for Release 6 to 0.77 ($\widehat{SE}$ =0.06) for Release 5, with a population-level average of 0.57 ($\widehat{SE}$ =0.02) (see Table 2-20). In the Old River route, estimates of regional survival to the entrances of the water export facilities (CVP, RGU) or the northern Old River receivers at Highway 4 (ORN) ($S_{B(region)}$) ranged from 0.93 ($\widehat{SE}$ =0.05-0.07) for both releases 1 and 3, to 1.43 ($\widehat{SE}$ =0.57) for Release 6 with a population-level average of 1.00; ($\widehat{SE}$ =0.09) (see Table 2-20). These estimates exceeded the comparable estimates from 2009 by approximately 0.4-0.5 for both routes, with $\hat{S}_{A(region)}$=0.10 and $\hat{S}_{B(region)}$ =0.58 in 2009 (including predator-type detections).

For most releases, the largest component of the estimated Old River route survival through the southern Delta ($S_{B(region)}$) came from the transition to the Central Valley Project trash rack ($\varphi_{B2,E1}$) when predator-type detections were included. It was not possible to estimate the transition probability to the trash rack for Release 4 when predator-type detections were included in the model, probably because of failure of the assumption that all tags observed at the trash rack had the same probability of moving on to the holding tank (with predators less likely to move to the holding tank). Without that component of overall survival through the southern Delta, the estimate of the Old River survival through that region was only 0.52 ($\widehat{SE}$ =0.06) for Release 4, considerably lower than the estimates for the other releases, in which the transition probability to the trash rack was included (see Table 2-20). The very high point estimate of $S_{B(region)}$ observed for Release 6 resulted from the long travel times observed among tags classified as being in predators, in particular long travel times to the Central Valley Project trash rack. These long travel times resulted in large corrections in survival estimates due to tag failure, producing impractical point estimates of survival in the Old River route through the southern portion of the Delta. Estimates of the total survival through the southern portion of the Delta, including both routes, ($S_{Total(region)}$) ranged from 0.76 ($\widehat{SE}$ =0.06) for Release 3 to 0.94 ($\widehat{SE}$ =0.06) for Release 5, with a population-level average of 0.79 ($\widehat{SE}$ =0.05) (see Table 2-20). Again, the estimate for Release 4 (0.56, $\widehat{SE}$ =0.05) was lower than the others, but did not include survival to the Central Valley Project trash rack. The 2010 estimates of overall survival through the 2009 study area were considerably higher than the comparable estimates from 2009: $\hat{S}_{Total\ (region)}$ = 0.34 for 2009, including predator-type detections. Estimates of survival through both the Old River region ($S_{B(region)}$) and through the entire southern region ($S_{Total(region)}$) must be interpreted with caution, especially when based on estimates that included detections classified as coming from predators, because of likely violation of model assumptions.

The point estimates of the overall survival to Chipps Island (S_{Total}) were consistently higher for the full data set that included the predator-type detections than for the reduced data set that excluded those detections (Table 2-19 vs. Table 2-20), with the releases 1 and 2 showing the smallest differences (0.04) and releases 4 and 5 showing the largest differences (0.09 and 0.08, respectively). Exclusion of the predator-type detections had little effect on estimates of the route entrainment probability at the head of Old River (ψ_A). Exclusion of the predator-type detections had no effect on the route-specific survival to Chipps Island through the San Joaquin River route (S_A) for Release 2; both the full data set, including predator-type detections, and the reduced data set, including only smolt-type detections, produced a very low estimate of S_A for Release 2 (0.01, $\widehat{SE}$ =0.01-0.03). However, for all other releases, including the predator-type detections increased the point estimate of survival through the San Joaquin River route by a range of 0.04 to 0.12 (Table 2-19 vs. Table 2-20). The increase in the point estimates of survival to Chipps Island through the Old River route (S_B) was more stable, ranging from 0.04 (releases 1 and 6) to 0.07 (Release 2). On the smaller, regional scale, comparable to the study area in the 2009 study, the increase in point estimates of survival through the southern Delta ($S_{Total(region)}$) ranged from 0.15 (Release 1) to 0.45 (Release 6). As noted above, the very large increase in survival for Release 6 that was seen using all detections relative to only smolt- type detections is likely due to long travel times within the western Old River region that artificially increased the point estimates of the transition probabilities, and that were interpreted as evidence of predation.

Travel Time

For tags released at Durham Ferry and classified as being in salmon smolts, average travel time through the reaches ranged from 0.15 days ($\widehat{SE}$ =0.01) from the Stockton USGS gauge (STS) to the Navy Bridge in Stockton (STN) (approximately 3 km), to 3.14 days (=0.36) from Medford Island (MFE/MFW) to Chipps Island (CHP) (Table 2-21). There were multiple paths between Medford Island and Chipps Island; the path that used only the San Joaquin River was approximately 46 km. When all detections were considered, including those classified as being in predators, there was little change in travel times through the southern part of the Delta (e.g., through Stockton; see Table 2-21). However, as the distance from Durham Ferry increased, the difference in average travel time associated with predator-type detections generally increased as well. The longest travel times for Durham Ferry tags (including predator-type detections) were observed between the Old River South receivers (ORS) and the Central Valley Project trash rack (CVP), with an average travel time of 7.15 days ($\widehat{SE}$ =1.07), and from Turner Cut (TCN/TCS) to Chipps Island, with an average travel time of 9.43 days ($\widehat{SE}$ =1.46). Without the predator-type detections, no tags were observed to move from Turner Cut to Chipps Island, and the average transition from Old River South to the Central Valley Project trash racks was only 1.03 days ($\widehat{SE}$=0.07) (see Table 2-21). It is not surprising that travel times were longer on average when the predator-type tags were included, because the decision process used to identify predator detections was partly based on travel time.

Tags released at Old River and classified as being in salmon had travel times ranging from 0.10 days ($\widehat{SE}$ <0.01) for the transition from the first Old River receivers (OR1/OR2) to Old River South, to 1.75 days ($\widehat{SE}$ =0.11) from the Central Valley Project holding tank to Chipps Island (see Table 2-21). In general, average travel times were longer when predator-type detections were included, although the difference was not consistently significant (α=0.05). Tags released at Stockton and classified as being in salmon had travel times that were very similar to those observed for the Durham Ferry releases (see Table 2-21). When predator-type detections were included, average travel times tended to be longer.

Table 2-21. Average Travel Time in Days of Acoustic-tagged Juvenile Chinook Salmon through the San Joaquin River Delta during the 2010 VAMP Study

Reach		Durham Ferry Release Groups					
		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)	463	1.22	0.01	468	1.25	0.02
Banta Carbona (BCA)	Mossdale (MOS)	439	0.2	<0.01	444	0.25	0.03
Mossdale (MOS)	Lathrop (SJ1/SJ2)	202	0.18	0.01	232	0.31	0.12
	Old River (OR1/OR2)	228	0.09	<0.01	244	0.14	0.02
Lathrop (SJ1/SJ2)	Stockton USGS Gauge (STS)	169	0.69	0.02	206	0.82	0.05
Stockton USGS Gauge (STS)	Stockton Navy Bridge (STN)	150	0.15	0.01	186	0.26	0.06
Stockton Navy Bridge (STN)	Shipping Channel Markers (C18/C16)	69	1.44	0.06	110	2.93	0.37
	Turner Cut (TCN/TCS)	5	1.87	0.35	18	2.69	0.33
Shipping Channel Markers (C18/C16)	Medford Island (MFE/MFW)	28	0.33	0.06	69	0.91	0.16
Old River (OR1/OR2)	Old River South (ORS)	205	0.11	<0.01	233	0.14	0.01
Old River South (ORS)	Old River North (ORN)	58	1.35	0.13	40	3.16	0.5
	Clifton Court Forebay Access Channel (RGU)	50	1.03	0.08	70	2.37	0.25
	Central Valley Project trashrack (CVP)	53	1.03	0.07	74	7.15	1.07
Clifton Court Forebay Access Channel (RGU)	Clifton Court Forebay Interior (RGD)	18	0.31	0.08	53	1.02	0.39
Central Valley Project trashrack (CVP)	Central Valley Project Holding Tank (CVPtank)	11	0.18	0.09	19	0.3	0.08
Medford Island (MFE/MFW)	Chipps Island (CHP)	8	3.14	0.36	24	4.05	0.35
Turner Cut (TCN/TCS)		0	NA	NA	2	9.43	1.46
Old River North (ORN)		1	3.84	NA	3	4.6	1.74
Clifton Court Forebay Interior (RGD)		0	NA	NA	0	NA	NA
Central Valley Project Holding Tank (CVPtank)		19	1.02	0.16	28	1.02	0.12
Reach		**Old River Release Groups**					
		Without Predator-Type Detections			**With Predator-Type Detections**		
Upstream Boundary	**Downstream Boundary**	**N**	**Travel Time**	**SE**	**N**	**Travel Time**	**SE**
Old River Release Site	Old River (OR1/OR2)	243	1.07	0.02	245	1.11	0.03
Old River (OR1/OR2)	Old River South (ORS)	229	0.1	<0.01	236	0.1	<0.01
Old River South (ORS)	Old River North (ORN)	55	1.4	0.1	51	1.74	0.7
	Clifton Court Forebay Access Channel (RGU)	82	0.96	0.07	63	1.21	0.14
	Central Valley Project trashrack (CVP)	35	1.25	0.1	72	9.6	0.99
Clifton Court Forebay Access Channel (RGU)	Clifton Court Forebay Interior (RGD)	31	0.16	0.03	50	0.4	0.08
Central Valley Project trashrack (CVP)	Central Valley Project Holding Tank (CVPtank)	12	0.19	0.05	18	0.38	0.14
Old River North (ORN)	Chipps Island (CHP)	0	NA	NA	1	20.65	NA
Clifton Court Forebay Interior (RGD)		0	NA	NA	1	1.42	NA
Central Valley Project Holding Tank (CVPtank)		16	1.75	0.11	26	1.45	0.22
Reach		**Stockton Release Groups**					
		Without Predator-Type Detections			**With Predator-Type Detections**		
Upstream Boundary	**Downstream Boundary**	**N**	**Travel Time**	**SE**	**N**	**Travel Time**	**SE**
Stockton Release Site	Stockton Navy Bridge (STN)	208	1.37	0.02	222	1.64	0.09
Stockton Navy Bridge (STN)	Shipping Channel Markers (C18/C16)	69	1.43	0.06	117	2.73	0.26
	Turner Cut (TCN/TCS)	7	1.54	0.25	15	2.64	0.5
Shipping Channel Markers (C18/C16)	Medford Island (MFE/MFW)	43	0.34	0.06	81	0.87	0.11
Medford Island (MFE/MFW)	Chipps Island (CHP)	11	3.68	0.31	26	4.83	0.44
Turner Cut (TCN/TCS)		0	NA	NA	0	NA	NA

Table 2-21 note: Average travel time is an arithmetic mean.

Comparison of NPB Fate Assignment and VAMP Detections

The NPB fate assignment and the VAMP decision rule used to distinguish between detections of salmon smolts and detections of predators focused on different sets of information. The NPB analysis focused mainly on near-field movements of the tag in the presence of the 2-dimensional array of receivers located at the Head of Old River Barrier, with secondary attention paid to downstream tag detections. The VAMP analysis, on the other hand, focused on mid-field and far-field tag movements in conjunction with observations of river flow and water velocity. The VAMP decision rule used the NPB predator classifications in cases where migration rates seemed counter to flow patterns (i.e., fast migration rates during low flow, or slow migration rates during high flow). Thus, it is not expected that the two methods agree perfectly on predator classification. The VAMP analysis classified 39 tags as in predators for the first time after leaving the NPB area, corresponding to predator mortality of 9% in that region. The draft NPB analysis estimated a higher rate of mortality due to predation in the NPB area, based on detections of VAMP fish at the Old River barrier in 2010 (Bowen and Bark 2010) however Bowen's estimate will be reduced when the draft NPB report is finalized based in part, on the information provided by the far field observations from the VAMP study (M. Bowen, personal communication).

After accounting for differences in predation classification, there were only five conflicts in route assignment between the NPB analysis and the VAMP analysis. For three tags, the barrier data assigned the San Joaquin River and VAMP detections assigned Old River; for two tags, the barrier data assigned Old River and VAMP detections assigned the San Joaquin River. For each of these five tags, the tag was not detected on the VAMP receiver in the route assigned in the barrier data. It is possible that after initially moving in one direction, the fish eventually turned to go down the other river without being detected on the ORB receivers.

A total of 316 tags were detected on the HORB receivers and classified as both entering the area (i.e., leaving Mossdale) in smolts in the VAMP analysis and also leaving the area in smolts by the NPB study (draft analysis). Of these 316 tags, 100% were detected on downriver receivers, including those that were newly classified as being in predators between leaving the HORB area and being detected on downriver receivers. Without these "new predator" detections, 309 of the 316 tags (98%, $\widehat{SE}$ =1%) were detected on downriver receivers. Each of the 7 tags (out of 316) not treated as survivors in the "smolt-only" data set were detected in Old River at OR1/ OR2, but were newly classified as in predators there because of either unexpectedly long or unexpectedly short transition times from Mossdale. Assuming that these 7 new predator classifications at OR1/OR2 were appropriate, the difference between the assumed (100%) and estimated (98%) survival from the head of Old River to the Old River receivers would have a negligible effect on estimates of route entrainment probability at the head of Old River, with differences considerably smaller than the standard error on route entrainment estimates ($\widehat{SE}$ estimates ranged from 0.06-0.07). Thus, the assumption of 100% survival from the head of Old River to the Lathrop or Old River receivers was acceptable.

Mobile Telemetry

Mobile tracking efforts in previous years identified three sites of high juvenile salmon mortality or tag defecation: 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, 2007b and Vogel, 2010). Based on the 2010 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 (Figure 2-17).

Figure 2-17. Approximate Last Known Location of 94 Acoustic Tags Detected as Immobile by Mobile Monitoring in Old River and Grant Line Canal between the Head of Old River and the State and Federal Pumping Facilities

Survival in the San Joaquin River between Banta Carbona and Old River was high during the 2010 VAMP. Of the few tags lost in this reach that had been released at Durham Ferry, five were detected by mobile tracking and were found to be distributed evenly throughout the reach with no apparent hot spots (Figure 2-18).

A total of 128 tags from marked salmon were detected in the San Joaquin River between Old River and Turner Cut. Nine of these tags were later detected at a downstream fixed acoustic station, indicating that the tag was in a live fish (smolt or predator) that moved out of the reach sometime after detection by the mobile array. The remaining 119 detections represent the last known location for those tags. Precise hotspots were not detected. Sixty-eight percent (68%) of the detected immobile tags in this reach of the San Joaquin River were found in the Stockton Deep Water Ship Channel (DWSC) (n=87), while 18% (n=23) were detected between its junction with Old River and the Stockton release site, and 14% (n=18) were detected between the Stockton release site and the DWSC (see Figure 2-18).

A total of 120 tags were detected in Old River and Grant Line Canal between the Head of Old River and the State and federal pumping facilities. Twenty-six of these tags were later detected at a downstream fixed acoustic station, indicating that the tag was in a live fish (smolt or predator) that moved out of the reach sometime after detection by the mobile array. The remaining 94 tag detections represent the last known location for those tags. Precise hotspots were not detected. The highest concentration of the tags detected by mobile monitoring in this reach were found in the vicinity of the State and federal Pumping facilities 44% (n=87), while 28% (n=33) were detected in Old River upstream of Grant Line Canal, and 28% (n=34) were detected in Grant Line Canal. In general, there was a trend of increased tag detections as distance to the State and federal pumping facilities decreased (see Figure 2-17 and Figure 2-18).

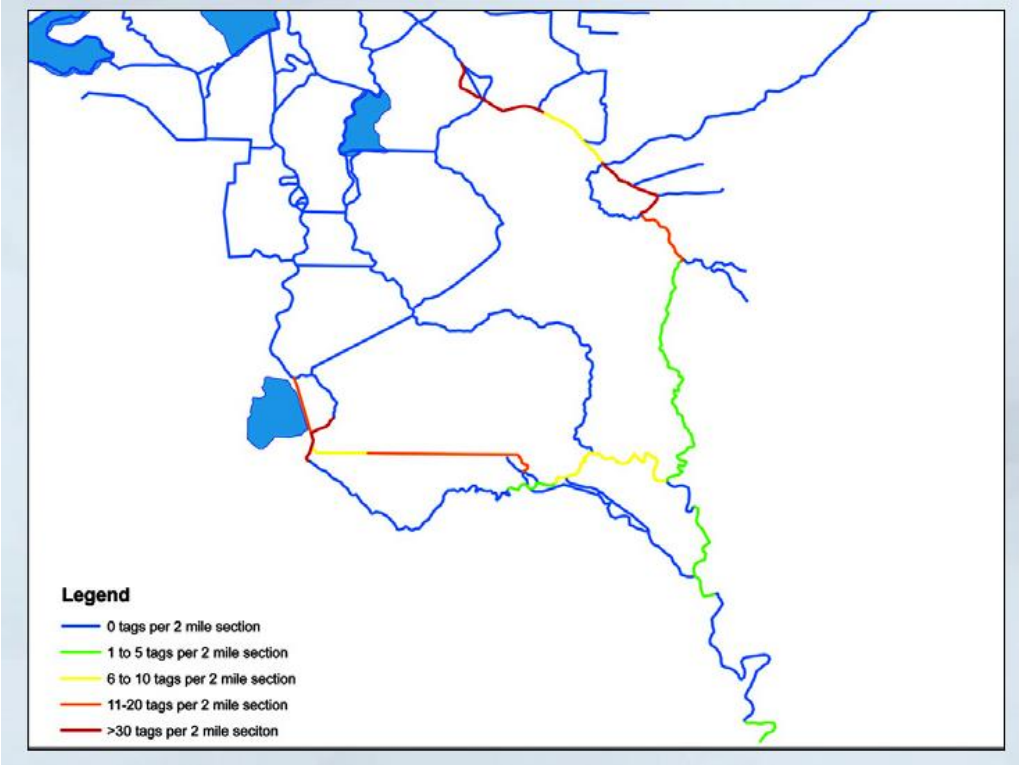


Fig 2-18 note: Immobile tags were defined as the Last Known Location of Acoustic Tags that were Found to be Immobile by Mobile Monitoring Conducted by Boat throughout the 2010 VAMP Program.

Figure 2-18. Approximate Density of Observed Immobile Acoustic Tags per Two-mile Reach of the Main Stem San Joaquin River from Old River Ferry to Turner Cut and from the Head of the Old River to the State and Federal Pumping Facilities

San Joaquin River Salmon Protection - Comparison with Past Years

One of the objectives of VAMP is to improve conditions to increase the survival of juvenile Chinook salmon smolts produced in the San Joaquin River tributaries during their downstream migration through the lower river and Delta. It has been hypothesized that actions aimed at improving conditions for the juveniles will translate into greater adult abundance and escapement in future years.

To determine if VAMP has been successful in targeting the migration period of naturally produced juvenile salmon, catches of unmarked salmon in the Kodiak trawl at Mossdale and in salvage at the CVP and SWP facilities were compared prior to, during, and after the 2010 VAMP period.

Unmarked and Marked Salmon Captured at Mossdale

The general time period for VAMP of mid-April to mid- May was chosen based on historical data that indicated a high percentage of the salmon smolts emigrating from the San Joaquin tributaries pass Mossdale during this time. The 2010 VAMP period was April 25th - May 25th, and trawl sampling at Mossdale was conducted three days/week January – March; five days per week April – May; and three days per week in June. Densities (catch per 10,000 cubic meters) of unmarked juvenile salmon captured at Mossdale from January through June are shown in Figure 2-19. 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 MRH. However during 2010, all unmarked hatchery fish from MRH were released in the San Joaquin River at Jersey Point, 43.9 miles downstream of Mossdale. Zero adipose fin-clipped or acoustically tagged fish were captured, and the only

externally marked fish captured in the Mossdale trawl during 2010 were Panjet marked fish released immediately upstream of the trawl to estimate capture efficiency.

Average daily densities of unmarked juvenile salmon were highly variable during 2010, ranging from zero to nearly 40 salmon per 10,000 cubic meters. Densities began to rise in late March, prior to VAMP, and remained elevated through late May (see Figure 2-19). With the exception of a one day peak in early June, post-VAMP densities were frequently zero. Densities may have been as high or higher on days when no sampling was conducted (sampling was only conducted 5 days/week in April-May). The size of juvenile salmon captured in the Mossdale trawl between January and June is shown in Figure 2-20.

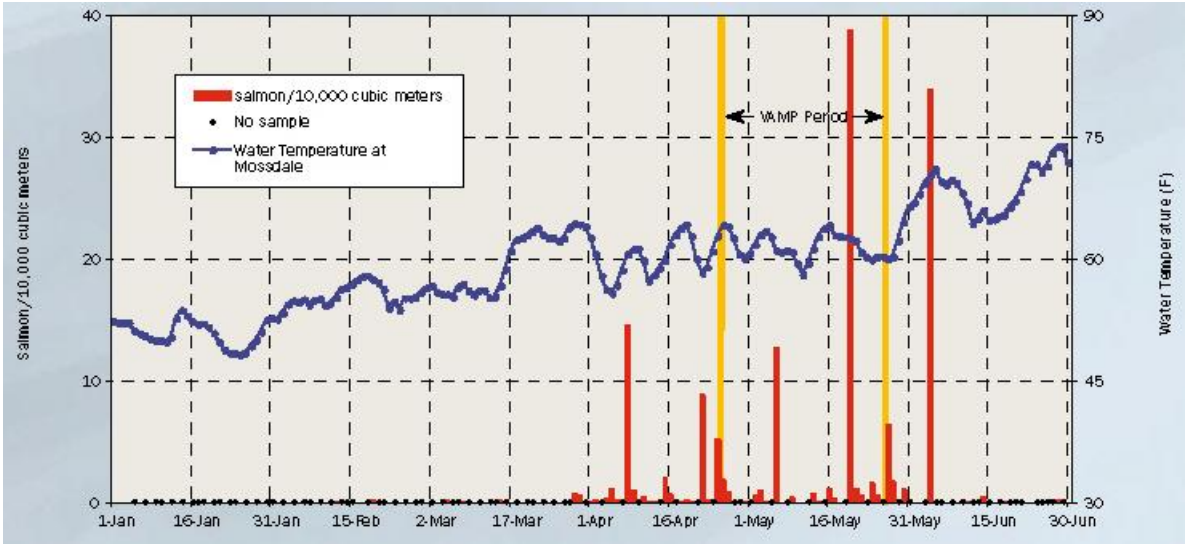


Figure 2-19. Average Daily Densities of Unmarked Juvenile Chinook Salmon Caught in the Mossdale Kodiak Trawl in 2010 on the San Joaquin River

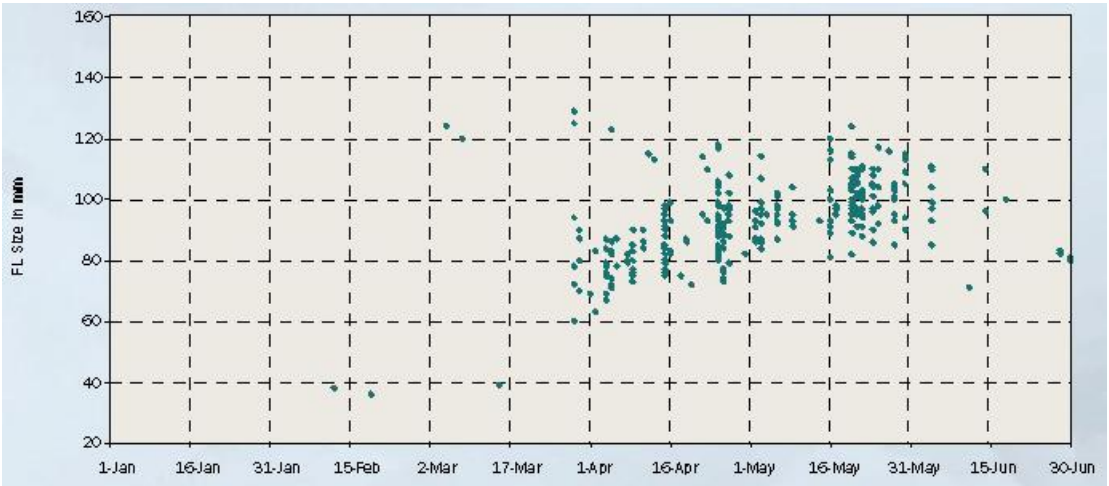


Figure 2-20. Individual Daily Forklengths (FL) in Millimeters of Juvenile Chinook Salmon from the Mossdale Kodiak Trawl on the San Joaquin River, January through June 2010

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 untagged salmon are potentially from any source in the Central Valley. It is uncertain which of the unmarked salmon recovered are of San Joaquin 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 2010 exceeded the flow at Vernalis prior to early-April and during the majority of June, and ranged from 47 to 76% less than Vernalis flow from early April to early June (Figure 2-21).

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 DFG 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 HORB, and the amount of water pumped by each facility are a few of the factors that influence the number of juvenile salmon salvaged and lost. Salmon density at the facilities can be an indicator of periods of time when more juvenile salmon may be susceptible to the export and salvage system. Salvage efficiency is likely lower for smaller-sized salmon (fry and parr), so their salvage numbers and estimated losses would 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 April at CVP and in late-April at SWP and remained elevated through mid-May (Figure 2-22 and Figure 2-23). Additionally, there were three weeks of elevated levels of estimated loss (> 500 salmon) at SWP in late-January and early-February. Salmon densities based on combined salvage and loss estimates divided by 1,000 acre feet of export were also highest during much of the typical VAMP period at both facilities (Figure 2-24). Densities at the SWP had a distinct peak in mid-May, in contrast the CVP did not show a defined peak during the VAMP period.

The size and timing distributions of unmarked salmon in the Mossdale trawl (see Figure 2-19) during January through June corresponds well with the distributions of the fish salvaged at the facilities during this same time period (Figure 2-25). Based on comparisons with Mossdale data, it appears that many salmon salvaged from late March to late May period could have originated from the San Joaquin basin.

These results demonstrate that the primary 2010 San Joaquin River salmon smolt migration period from the beginning of April to mid-late May coincided with the higher salvage period of the CVP/SWP facilities. In addition, the timing corresponded with the operation of the Non-Physical Barrier (NPB) (often called the Bio- Acoustical Fish Fence or BAFF), which was installed April 15th through June 16th. Sampling frequency at Mossdale in 2010 was more limited than in most recent years during the VAMP period and occurred only 5 days a week while in past years, sampling occurred 7 days per week in April and May. Production estimates at Mossdale could be improved by ensuring that sampling is conducted daily when most salmon smolts are emigrating.

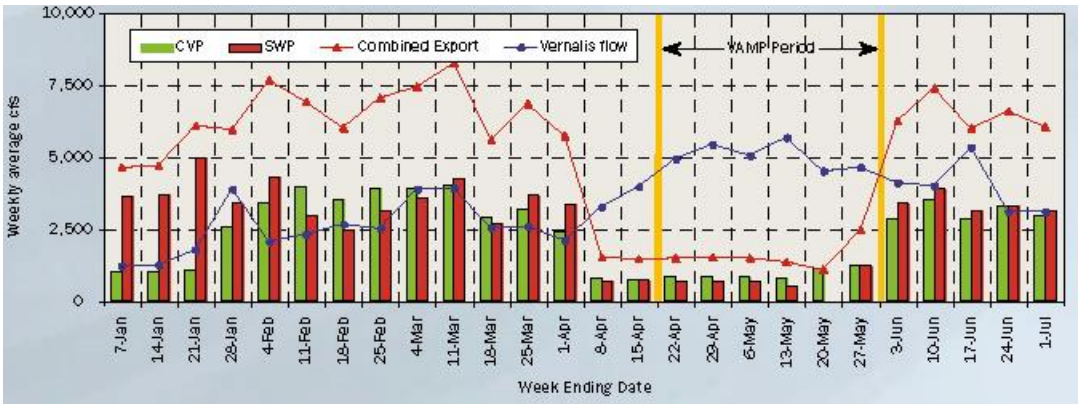


Figure 2-21. Weekly Average Export Rates from January through June 2010 from the State Water Project (SWP) & Central Valley Project (CVP) and Vernalis Flow in Cubic Feet per Second (cfs)

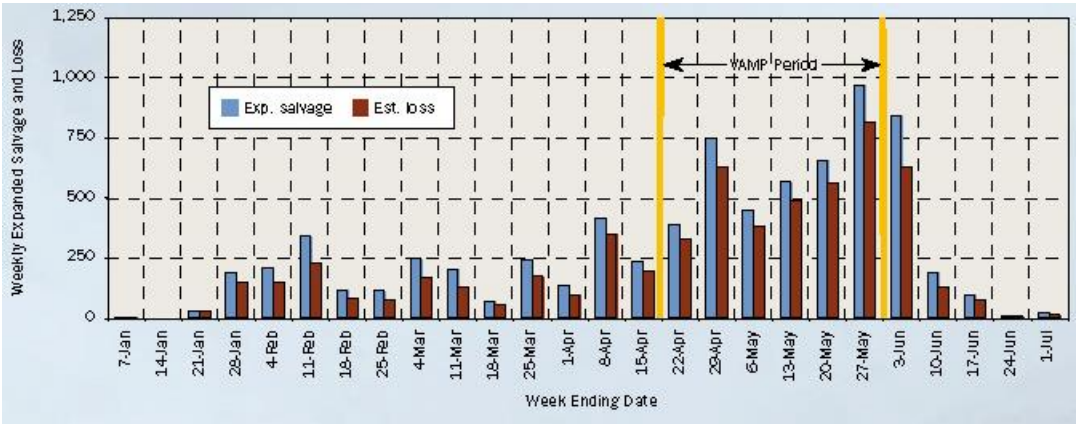


Figure 2-22. Central Valley Project Estimated Juvenile Chinook Salmon Salvage and Loss from January through June 2010

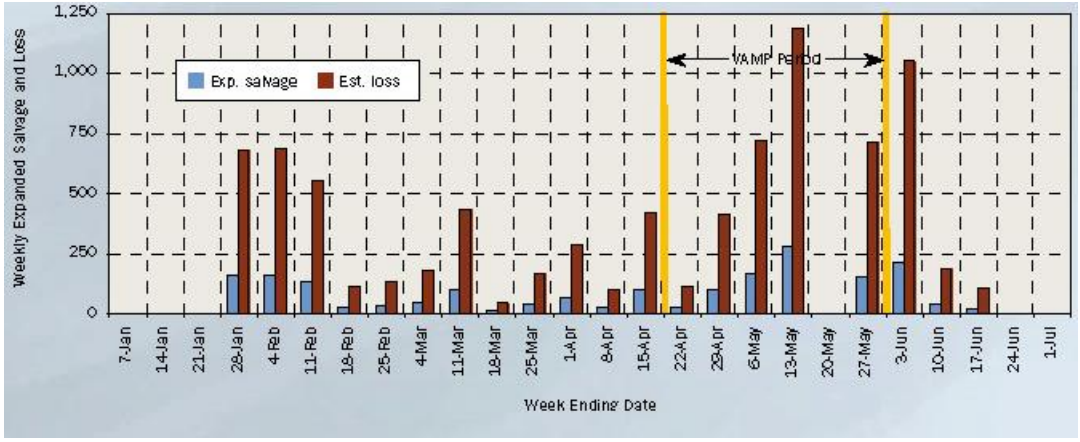


Figure 2-23. State Water Project Estimated Juvenile Chinook Salmon Salvage and Loss from January through June 2010

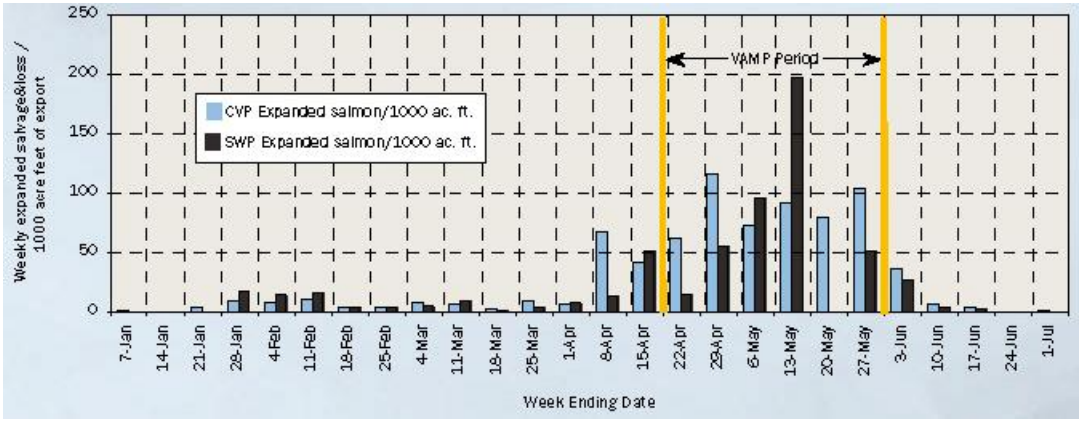


Figure 2-24. State Water Project and Central Valley Project Combined Juvenile Chinook Salmon Salvage and Loss Density Estimates per 1,000 Acre Feet of Export from January through June 2010

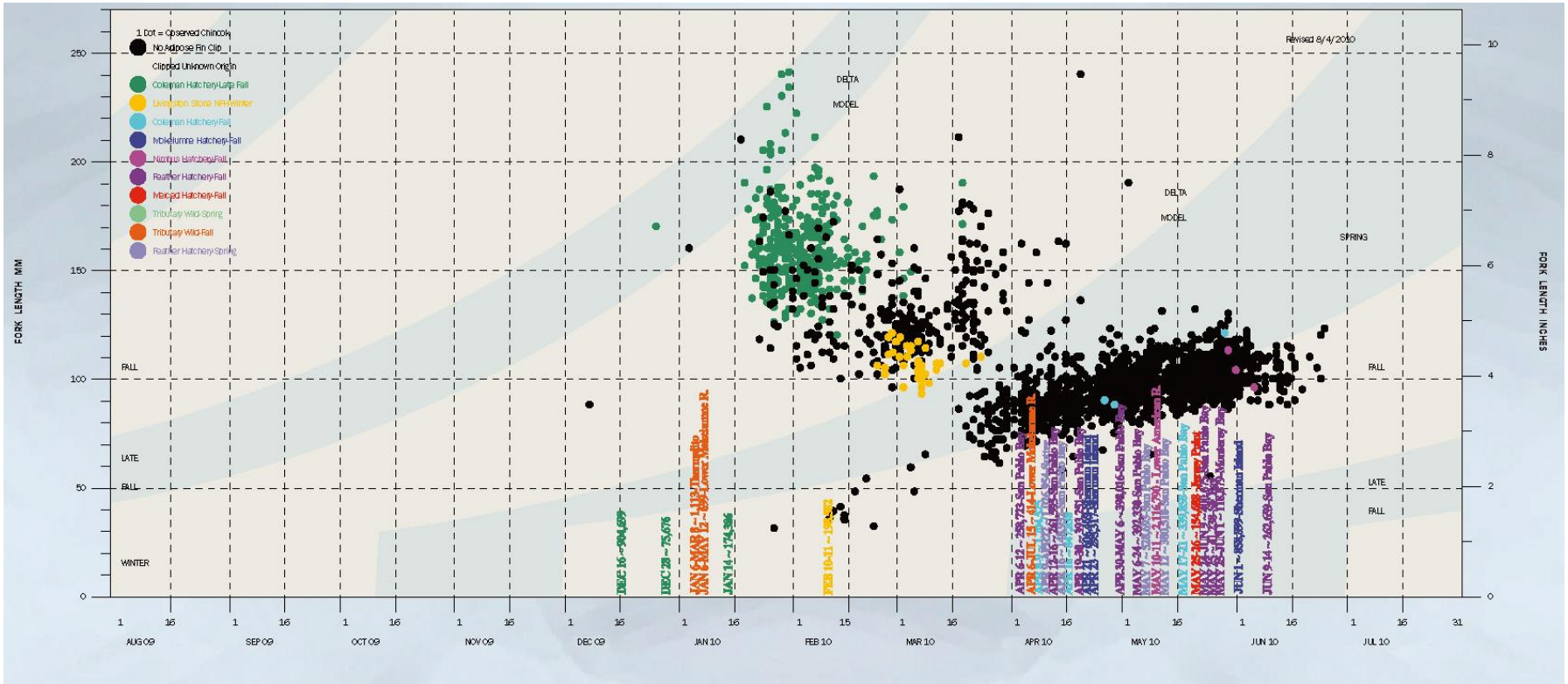


Figure 2-25. Observed Juvenile Chinook Salmon Salvage at the State Water Project and Central Valley Project Delta Fish Facilities from 8/1/2009 Through 7/31/2010 (Source: S Greene, DWR)