Highlights from 2011-2014 results from Six-Year Study

(summarizing 689 pages of draft and final reports)

- Four years of the total six years of studies have been written up as either final or draft reports
    - Final Reports available for 2011-2013
    - Draft report available for 2014
- Studies released acoustically tagged hatchery steelhead into the San Joaquin River at Durham Ferry and tracked them through the Delta system using multiple releases and multiple acoustic receiver locations throughout the lower San Joaquin River and Delta. (see Table 1 and Figure 1)
    - 2011 – Five releases, total of 2,196 fish tagged and released at Durham Ferry from late March through mid-June.
    - 2012 – Three release, total of 1,435 fish tagged and released at Durham Ferry from early April through mid-May.
    - 2013 – Three releases, total of 1,425 fish tagged and released at Durham Ferry from early March through early May.
    - 2014 – Three release, total of 1,432 fish tagged and released at Durham Ferry from late March through late May.
- Studies occurred during a wet year (2011) and three dry/critically dry years (2012-2014; the first three years of the 5-year drought) (see Figure 2).
    - Flows during the wet year (2011) were typically above 10,000 cfs at Vernalis, and peaked at approximately 29,000 cfs.
    - Flows during 2012 through 2014 were considerably less, never exceeding 5,000 cfs at at Vernalis, and typically less than 2,500 cfs for most of the period of interest.
    - The HOR barrier was installed during 2012 and 2014. In 2014 the HOR barrier went in after the first release of fish occurred. With the barrier in, few fish were entrained into the Old River route at the junction of Old River and the San Joaquin River (see Table 2 and Table 3a and 3b).
- During the wet year (2011) survival was better than the drought years (2012-2014) for both the San Joaquin River route (S_A) and the Old River route (S_B), as well as total survival (S_{total}) through the system. See Tables 2 and 3a and b.
    - Absolute survival through the San Joaquin River route was better than the Old River route in 3 of the 4 study years (2011, 2012, and 2014) but not statistically significant.
    - Survival through the sub-routes; south Delta and middle Delta (S_{SD} and S_{MD}), were variable and release group dependent. Clear distinctions between the Old river and San Joaquin River routes were not consistent.
- The presence of the HOR barrier was important in determining the proportion of fish entering Old River (see Tables 2 and 3a, 3b) in relation to those remaining in the San Joaquin River route.
    - During low flow years, when the barrier was out, (2013, first release in 2014), and fish were released into the system at Durham Ferry, higher numbers of fish entered the Old River route at the HOR junction. This appears to be a function of river stage, tides, and shunting of flow into the Old River channel.

  - When flows were high (2011) the distribution of fish into Old River and the San Joaquin were nearly equal.
- Water temperatures were elevated in 3 out of the 4 study years (2012-2014) during the fish releases (see Figures 3-6).
  - Waters temperatures (as measured at Mossdale) were consistently lower in 2011 compared to 2012-2014 during fish releases.
  - Water temperatures in 2012 were consistently above 18ºC for the second and third releases. Water temperatures following the first release were between 15 and 18ºC.
  - Water temperatures in 2013 were slightly below 15ºC during the first release, but were above 15ºC during the second and third releases.
  - Water temperatures in 2014 were between 15 and 18ºC during the three releases, with spikes following the first and third releases.
- Survival, as measured per kilometer travelled, is depicted in Tables 4 and 5, cumulative mortality /survival in Figures 7-12.
  - Overall cumulative mortality is higher in the reaches between Durham Ferry and Mossdale (Figures 7-12), which is common between the Old River route and the San Joaquin River route. The survival per kilometer is approximately 96% or higher (Table 4) but accounts for approximately 40-60% of overall mortality (Figures 7-12).
  - Cumulative mortality in the San Joaquin River route is inconsistent, with some years having high mortality in the reach between Mossdale and the Stockton Deepwater Ship Channel (Garwood Bridge/ Navy Bridge) and again in the lower reaches of the San Joaquin River route (MacDonald Island to Chipps Island).
  - Increased cumulative mortality in the Old River route occurs between the entrance to the Old River corridor (Old River south) and Chipps Island via the fish collection facilities (Figures 8,10, and12).

Table 1: Number of steelhead with acoustic tags released for each study year. Note that because of differences in routing with HORB in vs. out, the sample size for the survival estimates in the San Joaquin River route vs. the Old River route is very different.

Study Year	Total # Tags Released	Release Groups	Date of Release	Number Tags Released	Number Assigned to Old River Route	Number Assigned to San Joaquin River route
2011	2,196	1	3/22 – 3/26	477		
HORB out		2	5/3 – 5/7	474		
		3	5/17 – 5/21	477		
		4	5/22 – 5/26	480		
		5	6/15 – 6/17	285		
2012	1,435	1	4/4 – 4/7	477	20	304
HORB in		2	5/1 – 5/6	478	11	297
		3	5/17 – 5/23	480	17	150
2013	1,425	1	3/6 – 3/9	476	278	16
HORB out		2	4/3 – 4/6	477	279	31
		3	5/8 – 5/11	472	265	40
2014	1,432	1	~3/26 – 3/29	474		
HORB in		2	~4/26 -4/29	480		
		3	~5/20 -5/23	478		

Table 2: Summary of 6-Year Steelhead Parameters: 2011 - 2014

Study Year	Proportion using Route		Survival Probability Estimate			HORB Status	Water Year Type
	SJR (ψ_A)	OR (ψ_B)	SJR Route (S_A)	Old River Route (S_B)	Total Survival (S_{Total})		
2011	0.51	0.49	0.55	0.52	0.54	Out	Wet
2012	0.94	0.06	0.33	0.07	0.32	In	Dry
2013	0.12	0.88	0.11	0.15	0.15	Out	Critical
2014	0.92	0.08	0.25	0.19	0.24	In	Critical

Model Parameters estimated:

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

$\boldsymbol{S_{hi}}$ = perceived survival probability: joint probability of migration and survival from telemetry station i to i+1 within route h, conditional on surviving to station i.

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

$\Phi_{kj,\ hi}$ = transition probability: joint probability of migration, route selection, and survival; the probability of migrating, surviving, and moving from station j in route k to station i in route h, conditional on survival to station j in route k.

λ = joint transition and detection probability: joint probability of moving downstream from Chipps Island, surviving to Benicia Bridge, and detection at Benicia Bridge, conditional on survival to Chipps Island.

Table 3a: Performance metric estimates for tagged juvenile steelhead for study years 2011 -2012, excluding predator – type detections. Standard errors in parentheses.

Parameter	Year										
	2011							2012			
	Release Group							Release Group			
	1	2	3	4	5	Pop Est.		1	2	3	Pop Est
Ψ_{AA}	0.47 (0.03)	0.35 90.03)	0.37 (0.03)	0.36 (003)		0.39 (0.02)		0.72 (0.04)	0.75 (0.03)	0.58 (0.04)	0.68 (0.02)
Ψ_{AF}	0.05 (0.01)	0.16 (0.02)	0.12 (0.02)	0.17 (0.02)		0.12 (0.01)		0.21 (0.04)	0.23 (0.03)	0.26 (0.02)	0.26 (0.02)
Ψ_{BB}	0.44 (0.0)	0.46 (0.03)	0.49 (0.03)	0.45 (0.03)		0.46 (0.02)		0.06 (0.01)[a]	0.03 (0.01)[a]	0.06 (0.01)[a]	0.06 (0.01)[a]
Ψ_{BC}	0.04 (0.01)	0.03 (0.01)	0.01 (0.01)	0.03 (0.02)		0.03 (0.01)		0.00[a]	0.00[a]	0.00 [a]	0.00 [a]
S_{AA}	0.72 (0.04)	0.68 (0.05)	0.51 (0.05)	0.69 (0.05)		0.65 (0.02)		0.33 (0.03)	0.43 (0.03)	0.45 (0.05)	0.40 (0.02)
S_{AF}	0.33 (0.12)	0.27 (0.07)	0.26 (0.07)	0.59 (0.07)		0.36 (0.04)		0.10 (0.04)	0.14 (0.04)	0.21 (0.05)	0.15 (0.03)
S_{BB}	0.68 (0.04)	0.50 (0.05)	0.44 (0.04)	0.55 (0.05)		0.54 (0.02)		0.07 (0.04)	0.10 (0.07)	0.05 (0.03)	0.07 (0.03)
S_{BC}	0.67 (0.08)	0.30 (0.13)	0.48 (0.06)	0.22 (0.17)		0.42 (0.06)		NA	NA	NA	NA
Ψ_{A}	0.52 (0.03)	0.51 (0.03)	0.49 (0.03)	0.53 (0.03)	0.52 (0.05)	0.51 (0.02)		0.94 (0.01)*	0.97 (0.01)*	0.92 (0.02)*	0.94 (0.01)*
Ψ_{B}	0.48 (0.03)	0.49 (003)	0.51 (0.03)	0.47 (0.03)	0.48 (0.05)	0.49 (0.02)		0.06 (0.01)*	0.03 (0.01)*	0.08 (0.02)*	0.06 (0.01)*
S_{A}	0.69 (0.04)	0.55 (0.04)	0.45 (0.04)	0.66 (0.04)*	0.32 (0.06)	0.55 (0.02)		0.28 (0.03)	0.33 (0.03)	0.36 (0.04)	0.33 (0.02)
S_{B}	0.68 (0.04)	0.48 (0.04)	0.44 (0.04)	0.53 (0.05)*	0.44 (0.07)	0.52 (0.02)		0.07 (0.04)	0.10 (0.07)	0.05 (0.03)	0.07 (0.03)
S_{Total}	0.69 (0.03)	0.52 (0.03)	0.44 (0.03)	0.60 (0.03)	0.38 (0.05)	0.54 (0.01)		0.26 (0.02)	0.35 (0.03)	0.33 (0.04)	0.32 (0.02)
$S_{A(MD)}$	0.82 (0.03)*	0.50 (0.04)*	0.39 (0.04)*	0.52 (0.04)*		0.56 (0.02)		0.32 (0.03)	0.46 (0.03)	0.45 (0.04)	0.41 (0.02)
$S_{B(MD)}$	0.53 (0.04)*	0.05 (0.02)*	0.09 (0.03)*	0.06 (0.02)*		0.18 (0.01)		0.00[a]	0.00	0.00	0.00
$S_{Total(MD)}$	0.68 (0.03)	0.28 (0.03)	0.24 (0.03)	0.30 (0.03)		0.37 (0.01)		0.30 (0.03)	0.45 (0.03)	0.41 (0.04)	0.39 (0.02)
$S_{A(SD)}$	0.89 (0.03)	0.83 (0.03)	0.74 (0.04)	0.85 (0.03)		0.83 (0.02)		0.78 (0.04)	0.82 (0.02)	0.89 (0.03)	0.83 (0.02)
$S_{B(SD)}$	0.91 (0.03)	0.75 (0.04)	0.71 (0.04)	0.77 (0.04)		0.78 (0.02)		0.80 (0.08)	0.62 (0.17)	0.23 (0.11)	0.55 (0.07)
$S_{Total(SD)}$	0.90 (0.02)	0.79 (0.03)	0.72 (0.03)	0.81 (0.03)		0.81 (0.01)		0.78 (0.04)	0.81 (0.02)	0.84 (0.03)	0.81 (0.02)

* Significantly different at $\alpha = 0.05$

[a] No tags were detected in subroute "C" or insufficient tags were detected to subroute "C" for use in analysis. No estimate for survival in subroute C was available.

Table 3b: Performance metric estimates for tagged juvenile steelhead for study years 2013 -2014, excluding predator – type detections. Standard errors in parentheses.

Parameter	Year							
	2013					2014		
	Release Groups					Release Groups		
	1	2	3	Pop Est.		1	2	3	Pop Est
Ψ_{AA}	NA[a]	0.07(0.02)	0.11 (0.02)	NA[a]		NA[a]	0.66 (0.03)	0.77 (0.08)	0.71 (0.04)
Ψ_{AF}	NA[a]	0.06 (0.02)	0.05 (0.02)	NA[a]		NA[a]	0.30 (0.03)	0.11 (0.07)	0.21 (0.04)
Ψ_{BB}	0.89 (0.02)	0.85 (0.02)	0.83 (0.02)	0.86 (0.01)		0.87 (0.03)	0.04 (0.01)	NA[a]	NA[a]
Ψ_{BC}	0.03 (0.01)	0.02 (0.01)	0.01 (0.01)	0.02 (<0.01)		0.04 (0.02)	0.00 (<0.01)	NA[a]	NA[a]
S_{AA}	NA[a]	0.19 (0.07)	0.31 (0.07)	NA[a]		NA[a]	0.57 (0.03)	0.07)0.03)	0.32 (0.02)
S_{AF}	NA[a]	0.06 (0.05)	0.00	NA[a]		NA[a]	0.13 (0.03)	NA[a]	NA[a]
S_{BB}	0.17 (0.02)	0.08 (0.02)	0.20 (0.03)	0.15 (0.01)		0.20 (0.04)	0.33 (0.09)	NA[a]	NA[a]
S_{BC}	0.07 (0.05)	0.06 (0.04)	0.06 (0.06)	0.06 (0.03)		0	NA[a]	NA[a]	NA[a]
Ψ_{A}	0.08 (0.02)	0.12 (0.02)	0.16 (0.02)	0.12 (0.01)		0.09 (0.02)	0.96 (0.01)	0.88 (0.03)	0.92 (0.02)
Ψ_{B}	0.92 (0.02)	0.88 (0.02)	0.84 (0.02)	0.88 (0.01)		0.91 (0.02)	0.04 (0.01)	0.12 (0.03)	0.08 (0.02)
S_{A}	0.00	0.13 (0.05)	0.20 (0.06)	0.11 (0.03)		0	0.43 (0.03)	0.06 (0.02)	0.25 (0.02)
S_{B}	0.16 (0.02)	0.08 (0.02)	0.20 (0.02)	0.15 (0.01)		0.19 (0.03)	0.31 (0.09)	0.07 (0.07)	0.19 (0.06)
S_{Total}	0.15 (0.02)	0.09 (0.02)	0.20 (0.02)	0.15 (0.01)		0.18 (0.03)	0.43 (0.03)	0.06 (0.02)	0.24 (0.02)
$S_{A(MD)}$	0.00	0.13 (0.05)	0.24 (0.06)	0.12 (0.03)		NA[a]	0.44 (0.03)	0.07 (0.03)	0.26 (0.02)
$S_{B(MD)}$	0.01 (0.01)	0.01 (0.1)	0.06 (0.02)	0.03 (0.01)		NA[a]	0	NA[a]	NA[a]
$S_{Total(MD)}$	0.01 (0.01)	0.03 (0.01)	0.09 (0.02)	0.04 (0.01)		NA[a]	0.43 (0.03)	NA[a]	NA[a]
$S_{A(SD)}$	NA[a]	0.23 (0.07)	0.37 (0.07)	NA[a]		NA[a]	0.77 (0.02)	0.16 (0.04)	0.46 (0.02)
$S_{B(SD)}$	0.53 (0.03)	0.56 (0.03)	0.75 (0.03)	0.61 (0.02)		0.56 (0.04)	0.83 (0.09)	NA[a]	NA[a]
$S_{Total(SD)}$	NA[a]	0.52 (0.03)	0.69 (0.03)	NA[a]		NA[a]	0.77 (0.02)	NA[a]	NA[a]

[a] NA estimates resulted when there were too few tags detected in the route to estimate route selection and/or survival.

Table 4: Heat Map Depicting Steelhead Survival Rates ($S^{(1/km)}$) Through San Joaquin River Reaches to Chipps Island.

Reach Name		Survival Estimate per km ($S^{(1/km)}$)					
	km	2011		2012		2013	2014
		CAMT SST	6-year Rpt	CAMP SST	6-year Rpt	6-year Rpt	6-year Rpt
Durham Ferry to Banta Carbona	11	0.962	0.9765	0.967	0.986	0.988	0.973
Banta Carbona to Mossdale	10	0.982	0.985	0.978	0.980	0.985	0.980
Mossdale to Lathrop/Old River	4	0.985	0.985	0.995	0.995	0.995	0.966
Lathrop to Garwood Bridge (SJR)	18	0.995	0.995	0.997	0.997	0.948	0.974
Garwood Bridge to Navy Bridge	3	0.993	0.993	0.990	0.990	0.958	0.976
Navy Bridge to Turner Cut/MacDonald Island	15	0.997	0.997	0.994	0.994	0.984	0.984
MacDonald Island to Medford Island	5	0.942	0.949	0.923	0.941		
Turner Cut to Jersey Point (includes interior Delta route but not SJR route)	28	0.958	0.957	0.934	0.933		
Medford to Jersey Point	21	0.992		0.987			
Jersey Point to Chipps Island	22	0.997		0.989			

Note: Darker red boxes have lower survival values and lighter boxes indicate higher survival rates (white ≥ 99% survival/km). Missing values reflect sparse data in the reach in question or the study had deficiencies that prevented estimates to be made.

Table 5: Heat Map depicting Survival Rates ($S^{(1/km)}$) through Old River Reaches to Chipps Island.

Reach Name		Survival Estimate per km ($S^{(1/km)}$)					
	km	2011		2012		2013	2014
		CAMT SST	6-year Rpt	CAMP SST	6-year Rpt	6-year Rpt	6-year Rpt
Old River (Head) to Middle River Head/ Old River (south)	6	0.990	0.9897	0.977	0.977	0.990	0.948
Old River (South) to CVP/CCF/HWY4	20	0.994	0.988	0.977	0.977	0.981	0.983
Old River (HWY4) to Jersey Point	60	0.992	0.992	0.958		0.972	0.978
CVP Holding Tank to Chipps Island	15	0.988	0.992	0.973	0.965	0.987	1.0/0.98
CCF Radial Gate (interior) to Chipps Island	24	0.979	0.983	0.924	0.914	0.957	0/ 0.95

Note: Darker red boxes have lower survival values and lighter boxes indicate higher survival rates (white ≥ 99% survival/km). Missing values reflect sparse data in the reach in question or the study had deficiencies that prevented estimates to be made.

Yellow highlighted cells have two survival estimates. Estimate from the first release in 2014 have a survival rate of 98% from the CVP holding tank to Chipps Island, and a survival rate of 95% from the CCFB interior radial gates to Chipps Island based on a joint tag survival and fish survival estimates due to premature tag failures occurring in the first release group. The 100 % survival for the CVP estimate is based on the second and third releases with a total of 12 fish detected in the holding tank and 12 fish detected at Chipps Island. The zero survival for the

CCFB radial gate to Chipps Island is based on 3 fish detected at the interior radial gate with none subsequently detected at Chipps Island.

Figure 1: Locations of Acoustic Receivers (general locations) as each study had a small number of additional/ removed or relocated acoustic receiver locations. (2012 study locations used as an example).

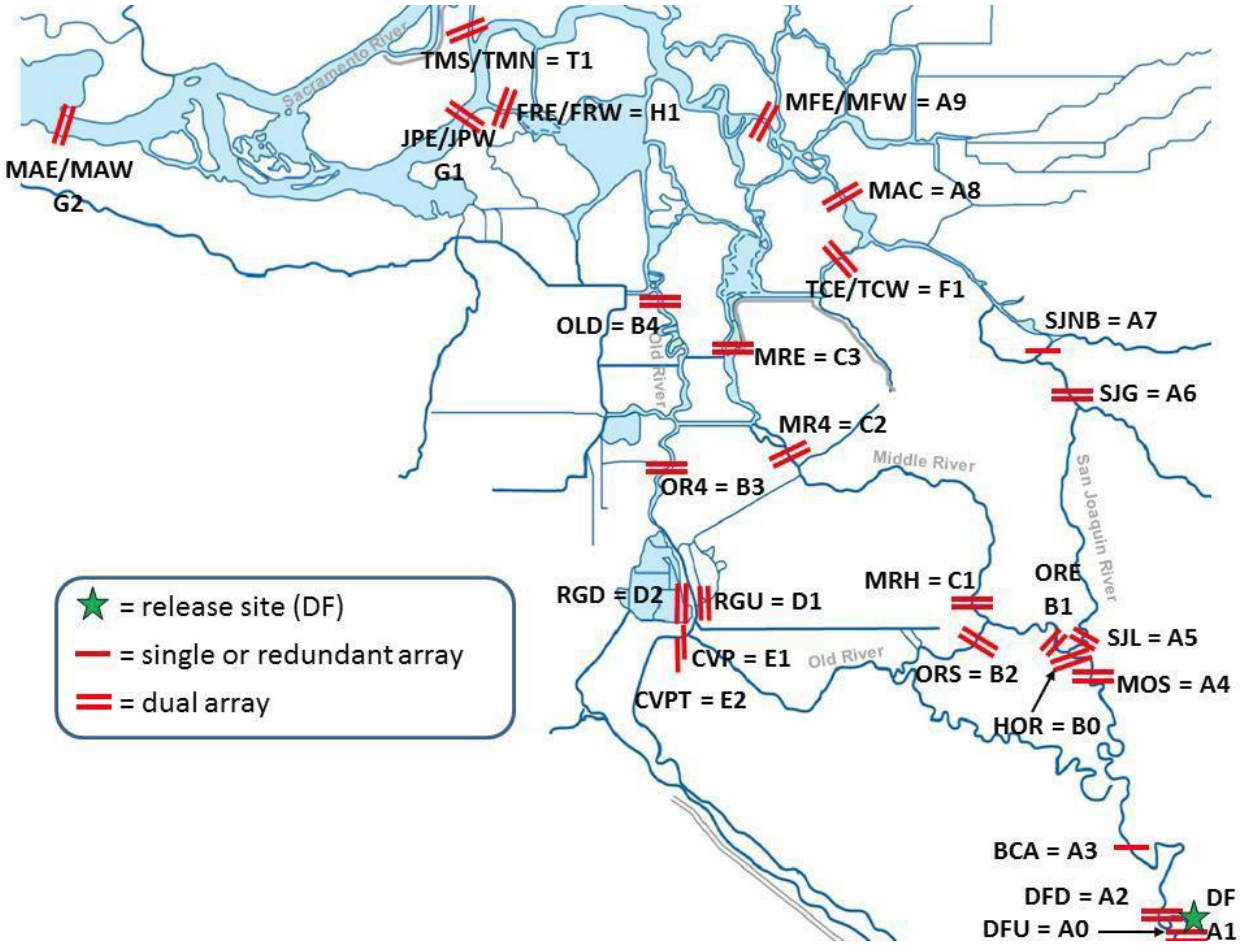


Figure 2: March through June Vernalis Flows for Study Years 2011 – 2014 with release groups.

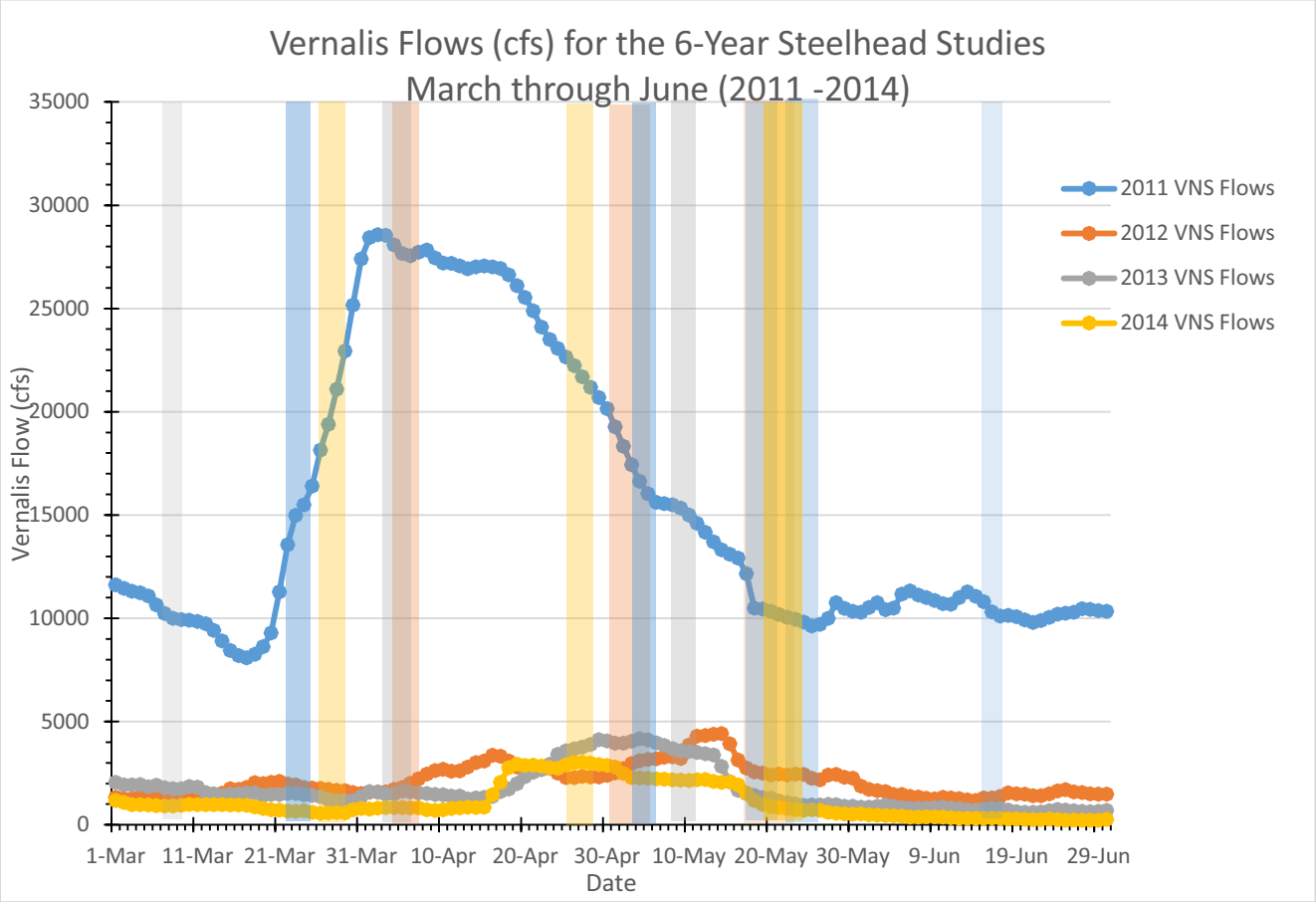
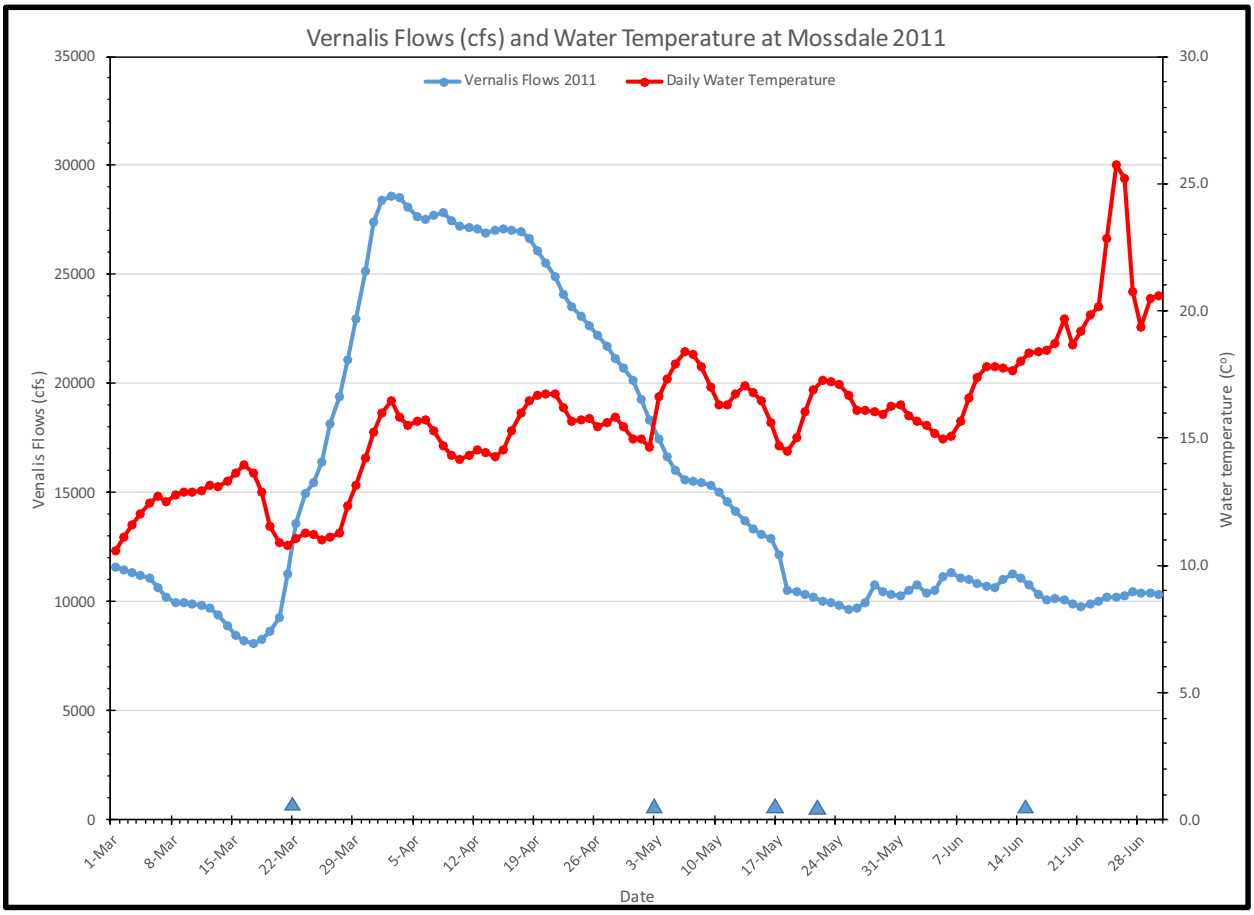
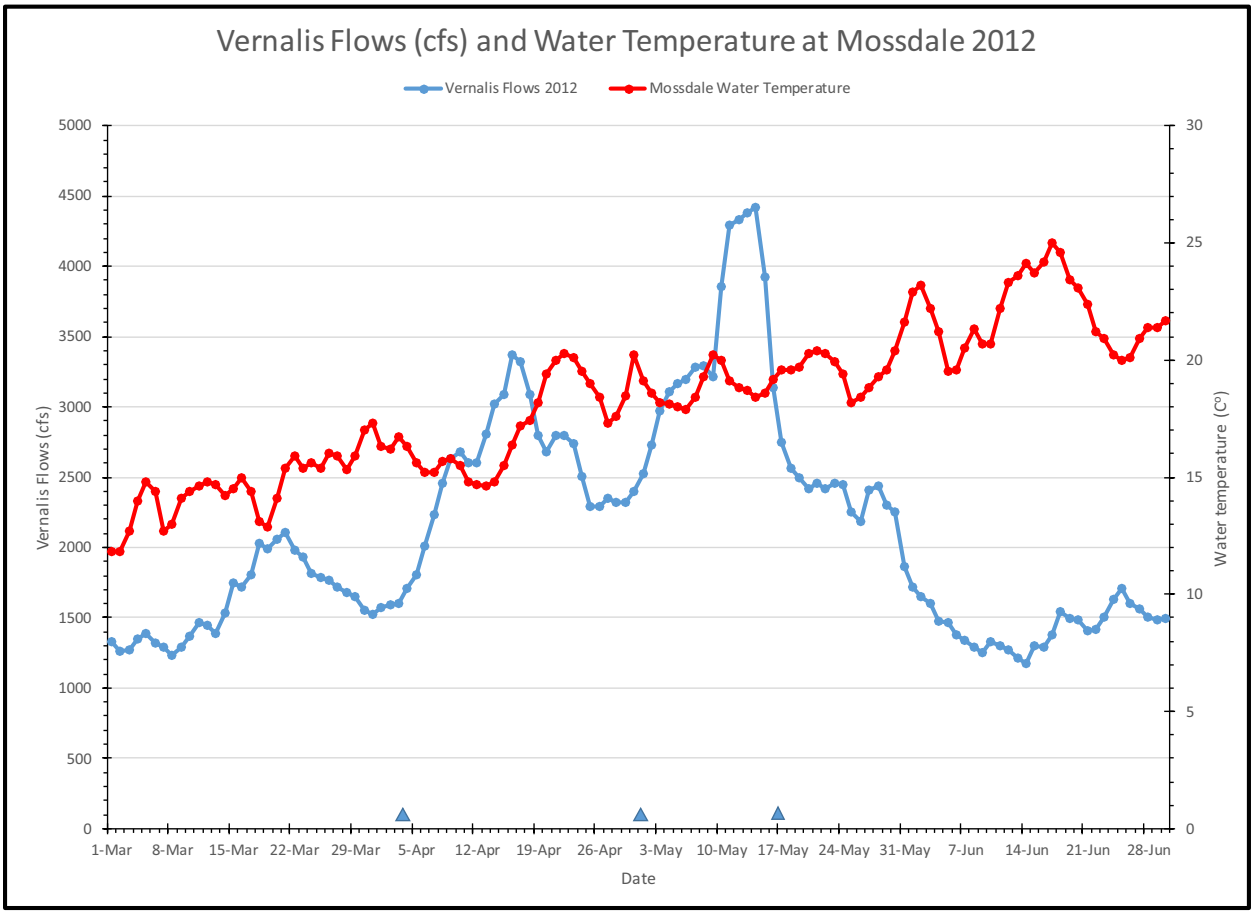


Figure 3:Vernalis Flows and Mossdale Water Temperatures March through June 2011



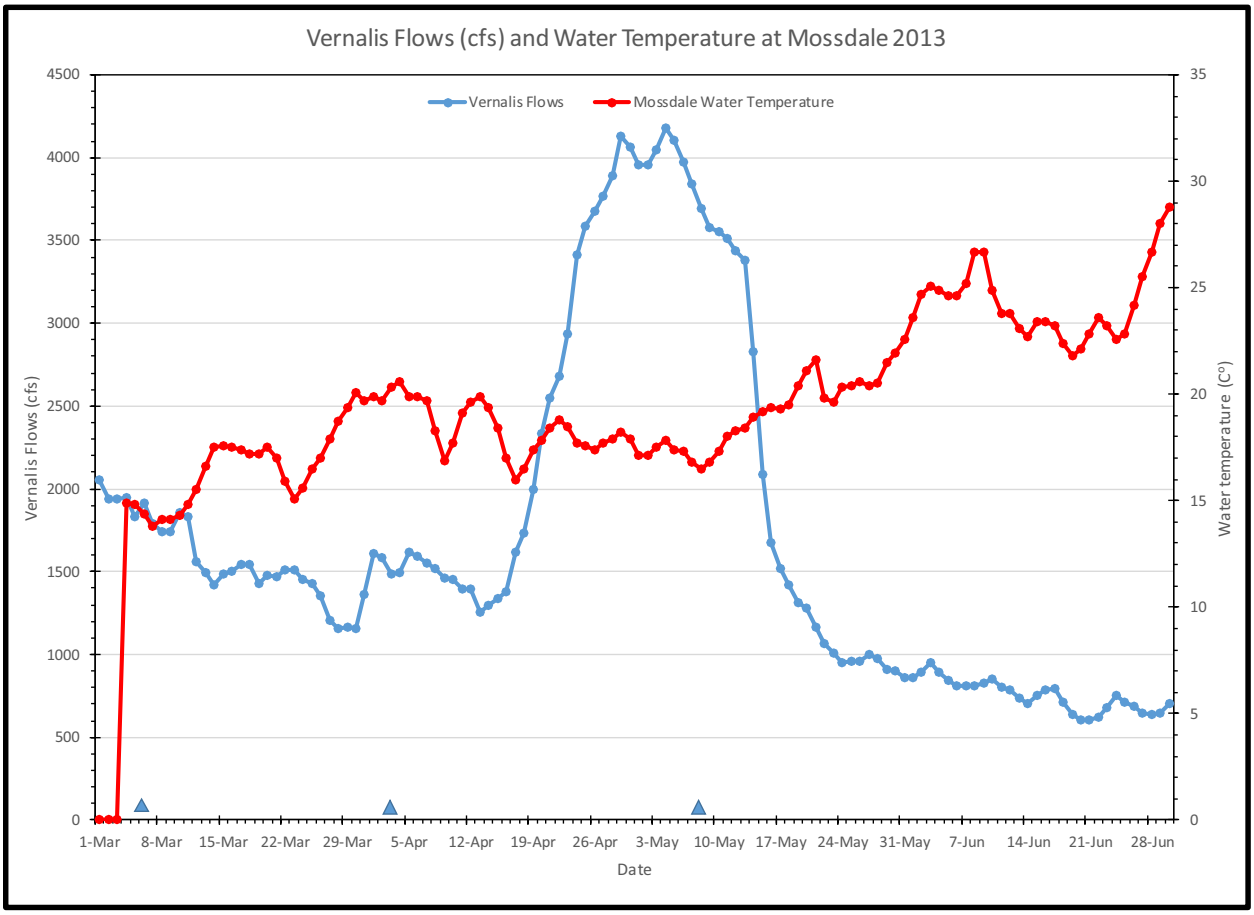
Triangles depict the initial date of releases for each release groups

Figure 4: Vernalis Flows and Mossdale Water Temperatures March through June 2012



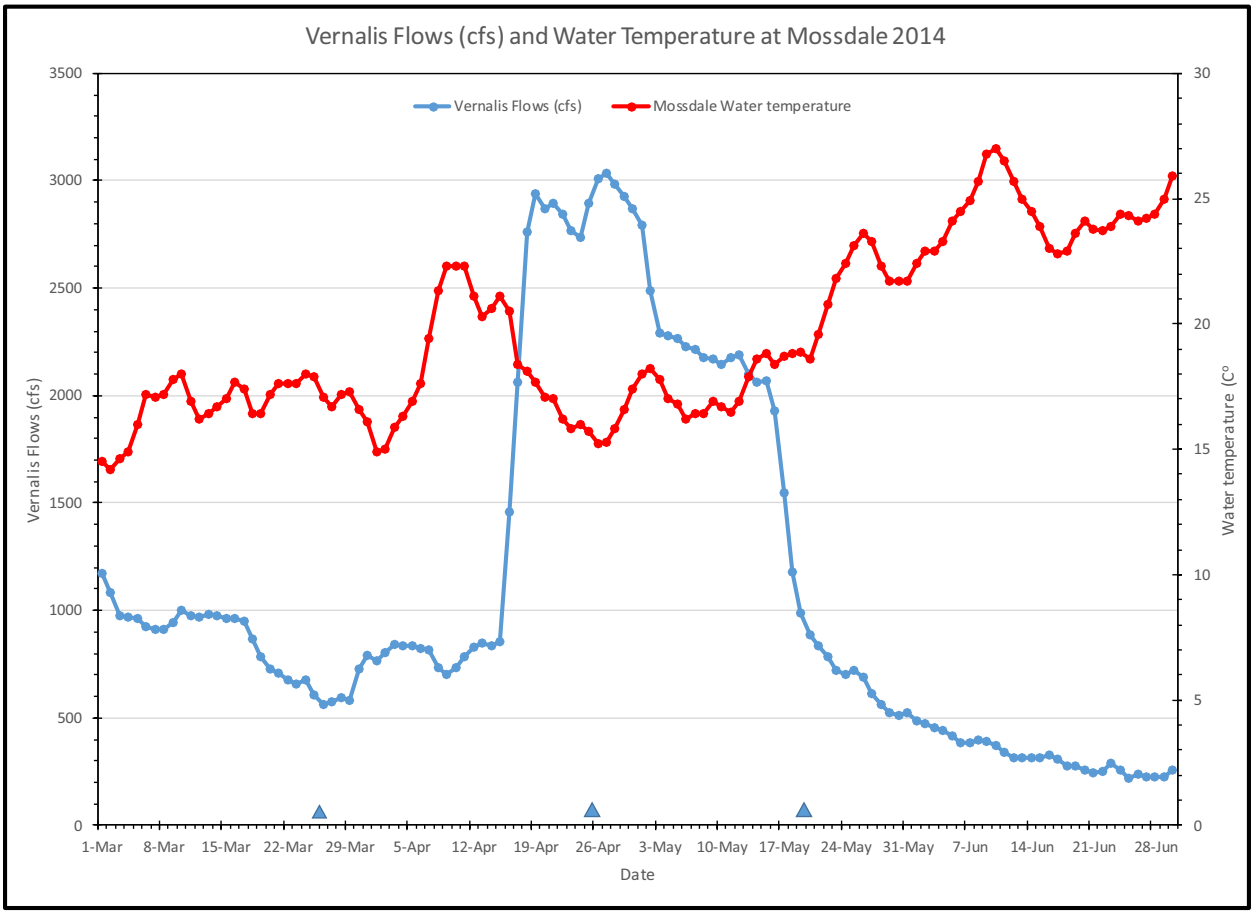
Triangles depict the initial date of releases for each release groups

Figure 5: Vernalis Flows and Mossdale Water Temperatures March through June 2013



Triangles depict the initial date of releases for each release groups

Figure 6: Vernalis Flows and Mossdale Water Temperatures March through June 2014



Triangles depict the initial date of releases for each release groups

Figure 7: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2012 study). Error bars are 95% confidence intervals.

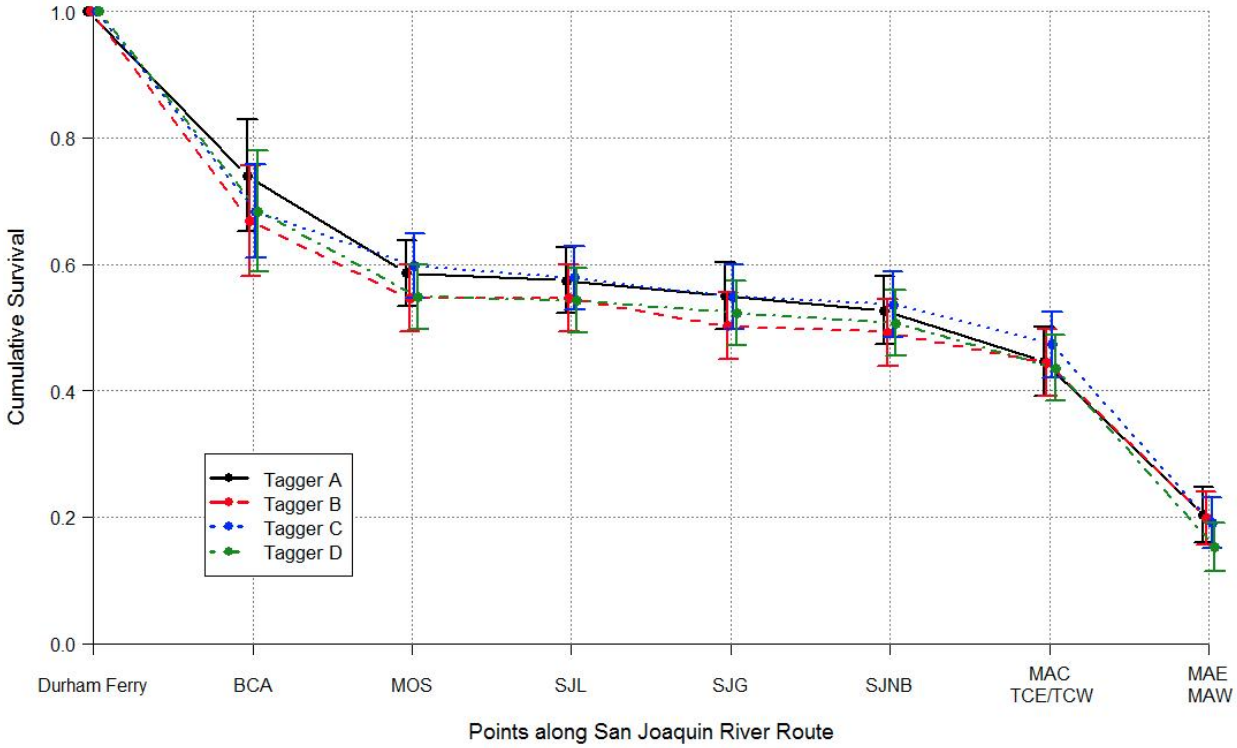


Figure 8: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2012 study). Error bars are 95% confidence intervals.

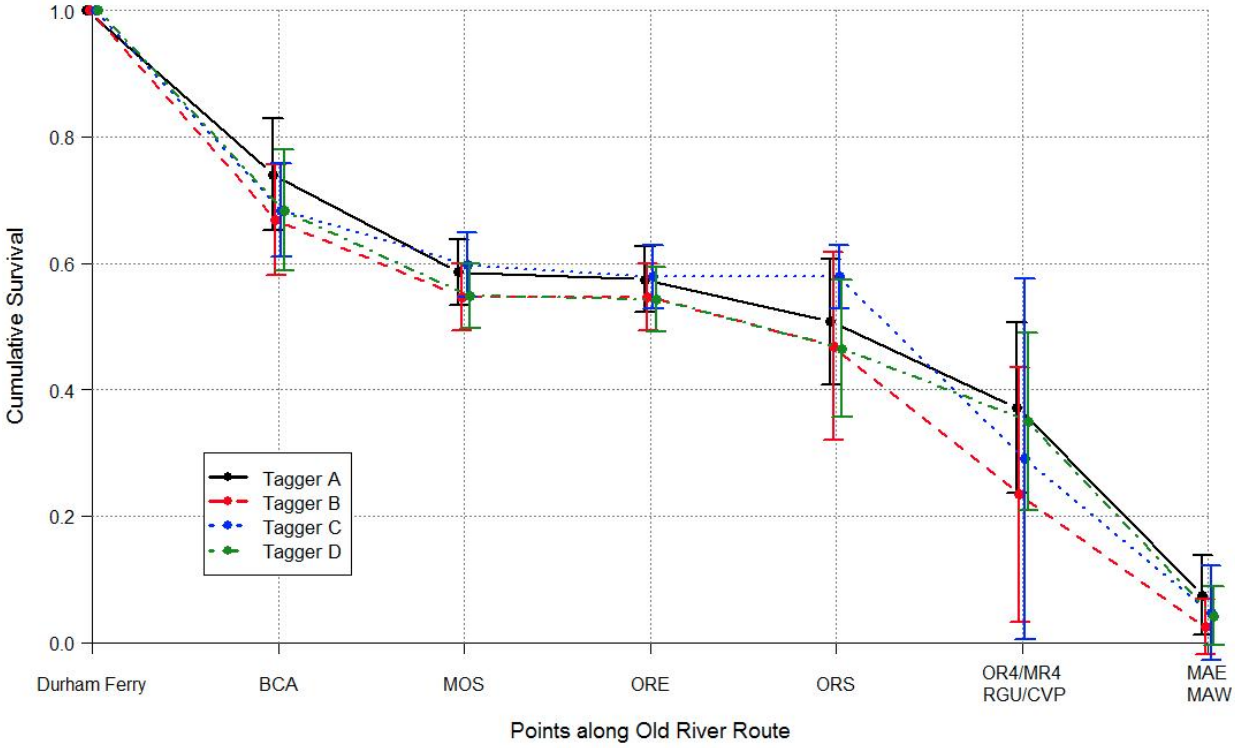


Figure 9: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2013 study). Error bars are 95% confidence intervals.

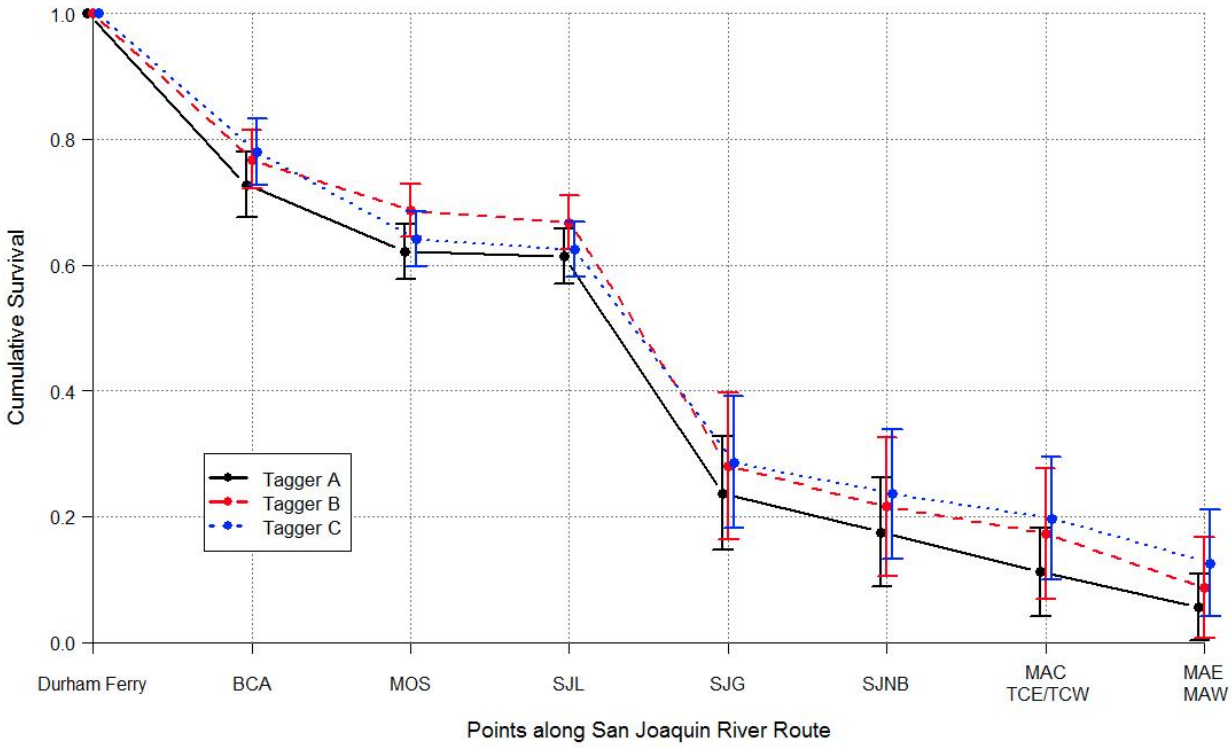


Figure 10: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2013 study). Error bars are 95% confidence intervals.

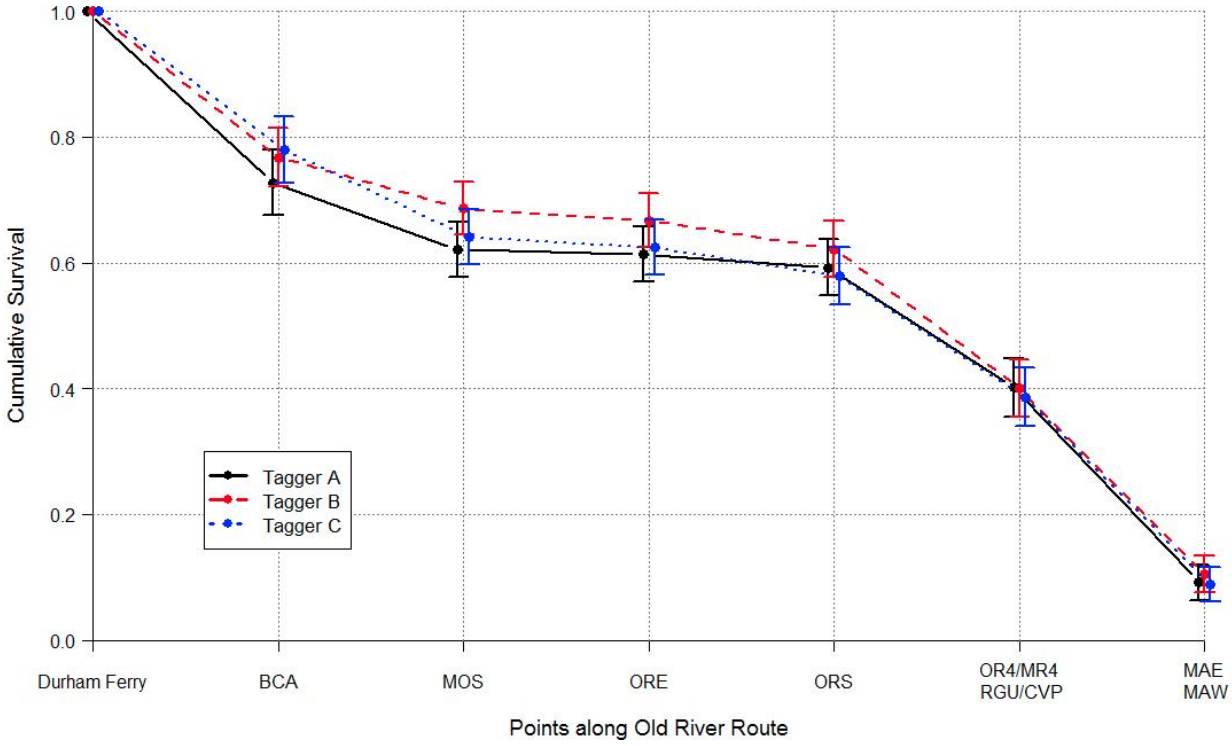


Figure 11: Cumulative survival from releases at Durham Ferry to various points along the San Joaquin River route to Chipps Island by surgeon (2014 study). Error bars are 95% confidence intervals. Estimates are of joint fish-tag survival.

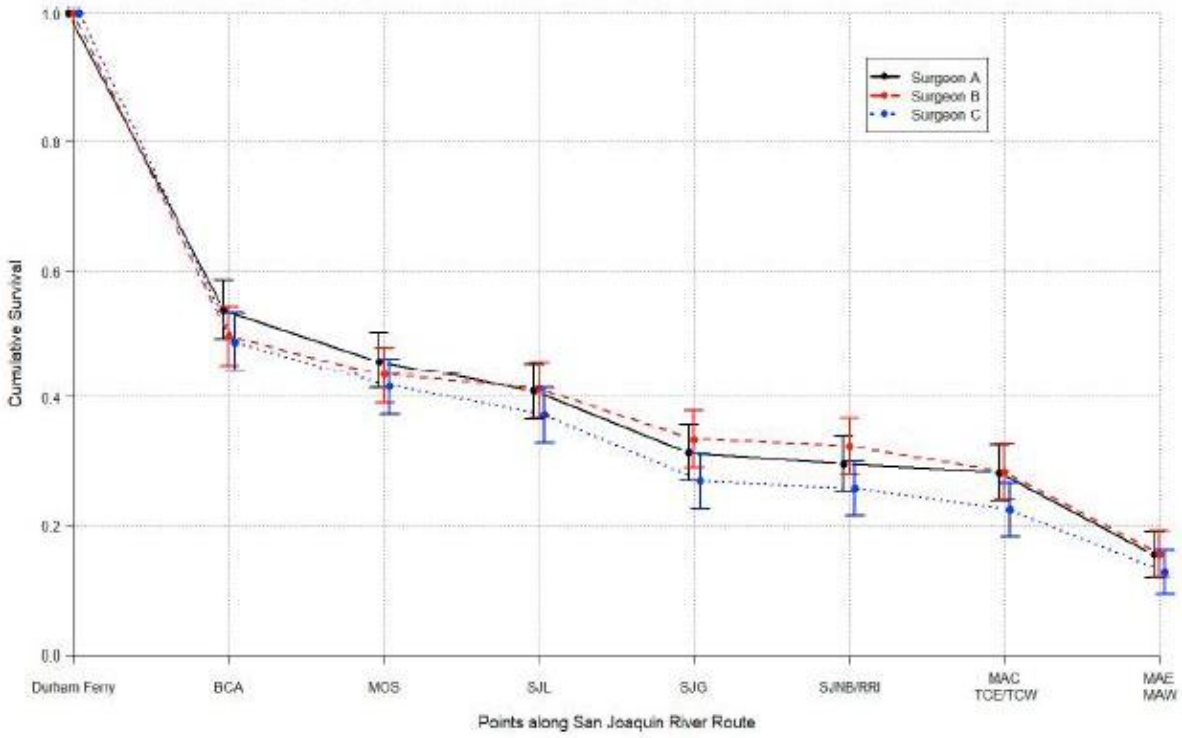


Figure 12: Cumulative survival from releases at Durham Ferry to various points along the Old River route to Chipps Island by surgeon (2014 study). Error bars are 95% confidence intervals. Estimates are of joint fish-tag survival.