Status Report for 2012 Acoustic Telemetry Stipulation Study

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Summary

In the spring of 2012, a mark-recapture experiment was performed to examine the survival and movement patterns of acoustically-tagged juvenile steelhead (*Oncorhynchus mykiss*) emigrating through the central and southern Delta. Three groups of approximately 167 acoustically-tagged juvenile steelhead were released every two weeks (beginning in April 16, 2012) at Buckley Cove in the lower San Joaquin River. For the purpose of this status report, detection data were evaluated to provide preliminary results from this study.

For those analyses examining entrainment into the interior delta from the San Joaquin River, our initial findings suggest that Colombia Cut exhibited the highest entrainment rate, while Middle River exhibited the lowest. Observed fish proportions exceeded daily flow proportions at Turner Cut and Colombia Cut, while observed fish proportions for Middle River junction were below those levels predicted by daily flow proportions. Initial evaluation at these junctions suggests no tendency for entrainment to the interior Delta to vary in relation to OMR levels (i.e., differences in entrainment rate varied among junctions, but not among release groups). However more detailed analyses are needed to fully explore how tidal conditions at the time fish arrived at these junctions may have influenced observed routing patterns.

Once in the interior delta, tagged fish from all three stipulation study release groups tended to migrate towards the pumping facilities (50-61%) rather than back towards the San Joaquin River (13-20%), and this pattern was consistent regardless of OMR flows and was also consistent for six year study fish. Preliminary results suggest that the timing and arrival number of acoustically tagged steelhead in the vicinity of Railroad Cut was relatively consistent among release groups, and therefore seemingly unrelated to Old and Middle River (OMR) flows. Analysis of fish travel times within the interior Delta also did not show significant differences among release groups. However, as with analysis of junction routing, these results are preliminary and more detailed analyses and in particular, exploration of location specific hydrodynamic conditions are needed.

Results generally show a rapidly decreasing number of individual fish detected the farther away they moved from the release location and these patterns appeared to be consistent between release groups (and

OMR flow levels). Though release and route specific survival rates have not yet been estimated, the observed pattern of detections suggests mortality through the interior Delta continues to be high.

With regard to using hydrodynamic metrics for predicting fish movement, initial observations suggest simulated particles from a particle tracking model do not accurately represent fish movements. We observed that steelhead arrival timing and proportion becomes more divergent from the arrival timing and proportion of particles as a function of temporal and spatial distance from the release location. While previous work suggests has shown DSM2 Hydro is suitable for depicting general hydrodynamic conditions in the Delta our attempt to use DSM2 Hydro data for fine scale analyses (e.g., pairing real-time fish detections to DSM2 Hydro data) was problematic due to apparent mismatches in flow magnitude and direction. Refinement of DSM2 Hydro data or other flow data will necessary to complete detailed analysis relating fish behavior to location specific, sub-daily hydrodynamics.

Introduction

This status report provides a summary of results prepared to date for the 2012 stipulation study. The schedule for analysis was set-back by delays in the availability of six-year study receiver data (all essential receivers did not become available until August 24th 2012). Despite unexpected delays, many useful and important analyses have been completed and are preliminarily described heir in, but will be explored more fully in the final synthesis report.

Study Background

On January 12,2012, Plaintiffs, Plaintiff-Intervenor, and Federal Defendants to the Consolidated Salmonid Cases (Case 1 :09-cv-Ol 053-LJO -DLB) signed and filed a joint stipulation (Document 659-2) that specified a study and Central Valley Project and State Water Project operations for April and May 2012. The 2012 stipulation agreement called for operation and maintenance of an acoustic receiver array in the lower San Joaquin River and Delta, fish tagging and releases, adaptive management of Old and Middle River (OMR) flows, and data analysis and report writing. The “stipulation” study was initiated by California Department of Water Resources (DWR) in February 2012, with field work occurring between April and June.

The stipulation agreement called for augmentation of acoustic telemetry studies already planned for spring of 2012 in order to gain additional information on the effects of SWP and CVP export operations on juvenile steelhead and fall-run Chinook salmon. Specific objectives of the 2012 stipulation study were to:

- Evaluate potential effects of Old and Middle River flows during April and May on the reach-scale survival, migration rate, and net migration direction of acoustically tagged juvenile steelhead and Chinook salmon in the lower San Joaquin River, Turner Cut, Columbia Cut, Middle River and Old River.

- Estimate route entrainment of juvenile steelhead and salmon into Middle River, Turner Cut, Columbia Cut, and Old River under different tidal conditions and OMR flows; and

- Perform daily and weekly data processing of detection data for acoustically tagged steelhead and Chinook salmon at key locations for use in monitoring the movement of juvenile salmonids through the Delta in order to provide information that can be used to adaptively manage OMR flows within the adaptive range specified in the joint stipulation. Please note, this element of the stipulation agreement has already been completed and will not be addressed in this status report.

Biological and Regulatory Background

Juvenile steelhead and Chinook salmon migrating downstream in the San Joaquin River are vulnerable to entrainment at the SWP and CVP export facilities and the associated exposure to pre-screen predation losses within Clifton Court Forebay (direct effects) and near the trashracks at the CVP fish collection facility. These facilities are located more than 40kms south from the confluence of the San Joaquin and Sacramento Rivers (Figure 1). Thus, by the time Endangered Species Act (ESA) listed salmonids are detected at salvage facilities, OMR changes may be enacted too late to achieve fish protection. In addition, changes in the direction and/or magnitude of flows in central and south Delta channels (e.g., OMR reverse flows, flows passing into Old River, etc.) have been hypothesized to result in altered migration pathways, migration delays, and other indirect effects that contribute to reduced survival of juvenile salmonids passing through the lower river and Delta. In response to these concerns, NMFS included several RPA actions in the biological opinion that focused on Delta flow management during the winter and spring. SWP and CVP export rates in the late winter and spring months have been regulated to reduce the magnitude of OMR reverse flows. Action IV.2.1 of the biological opinion restricts south Delta exports in April and May to a fraction of the flow in the lower San Joaquin River.

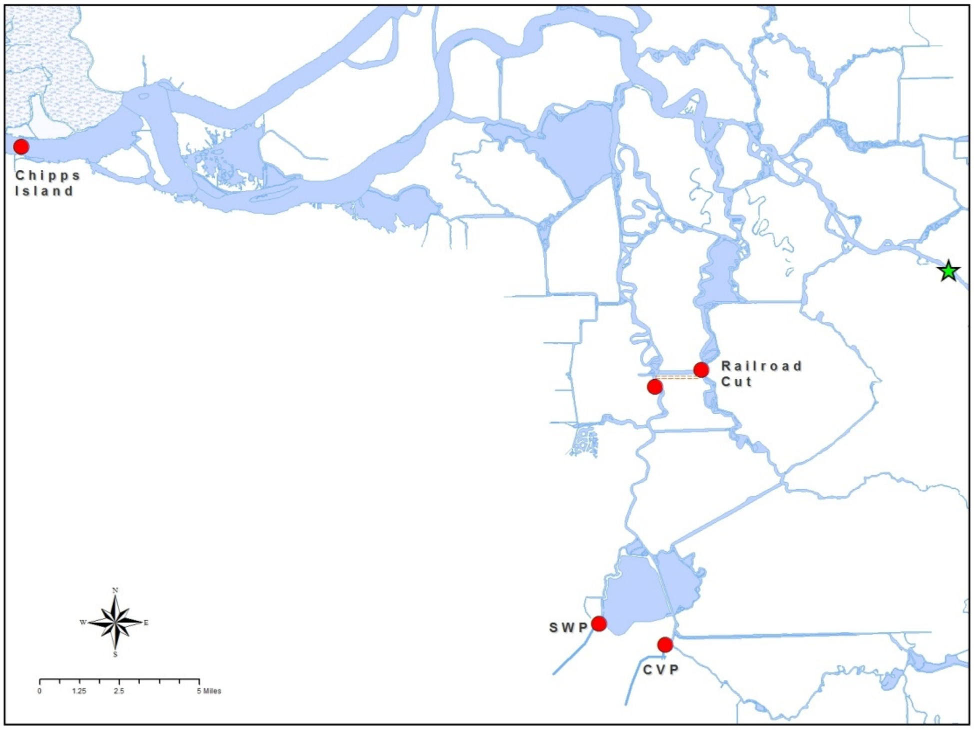

Figure 1. Locations of receiver arrays at Railroad Cut, SWP, CVP, and Chipps Island in relation to the release location (depicted by the green star).

Flow management during winter and spring has become the focus of management actions intended to provide fish benefits along the Old and Middle River corridor. These management actions are calendar and trigger based during the period when ESA covered salmonids are present in the Delta. If salmonid protection measures could be taken based on fish presence farther from the export facilities, it was hypothesized that: a) the duration of direct risks and indirect risks to salmonids, associated with the export facilities, may be reduced, b) the take of ESA covered salmonids at the facilities can be reduced, and c) exposure to ESA covered salmonids to predation in south Delta channels can be reduced.

The NMFS biological opinion included an RPA action that required the design and implementation of a six-year acoustic tag study (six-year study) of juvenile steelhead in the San Joaquin River. Studies of the survival and movement patterns of juvenile Chinook salmon in the San Joaquin River and Delta have also been conducted in the past as part of VAMP and other programs (e.g., south Delta temporary barrier project, etc.). The experimental design implemented for the 2012 stipulation represents an augmentation and expansion of the six-year study.

In addition to providing information about the effects of OMR flows on route selection and survival in the south Delta, the 2012 stipulation study also tested an alternative approach to managing water export risks to ESA listed salmonids. The experimental approach relies upon releases of “sentinel fish” and monitoring stations to detect patterns of movement of these fish within the south Delta. Sentinel fish are acoustically tagged fish assumed to represent wild fish in the system. Thus, rather than using modeling results to predict broad scale, often subtle hydrodynamic changes hypothesized to cause indirect effects on fish survival through the Delta, the "sentinel" fish approach sets a protection threshold based on the observed movement of tagged fish within the Delta.

In summary, the 2012 stipulation study sought to evaluate the relationship between OMR flows and the migration and survival of juvenile salmonids, while at the same conducting an adaptive management experiment intended to help refine decision making for protections of San Joaquin River steelhead. The study was implemented by DWR and DWR contractors, with collaboration from USBR, USFWS, and USGS.

Experimental Design

The 2012 acoustic tagging study included three release groups consisting of ~167 acoustically tagged juvenile steelhead. Yearling steelhead for the study were provided by the Mokelumne River Hatchery and were released near Buckley Cove in the lower San Joaquin River downstream of Stockton, and upstream of Turner Cut. Releases occurred every two weeks beginning on April 16th. The original experimental design called each two week experimental period to represent one of three OMR flow targets (-1250, -3500, and -5000 cfs). However real- time detections of stipulation study fish led NMFS to modify OMR operations during the experiment- resulting OMR flows during the stipulation study along with release group timing is shown in Figure 2. Average observed OMR flows during the first 7 days following release were -2446, -2933, and -5193 cfs for release groups 1, 2, and 3, respectively. Therefore, higher OMR flows occurring after the third release allowed for an examination of the effect of OMR flows on fish behavior by comparing release group 3 to release groups 1 and 2 in analyses described in this report.

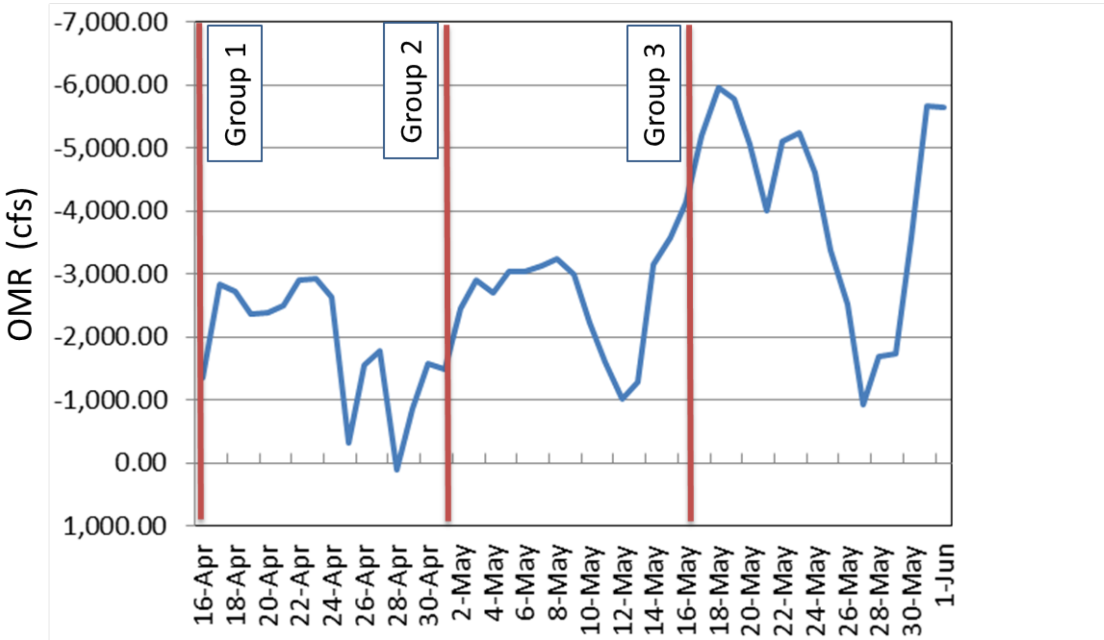

Figure 2. OMR conditions and release dates for acoustically tagged hatchery steelhead smolts for the 2012 stipulation study. Group 1 releases began on April 15th and finished on April 16th. Group 2 releases began on May 1st and finished on May 2nd. Group 3 releases began on May 15th and finished on May 16th.

Study Objectives and Approach

The 2012 stipulation study identified five objectives. Objectives 1, 2 and 3 were to be addressed in the first phase of analysis (in this status report). Objectives 4 and 5 were to be addressed in follow-up analyses contained in a subsequent synthesis report.

Objective 1: Measure the fraction of acoustically tagged steelhead that reach and are observed to be moving southward at Middle and Old rivers near Railroad Cut and use as an exposure risk trigger to manage OMR flows.

Objective 2: Evaluate how hydrodynamic factors influence the route entrainment into the interior Delta from Turner Cut, Colombia Cut and Middle River.

Objective 3: Evaluate how hydrodynamic conditions and OMR influence migration behavior and survival in the interior Delta.

Objective 4: Evaluate how hydrodynamic conditions and OMR influence survival in the mainstem San Joaquin River.

Objective 5: If hydrodynamic conditions affected by OMR are found to influence survival and/or behavior of tagged fish, what is a well-supported trigger to protect ESA listed salmonids in future operations?

Key assumptions for analyses presented in this status report include the following:

- Detection probabilities are assumed to be relatively high (>80%) as was typical for the 2010 VAMP acoustic telemetry study (SJRG 2011).
    - Note: We conducted a rough evaluation of this assumption by looking for sequential receiver arrays with significant discrepancies in fish detections. For example, did we see more unique tag detections at Array 7 than at Array 6 (implying that array 6 missed fish that must have passed through). More evaluation is needed and will be conducted in mark-recapture statistical analysis with future analyses, but generally we found that unique detections declined gradually (with mortality) along respective migration routes.
- Detection probabilities may vary among arrays, but are assumed not to vary between release groups within arrays.
    - Note: We conducted a rough evaluation of this assumption by looking for sequential receiver arrays with significant discrepancies in fish detections between release groups. For example, did we see more than expected tag detection for release group 1 at Array 7, based upon what we saw at Array 6? More evaluation is needed and will be conducted in mark-recapture statistical analysis of any future analysis, but generally we found consistent patterns of sequential detections among release groups.
- Higher average OMR flows for the first 7 days following release for release group 3 (-5,193 cfs) versus OMR flows for release groups 1 and 2 (-2446 and -2933 cfs) provided a sufficient treatment effect to evaluate the effect of OMR flows on fish behavior between these release groups.

Hydrodynamic Data

Flow patterns in the San Joaquin River and interior delta were analyzed using simulated flow data from DSM2 Hydro. The DSM2 Hydro model is a one-dimensional hydrodynamic model that simulates flows in the Delta's network of riverine and estuarine channels. For a given set of boundary conditions (including tides, river inflows, and exports) DSM2 Hydro provides stage and flow data at 15-minute intervals for hundreds of channels in the Delta. The model has been calibrated to observed flow and stage data and validated by comparing simulated data with field data from a different time period (Kimmerer and Nobriga 2008). DSM2 Hydro has been extensively tested by the California Department of Water Resources and is used for planning and operation of the State Water Project and Central Valley Project export pumping. More detailed information about the DSM2 Hydro model can be found at: http://baydeltaoffice.water.ca.gov/modeling/ deltamodeling/index.cfm.

Considerable effort has been devoted to calibrating DSM2 Hydro, and the model is regularly employed to accurately represent Delta salinity and flow conditions; a testament to the model's value and validity.

DSM2 Hydro is also an essential component for use of the Particle Tracking Model (PTM). More complex hydrodynamics models are available for the Delta (e.g., RMA Multidimensional Models, TRIM, and UnTrim) and for other estuaries. However, we believe that weaknesses of DSM2 Hydro relative to other hydrodynamic models are minor relative to the challenges of linking any hydrodynamic model to the behavior of migrating juvenile salmonids. Kimmerer and Nobriga (2008) made the same point, and though they presented PTM results, DSM2 Hydro data were an essential precursor to their analysis. Given the relative novelty of relating complex hydrodynamics to juvenile salmonid behavior, we believe the use of DSM2 Hydro data is a reasonable first step.

Sub-daily (15-minute) and daily hydrodynamic metrics (e.g. proportional flow movement at junctions, average flow, percent positive flow) were to be analyzed to assess effects on fish entrainment into the interior Delta and patterns of migration behavior and survival once fish enter the interior Delta (Objectives 2 and 3). However, as statistical analyses were being completed, we consistently observed fish moving opposite the direction of flow movement at Turner Cut junction (the only junction analyzed in this way). These unexpected movement patterns were observed for both steelhead and Chinook smolts, suggesting these findings likely were likely not a true observation of fish behavior, but rather a spurious artifact of fish timing not being in-sync with available sub-daily DSM2 flow data.

To examine if our fish and flow timing was out of sync, we compared DSM2 data (Channel 172) with observed flow data at a gauging station near Turner Cut. For an example 24-hour period, we examined how the 15-minute flow data for DSM2 Hydro Channel 172 immediately downstream of Turner Cut varied from observed flows at the DWR gauging station TRN (California Data Exchange Center (CDEC). Although the daily flow magnitude was similar between datasets, the tidal cycle appeared to be off-sync by approximately 2 hours (Figure 3). We were unable to determine how to correct DSM2 Hydro or CDEC data in time to influence analysis presented in this status report. If the CDEC data represents the true flow conditions, then by analyzing DSM2 Hydro data at Turner Cut we may be relating fish behavior with incorrect flow conditions.

Preliminarily, we believe our findings of fish (both Chinook and steelhead smolts) moving against flow movement are likely a result of fish timing being paired with flow conditions incongruent with what they may have actually experienced. Rapid changes in tidal flow conditions (Figure 3) mean small discrepancies in timing between predicted and actual flow patterns can lead to results directly opposite of expectations.

We believe it is necessary to re-evaluate whether or not sub-daily DSM2 Hydro data is suitable for site and time specific analysis. Even if it is, this problem has brought to our attention the extraordinary importance of having accurate times reported for fish detections. Minor discrepancies in clock settings for computers used to launch or download receiver data could lead to inaccurate time data in resulting data. It is important to note that this analysis is attempting to examine sub-daily fish behavior and flows in an unusually detailed way. Thus, challenges have arisen here that may have gone un-noticed in prior analyses which have focused on estimating group level survival rates.

As a consequence of these problems with how to use and reconcile DSM2 Hydro and CDEC data, findings for Objectives 2 and 3 in this report are largely descriptive—examining broad scale relationships between fish behavior and OMR conditions, or DSM2 data at a daily scale. Fine-scale fish behavior analyses may be conducted in the future if flow anomalies described above can be better understood and hopefully resolved.

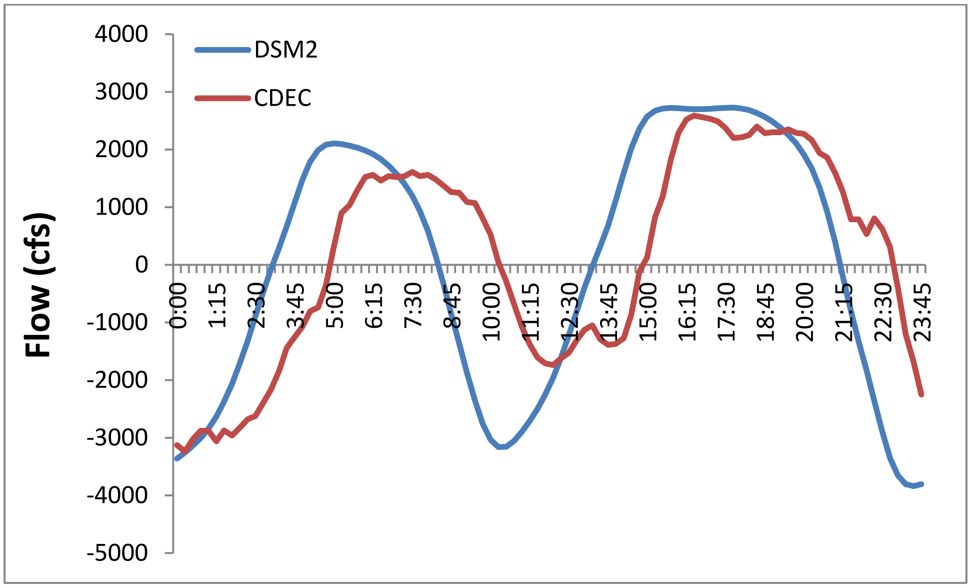

Figure 3. 15-minute flow data over an example 24-hour period for DSM2 channel 172 and DWR gauging station TRN, both indexing flow immediately downstream (towards pumping facilities) of the Turner Cut junction.

Results

All results are reported relative to the location and array labels indicated in Figure 4.

Is arrival at Railroad Cut (in the interior Delta) related to OMR flows? (Objective 1)

Objective 1 called for an evaluation of the fraction of acoustically tagged steelhead reaching Railroad Cut in relation to OMR flows as a potential real-time monitoring strategy. The use of stipulation study fish as "sentinels" was completed during April and May during the study. When detections at Railroad Cut (labeled Array 9 and 16 in this report) exceeded expectations, managers reduced South Delta exports in an effort to provide additional protection for ESA listed salmonids. Results reported subsequently (for other objectives) provide data related to the likely effectiveness of this action as a fish protective measure. In this objective we report only on observed patterns of movement to Railroad Cut in relation to OMR flows.

Results for the Railroad Cut array summarized in Figure 5 suggest that the timing and arrival number of acoustically tagged steelhead was relatively consistent among release groups- showing no pattern with OMR levels during the first seven days of the experiment. If fish movements to Railroad Cut were strongly influenced by OMR flows, we would expect to have observed fish from release group 3 (the group exposed to most negative OMR flows) to arrive with different timing (earlier?) and in different numbers (greater numbers?) relative to fish from release groups 1 and 2 (when OMR flows were more positive). Instead, we observed a relatively consistent increase in fish detections at Railroad Cut Array 9 with between 50 and 70 fish having arrived by Day 13 (Figure 5; upper panel). Release group 2 had the most rapid accumulation and highest number of tagged fish, during OMR flows comparable to release group 1 and much less negative than experienced by release group 3. Detection at Array 16 were lower than for Array 9, but also did not exhibit any visible pattern in relation to OMR flows (Figure 5, lower panel).

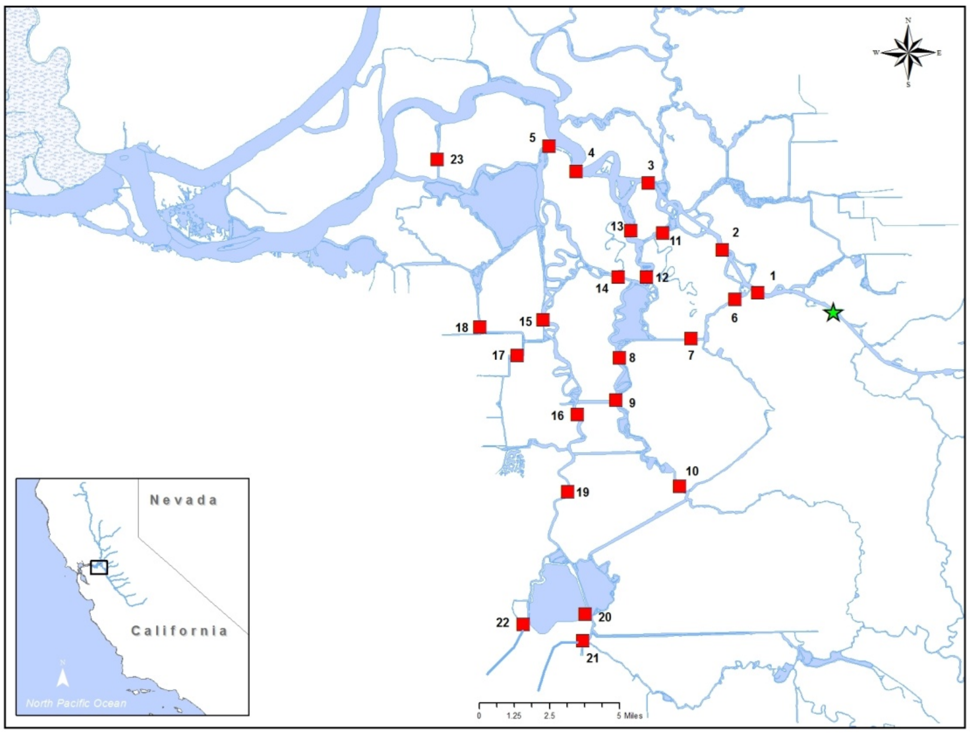

Figure 4. Locations and numeric labels for receiver arrays used for stipulation study analysis. Array 9 and array 16 are the Railroad Cut array used for real-time monitoring during the study.

Managers decreased exports beginning at or near Day 8 for all three release groups, and yet most fish which were to ever reach Railroad Cut at Array 9 had already arrived by the time reduced exports took effect (Figure 5). A similar pattern was observed at Railroad Cut Array 16 except for release 1 where unique detections continued to accumulate through Day 12. However, since exports were restricted similarly for all three release groups, it is possible that detections at Railroad Cut would have continued to accumulate if exports had remained higher.

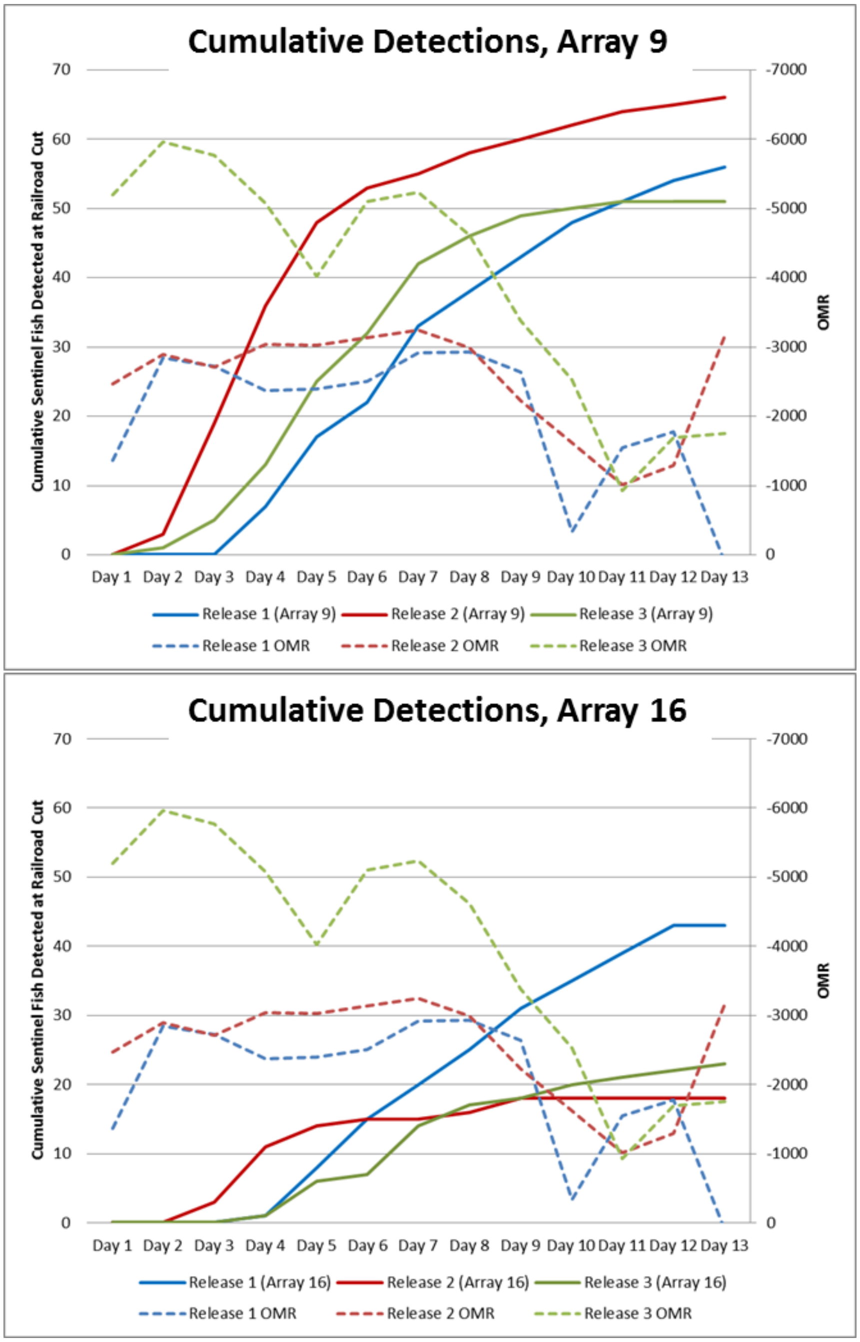

Figure 5. Cumulative detections of stipulation study fish at Array 9 (upper panel) and Array 16 (lower panel), the Railroad Cut receiver arrays, relative to OMR. X-axis indicates number of days from release for each release group. The timing and number of fish arriving at Railroad Cut was similar among release groups and suggested no obvious relationship with OMR.

Do hydrodynamic factors influence route entrainment into the interior Delta? (Objective 2)

We estimated proportion of fish moving into the interior Delta by analyzing detections among three arrays established around each of three junctions of interest: Turner Cut, Colombia Cut and Middle River. For Turner Cut, we identified the number of individual fish detected at Array 1 which were subsequently detected at downstream receivers on the mainstem San Joaquin river (Arrays 2, 3 or 4) or at downstream receivers along the interior Delta route (Arrays 6 and 7). For Colombia Cut, we identified the number of individual fish detected at Array 2 which were subsequently detected at downstream receivers on the mainstem San Joaquin river (Arrays 3 or 4) or at downstream receivers along the interior Delta route (Arrays 11, 12 or 13). For Middle River, we identified the number of individual fish detected at Array 3 which were subsequently detected at Array 4, downstream on the mainstem San Joaquin River, or at downstream receivers along the interior Delta route (Arrays 11, 12 or 13). Among this subset of fish, we calculated the proportion (within each release group) which were last detected in the interior Delta route. For this analysis (future analysis will include data from arrays from Mallard and Chipps Island arrays) we had only one receiver array downstream of the Middle River junction on the mainstem San Joaquin River (Array 4). If Array 4 had poor detection probabilities this would tend to positively bias the estimated proportion of fish entering the interior Delta.

A summary of the proportion of steelhead smolts entering the interior Delta at three junctions is provided in Figure 6. Release group specific sample sized declined (as would be expected) from Turner cut ($n \geq 130$) to Middle River ($n \geq 50$), but samples sizes appeared to be sufficiently large to reliably estimate routing probabilities. Colombia Cut exhibited the highest entrainment rate and Middle River exhibited the lowest. An evaluation of hydrodynamic factors which may have contributed to observed routing patterns is described below.

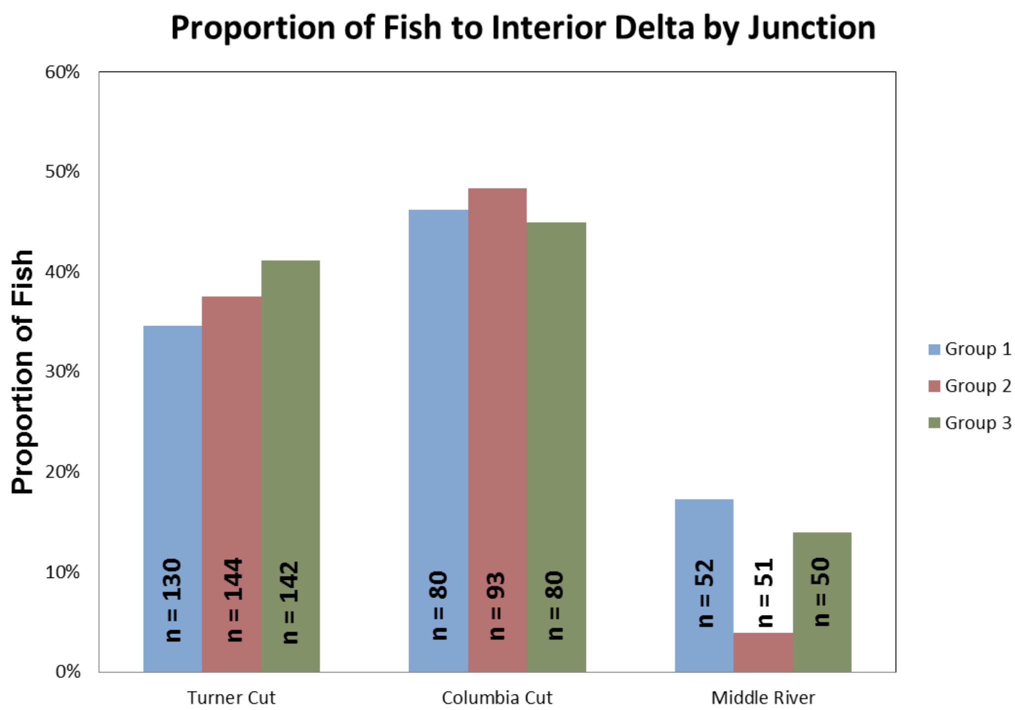

Figure 6. Proportion of acoustically tagged steelhead smolts entering the interior Delta from three junctions off the mainstem San Joaquin River. Colored bars represent fish release groups. "n" specifies number of fish used to estimate each proportion.

Objective 2 called for an evaluation of hydrodynamic conditions and hydrodynamic metrics which may influence entrainment into the interior Delta from Turner Cut, Colombia Cut and Middle River. Hindcast DSM2 Hydro data and Particle Tracking Model (PTM) simulations were requested from and provided by DWR for this purpose. Results from those analyses for Turner Cut are depicted in Figure 7. For analysis of DSM2 Hydro data we calculated daily flow proportion as described by Cavallo et al. (In review). For PTM, particles were injected at Buckley Cove matching the release of acoustically tagged steelhead. We then reported the cumulative fraction of particles entrained into Turner Cut. Results for daily flow proportion entrained into Colombia Cut and Middle River are provided in Figures 8 and 9. It was not possible to estimate particle entrainment into Colombia Cut and Middle River junctions from particles injected upstream of Turner Cut (i.e. near Buckley Cove), so PTM results are not reported for those junctions. Additional PTM runs could be requested from DWR if these results are thought to be important for the final report.

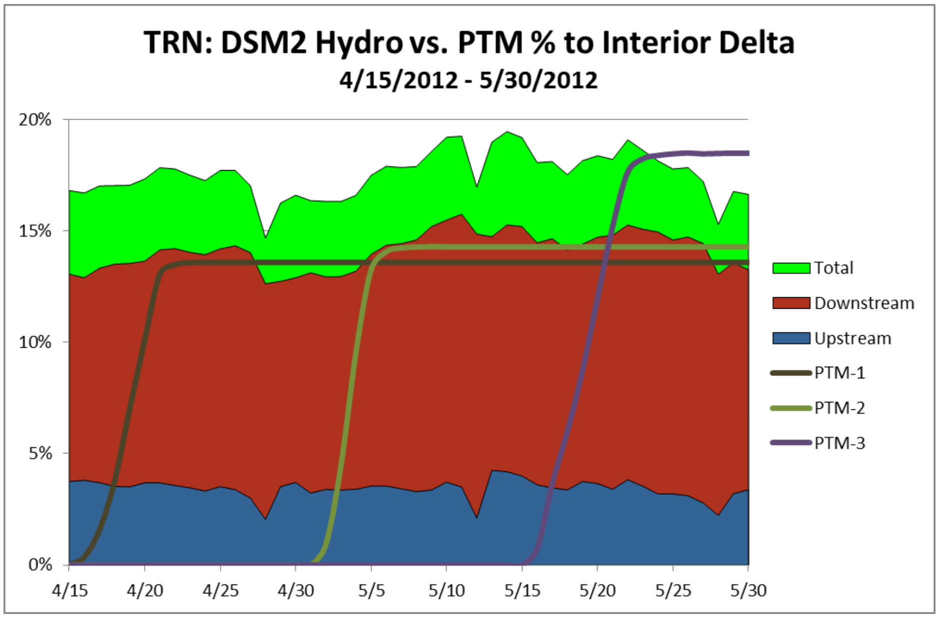

Figure 7. Summary of flow proportion and fraction of particles entering Turner Cut (Downstream + Upstream = Total) for the stipulation study period. Daily flow proportions were calculated for each day following methods described by Cavallo et al (In review). For PTM, particles were injected at the approximate location of Buckley Cove and matching the release timing of acoustically tagged steelhead. The daily cumulative proportion of particles entrained into Turner Cut was then reported. PTM-1, PTM-2 and PTM-3 refers to release groups.

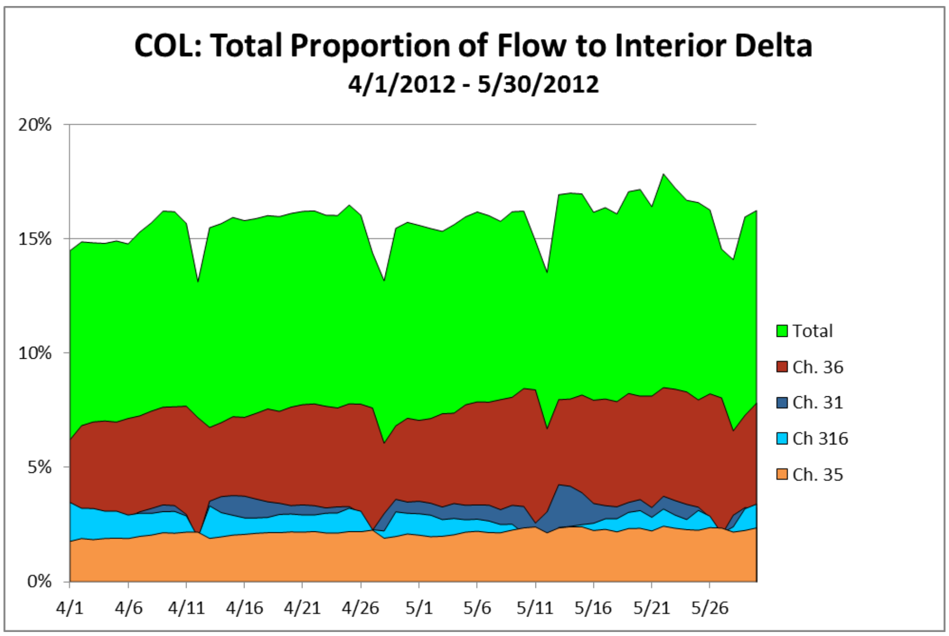

Figure 8. Summary of flow proportion entering Colombia Cut (Downstream + Upstream = Total) for the stipulation study period. Daily flow proportions were calculated for each day following methods described by Cavallo et al (In review).

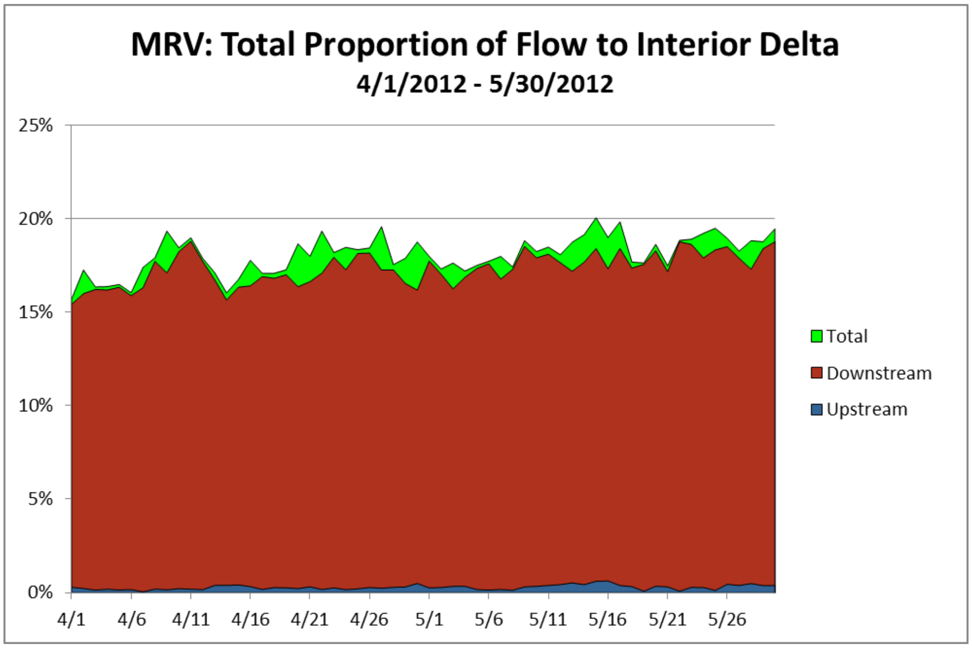

Figure 9. Summary of flow proportion entering Middle River (Downstream + Upstream = Total) for the stipulation study period. Daily flow proportions were calculated for each day following methods described by Cavallo et al (In review).

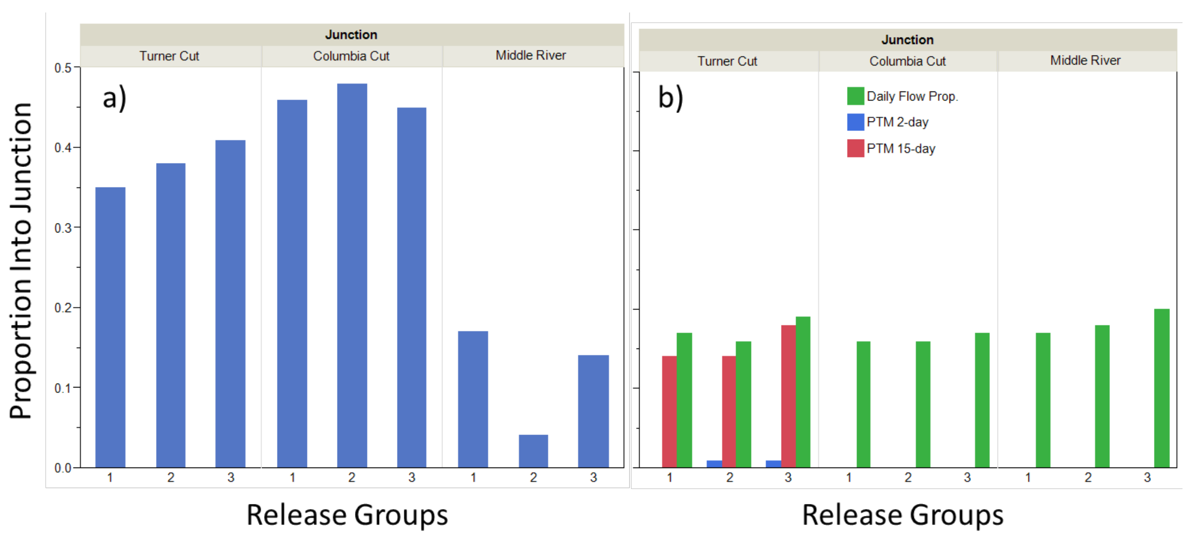

Figure 10. Proportion of acoustically tagged steelhead smolts (a) and alternative flow metrics (b) for proportion entering the interior Delta from three junctions off the mainstem San Joaquin River. Colored bars in (b) represent fish daily flow proportion (based upon DSM2 Hydro analysis), cumulative particle entrainment 3-days after injection at Buckley Cove, and cumulative particle entrainment 15-days after injection at Buckley Cove. PTM injections and entrainment data not yet available from for Columbia Cut and Middle River Junctions.

Daily flow proportion differed from observed fish entrainment for all junctions. At Turner Cut and Colombia Cut, observed fish proportions exceeded daily flow proportions (Figure 10). At the Middle River junction, observed fish proportions were below levels predicted by daily flow proportions. It is important to note that comparison of observed fish routing to daily flow proportion assumes random arriaval timing of fish at the junction. If most tagged fish tended to arrive during a particluar time or at a particular point in the tidal sycle, this would tend to result in an apparent mismatch with daily flow proportion-based predictions. More thorough analysis of sub-daily arrival timing at junctions and in relation to sub-daily hydrodynamic conditions will be provided in the synthesis report. Daily flow proportion values were consistent with fish observations in the sense that both showed little or no sensitivity to OMR levels (i.e. release groups).

PTM results two days after injection were a very small fraction of observed fish entrainment- suggesting that more 2-days are necessary for particles to be entrained (at Turner Cut at least). PTM results fifteen days after injection yielded results comparable to daily flow proportion (Figure 9). It was not possible to estimate particle entrainment into Colombia Cut and Middle River junctions from particles injected upstream of Turner Cut (i.e. near Buckley Cove), so PTM results are not reported for those junctions. Additional PTM runs could be requested from DWR if these results are thought to be important for the final report.

How do hydrodynamic conditions influence migration behavior in the interior Delta? (Objective 3)

We examined movement patterns of steelhead entering the interior Delta from Turner Cut in two ways. First, we assessed the proportion of these fish that migrated towards the pumping facilities (Railroad Cut: Array 9) and the proportion that migrated away from pumping facilities, towards the San Joaquin River, to arrays 12 or 14. We observed a higher proportion (50-72%) of steelhead that entered Turner Cut migrated towards the pumping facilities (Railroad Cut: Array 9) rather than migrating back to the San Joaquin River via arrays 12 or 14 (12-20%). Fifteen to 35% of steelhead which entered Turner Cut never reached arrays 12, 14, or 9, likely indicating they did not survive (Figure 11). These patterns were relatively consistent for stipulation and six year study release groups (Figure 11) and among stipulation release groups (Figure 12).

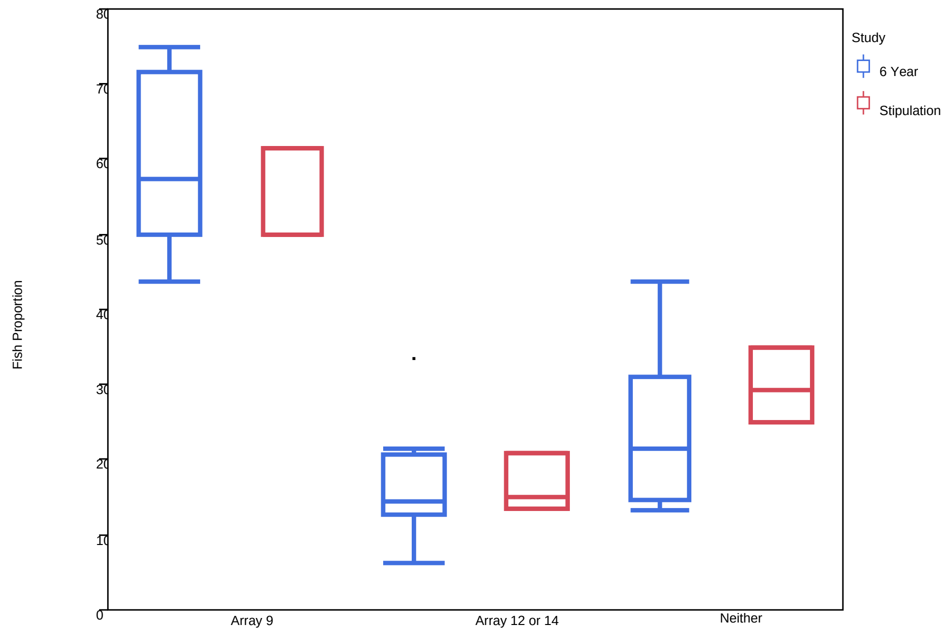

Figure 11. Colored box plots describing the destinations of stipulation (red) and six year study (blue) steelhead that entered the interior Delta from Turner Cut (through Array 6). See Figure 4 for locations of receiver arrays. Proportions of fish arriving at arrays (or not arriving) were comparable for six year and stipulation study releases.

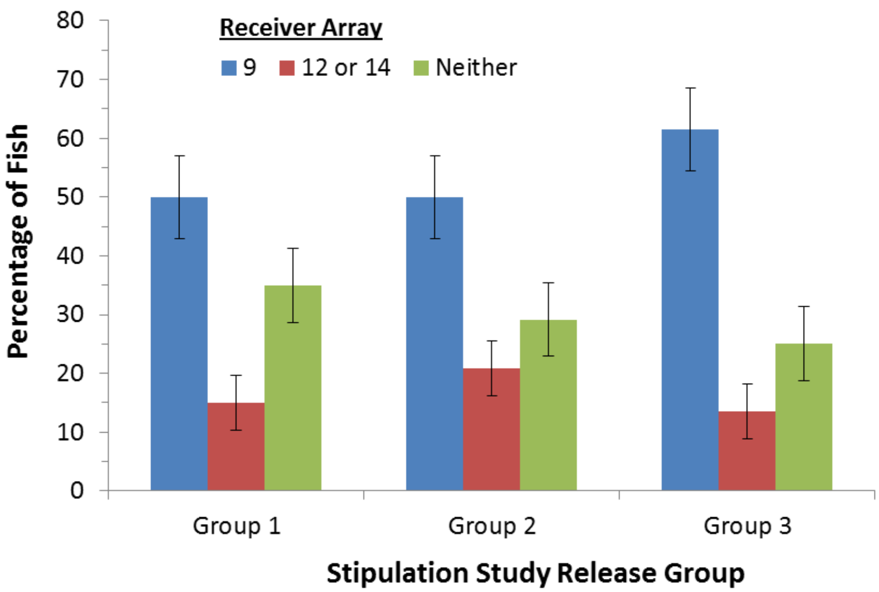

Figure 12. Movement of stipulation study steelhead that entered the interior Delta from Turner Cut. Colored bars indicate the percentage of fish of each release group that left receiver array 6 and moved away from the pumping facilities (receiver arrays 12 or 14), towards the pumping facilities (receiver array 9), or were undetected at either location. See Figure 4 for locations of receiver arrays. Error bars reflect 95% confidence intervals for fish proportions at each array based upon all available observations (stipulation and six year release groups). Patterns were relatively consistent (relative to within-group variation) among release groups.

To statistically evaluate whether the route (towards or away from the pumping facilities) steelhead took once entering the interior Delta from Turner Cut differed between stipulation release groups, a generalized linear model with binomial error structure was performed on the data summarized in Figure 12. No significant differences were observed for the relationship between initial interior delta route (e.g., detections at Receiver Array 9 vs. Array 12 or 14) and release group (GLM: P=0.64), suggesting differences in OMR flows may not have affected the routing of steelhead in the interior Delta.

Our second analysis related to interior Delta movement patterns examined travel times of steelhead that entered the interior Delta from Turner Cut. We observed travel times of steelhead that migrated to array 9 towards the pumping facilities or to arrays 12 or 14 towards the San Joaquin River were similar between release groups (Figure 13; Table 1). Mean travel times for steelhead travelling through the interior delta (via Turner Cut) were not significantly different between release groups (ANOVA: P=0.206), suggesting differences in OMR flows may not have affected the initial travel time of steelhead in the interior Delta.

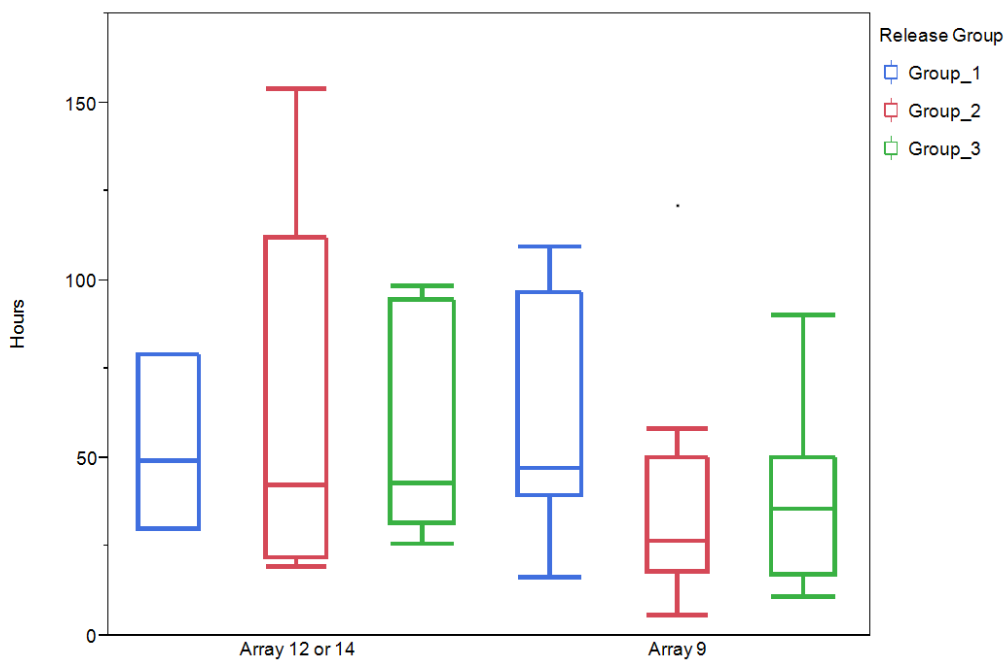

Figure 13. Travel time of stipulation study steelhead that entered the interior Delta from Turner Cut. Colored box plots indicate the distribution of travel time of fish from each release group that left receiver array 6 and initially arrived at receiver arrays 12 or 14 (moving away from the pumping facilities) or receiver array 9 (moving towards the pumping facilities).

Table 1. Mean travel times (in hours) and associated standard deviations for steelhead that entered the interior Delta through Turner Cut and migrated to arrays 12 or 14 (toward the San Joaquin River) or migrated to array 9 (toward the pumping facilities). The sample size specifies the number of fish travelling through the reach. Note that larger sample size for release group 3 was due to higher detection probability at receiver array 6 during this release.

Release Group	Mean Travel Time (Hr)	n	SD	se
1	58.4	13	30.4	8.4
2	44.6	17	39.2	9.5
3	41.1	39	25.2	4.0

In addition to examining proportion of fish routing and travel time, we also conducted a variety of analyses to describe general patterns of steelhead migration from each of the three release groups. Figure 14 for example depicts the spatial pattern of individual fish detected by release group. The results generally show a decreasing number individual fish detected the farther away fish moved from the release location, indicating declining fish numbers most likely resulting from mortality. The low rate of detections for routes exiting the vicinity of Railroad Cut (either north or south) suggests most stipulation study fish did not successfully exit the interior Delta during the study period. In contrast, last detections along the mainstem San Joaquin River appear somewhat higher, suggesting mainstem migrants may have been more successful. No consistent pattern between release groups appears evident, indicating that OMR flows may have had minimal effect on the general movement patterns of steelhead during the study.

Figure 15 depicts the spatial pattern of where steelhead were last detected by release group. The array with the most final detections was array 4, the array furthest downstream on the San Joaquin River and thus some portion of fish last detected at array 4 likely continued moving downstream and may have survived to Chipps Island. Future analysis should be able to account for these fish (at least as far as Chipps Island). However, the large proportion of final detections at Array 13 in the interior Delta likely represents high mortality occurring at or near this location, because if these fish passed array 13 and survived, they would have had subsequent detections at one of the numerous downstream arrays. No consistent pattern between release groups is evident, indicating that OMR flows likely were not driving the general patterns seen in the final detection spatial pattern.

Figure 16 depicts spatial patterns of residence time at each array by release group. The results indicate that time between first and last detections at each array was generally consistent among arrays, except for the arrays located at Clifton Court Forebay. Steelhead spent up to five times longer at arrays 20 and 21 at Clifton Court Forebay, indicating that steelhead may have been consumed by predatory fish and the tags defecated near those arrays. No consistent pattern between release groups appears evident, indicating that OMR flows likely were not driving the general patterns seen in fish residence time.

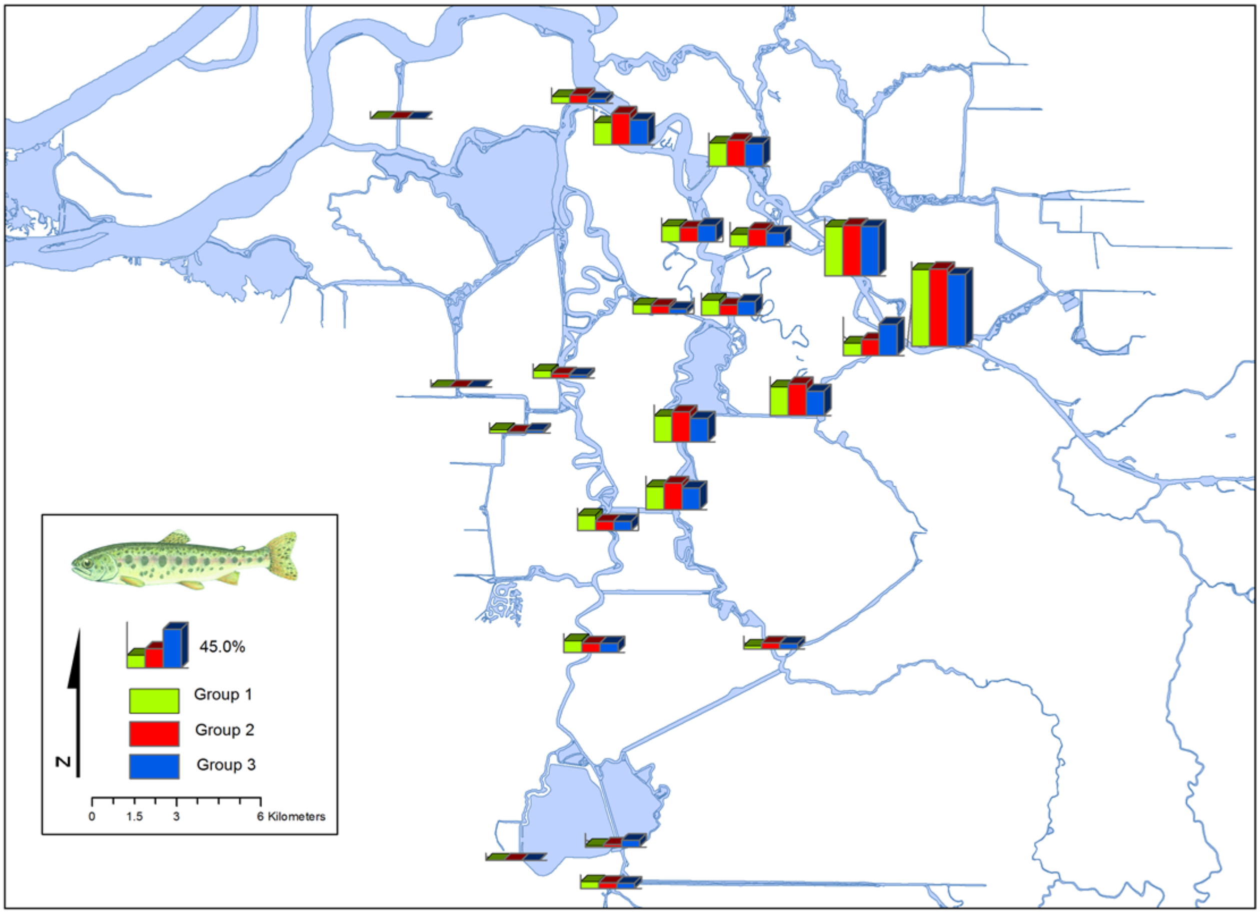

Figure 14. Percentage of individual stipulation study steelhead smolts detected in each array by release group. In the legend, the number next to the bar graph indicates the scale of the blue bar height is equivalent to 45%. See Figure 4 for array locations. See Table 2 for source data.

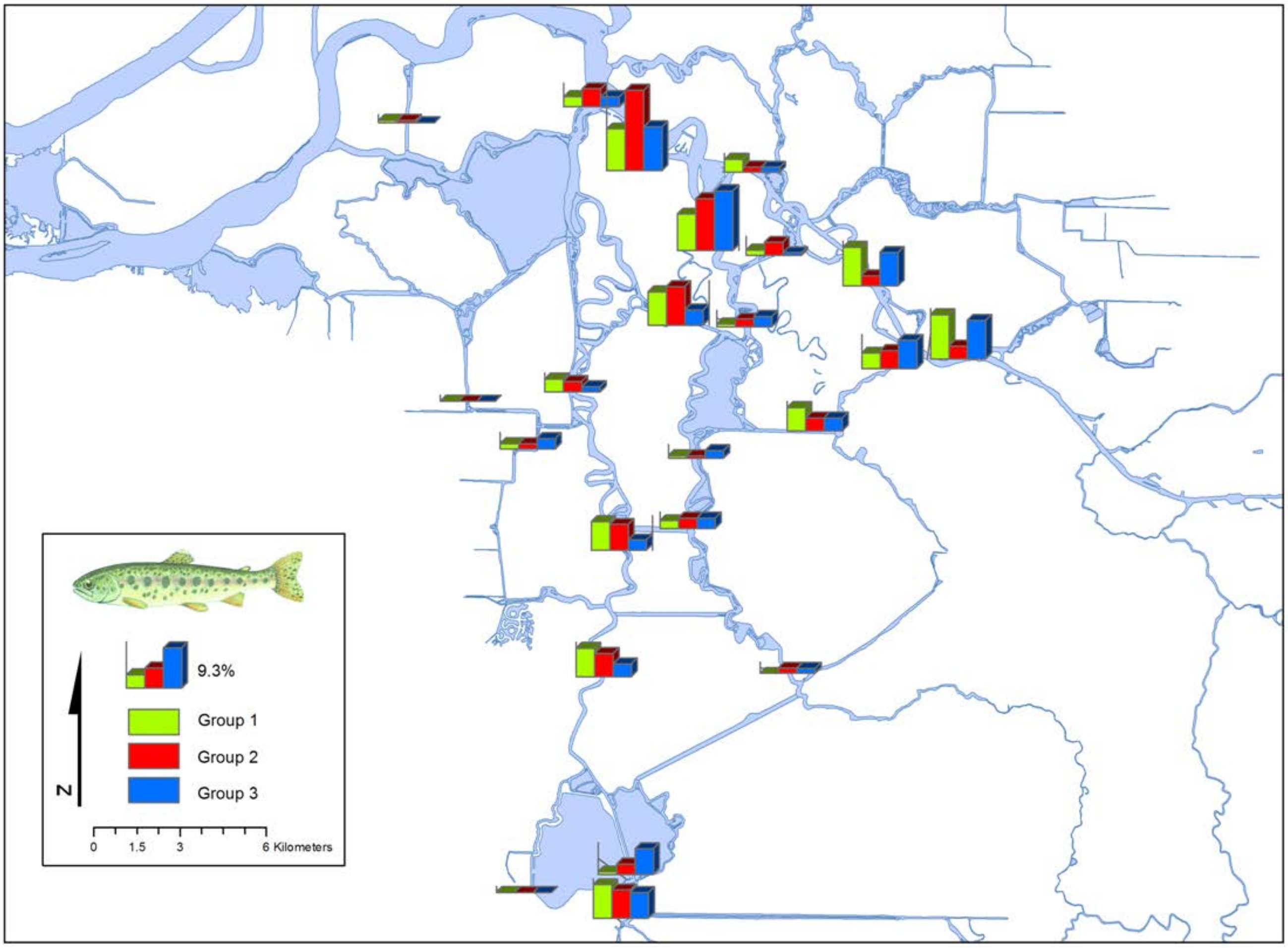

Figure 15. Percentage of stipulation study steelhead smolts that were last detected at each array by release group. The distribution of last detections indicates areas where fish mortality occurred or where fish left the area of receiver coverage. In the legend, the number next to the bar graph indicates the scale of the blue bar height is equivalent to 9.3%. See Figure 4 for array locations. See Table 3 for source data.

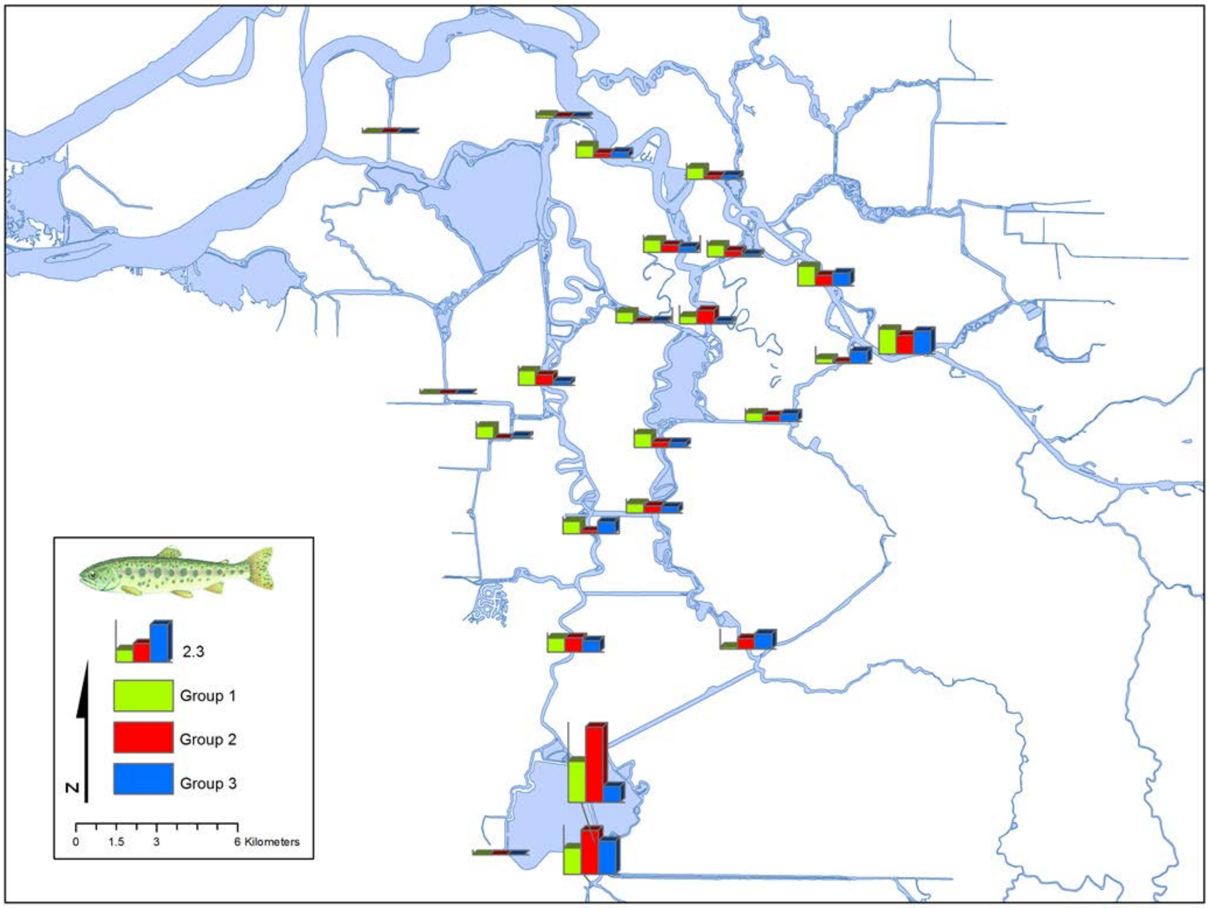

Figure 15. Average residence time of fish at each array by release group. Residence time is equal to the difference between last and first detections of individual fish. In the legend, the number next to the bar graph symbol indicates the scale of blue bar height equivalent to 2.3 days. See Table 4 for source data. See Figure 4 for array locations.

Table 2. Number and percentage (%) of stipulation steelhead smolts detected in each array by release groups within the 15-day period from the released dates.

Array	Number of Fish Detected			Proportion (%) of of Fish Detected		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
1	147	149	139	88.02%	89.22%	82.74%
2	95	98	96	56.89%	58.68%	57.14%
3	45	51	44	26.95%	30.54%	26.19%
4	42	60	48	25.15%	35.93%	28.57%
5	13	17	9	7.78%	10.18%	5.36%
6	24	31	61	14.37%	18.56%	36.31%
7	55	61	47	32.93%	36.53%	27.98%
8	50	58	46	29.94%	34.73%	27.38%
9	44	51	42	26.35%	30.54%	25.00%
10	6	12	11	3.59%	7.19%	6.55%
11	23	33	26	13.77%	19.76%	15.48%
12	29	20	27	17.37%	11.98%	16.07%
13	30	27	32	17.96%	16.17%	19.05%
14	18	16	10	10.78%	9.58%	5.95%
15	14	8	6	8.38%	4.79%	3.57%
16	29	18	18	17.37%	10.78%	10.71%
17	6	2	5	3.59%	1.20%	2.98%
18*	0	0	0	0%	0%	0%
19	22	18	18	13.17%	10.78%	10.71%
20	3	5	13	1.80%	2.99%	7.74%
21	13	11	10	7.78%	6.59%	5.95%
22*	0	0	0	0%	0%	0%
23	1	1	0	0.60%	0.60%	0%

Table 3. Number and percentage (%) of stipulation steelhead smolts last detected in each array by release groups within the 15-day period from the released dates.

Array	Number of Fish Detected			Proportion (%) of of Fish Detected		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
1	17	5	15	10.18%	2.99%	8.93%
2	15	4	13	8.98%	2.40%	7.74%
3	5	2	2	2.99%	1.20%	1.19%
4	16	31	17	9.58%	18.56%	10.12%
5	4	7	4	2.40%	4.19%	2.38%
6	6	7	11	3.59%	4.19%	6.55%
7	9	5	5	5.39%	2.99%	2.98%
8	1	1	3	0.60%	0.60%	1.79%
9	3	4	4	1.80%	2.40%	2.38%
10		2	2	0.00%	1.20%	1.19%
11	2	5	1	1.20%	2.99%	0.60%
12	1	3	4	0.60%	1.80%	2.38%
13	14	20	23	8.38%	11.98%	13.69%
14	13	15	6	7.78%	8.98%	3.57%
15	5	4	2	2.99%	2.40%	1.19%
16	11	10	4	6.59%	5.99%	2.38%
17	2	2	4	1.20%	1.20%	2.38%
18*	-	-	-	0.00%	0.00%	0.00%
19	11	9	5	6.59%	5.39%	2.98%
20	1	4	10	0.60%	2.40%	5.95%
21	13	11	10	7.78%	6.59%	5.95%
22*	-	-	-	0.00%	0.00%	0.00%
23	1	1	0	0.60%	0.60%	0.00%

Table 4 Average, minimum and maximum values of Stipulation fish residence time at each array by release groups. Fish residence time is equal to the difference between the last and first detection of individual fish at each array.

Array	Release Group 1			Release Group 2			Release Group 3		
	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
1	1.53	0.0014	14.60	1.17	0.0014	14.25	1.42	0.0004	12.39
2	1.20	0.0007	13.29	0.65	0.0004	14.04	0.80	0.0008	11.27
3	0.70	0.0020	9.67	0.20	0.0034	2.49	0.24	0.0038	2.39
4	0.74	0.0004	10.17	0.29	0.0011	1.69	0.36	0.0008	1.84
5	0.17	0.0050	1.11	0.08	0.0003	0.66	0.08	0.0097	0.32
6	0.29	0.0003	2.69	0.10	0.0003	1.18	0.73	0.0036	13.36
7	0.53	0.0007	4.62	0.39	0.0008	4.54	0.49	0.0033	10.69
8	0.85	0.0006	8.42	0.32	0.0008	4.03	0.31	0.0011	1.62
9	0.59	0.0008	10.16	0.46	0.0027	10.22	0.37	0.0006	5.48
10	0.13	0.0100	0.31	0.65	0.0070	3.61	0.94	0.0056	5.82
11	0.74	0.0035	8.92	0.38	0.0030	7.30	0.17	0.0062	1.08
12	0.47	0.0014	2.94	0.84	0.0048	9.37	0.17	0.0019	3.10
13	0.76	0.0050	5.39	0.46	0.0043	7.59	0.34	0.0078	3.37
14	0.66	0.0058	6.84	0.08	0.0056	0.56	0.12	0.0028	0.70
15	0.89	0.0004	3.25	0.64	0.0421	1.76	0.23	0.0029	0.87
16	0.76	0.0050	3.78	0.17	0.0022	0.80	0.72	0.0045	7.36
17	0.76	0.0017	3.13	0.02	0.0094	0.03	0.15	0.0036	0.42
18	-	-	-	-	-	-	-	-	-
19	0.86	0.0039	5.50	0.90	0.0046	8.95	0.71	0.0042	6.20
20	2.52	0.0219	5.77	4.64	0.0018	10.46	0.97	0.0013	6.97
21	1.63	0.1643	7.34	2.72	0.2138	10.22	2.05	0.1413	12.01
22	-	-	-	-	-	-	-	-	-
23	0.00	0.0014	0.00	0.02	0.0249	0.02	-	-	-

Figures 17, 18 and 19 contrast patterns of observed daily passage of tagged fish with model based estimates of daily particle passage. Differences in timing of arrival of steelhead versus particles at each array indicate when and where particle behavior diverges from behavior of tagged hatchery steelhead smolts.

Results generally indicate that steelhead arrival timing and proportion becomes more divergent from the arrival timing and proportion of particles as a function of temporal and spatial distance from the release location (Figures 17, 18, 19). For example, the timing of steelhead movement was most similar to particle movements at arrays 1, 2, and 6 (nearest the Buckley Cove release location). However, even at Array 1 there was already a ~1 day discrepancy in the peak of passage and a large difference proportion of fish or particles reaching the array. At arrays located further away from the release point (3, 4, 9, 16, 11, 12, and 13) arrival timing of fish was much earlier than arrival timing of particles. Earlier arrival of steelhead at more downstream arrays indicates that as migration progressed, steelhead generally migrated faster than the rate of "net" flow movement, indicating directed, volitional downstream movement. These findings are consistent with previous comparisons of CWT fish recoveries to particle tracking model simulations (e.g. Baker and Morhardt 2001).

References

Baker P.F. and J.E. Morhardt. 2001. Survival of Chinook salmon smolts in the Sacramento-San Joaquin Delta and Pacific Ocean. Pages 163-182 in R.L. Brown, Editor. Contributions to the Biology of Central Valley Salmonids, Volume 2, Fish Bulletin 179. California Department of Fish and Game, Sacramento, California.

Cavallo, B., P. Gaskill, and J. Melgo. In prep. Investigating the influence of tides, inflows, and exports on sub-daily flows at junctions in the Sacramento-San Joaquin Delta. For submittal to: San Francisco Estuary and Watershed Science.

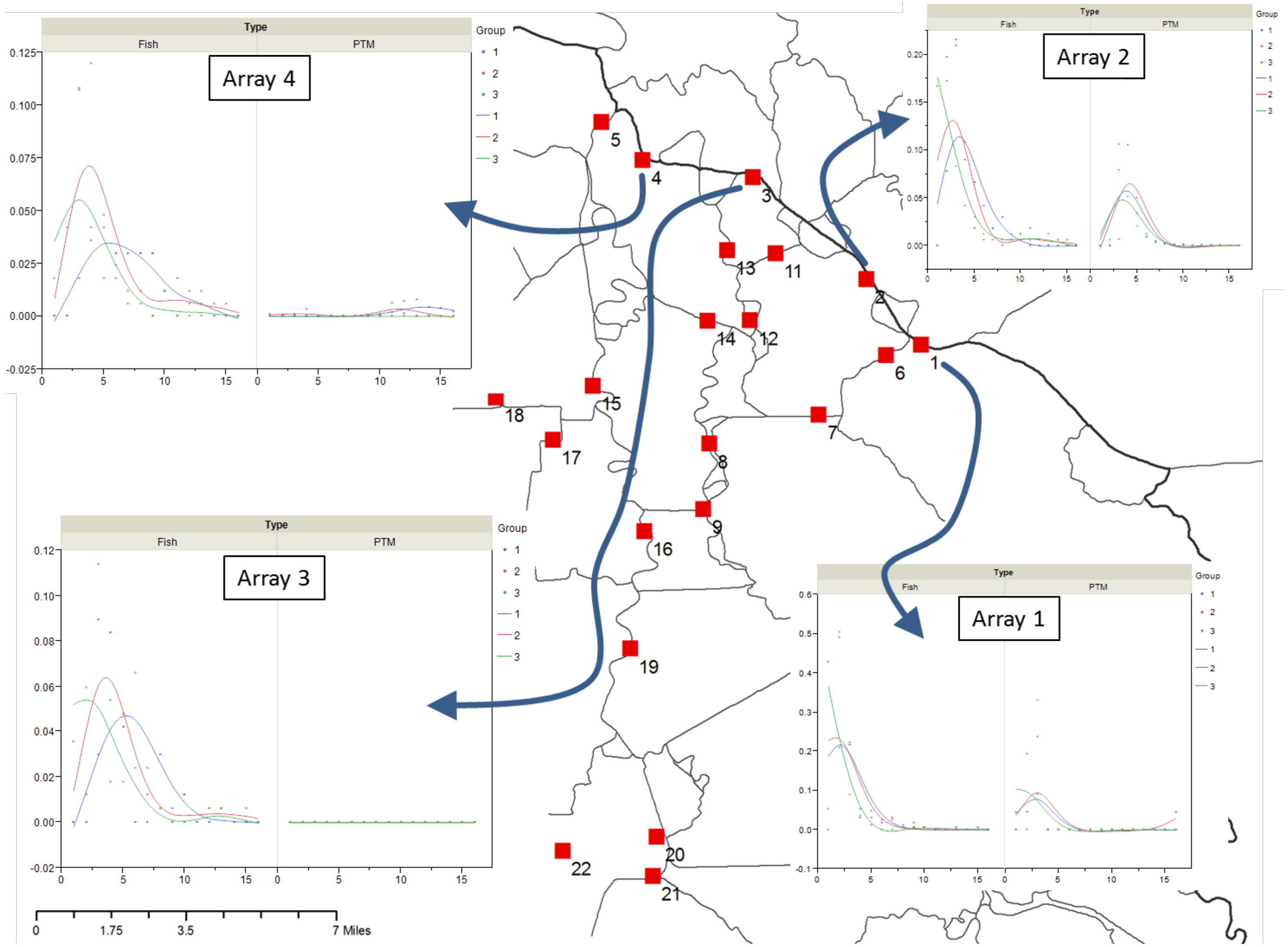

Figure 17. Daily proportion of fish (in days from release) relative to daily proportion of particles for arrays along the mainstem San Joaquin River. Results indicate generally similar patterns of tagged fish passage among release groups (colored lines), and demonstrate how particles become increasingly divergent with time and distance from location and time of release.

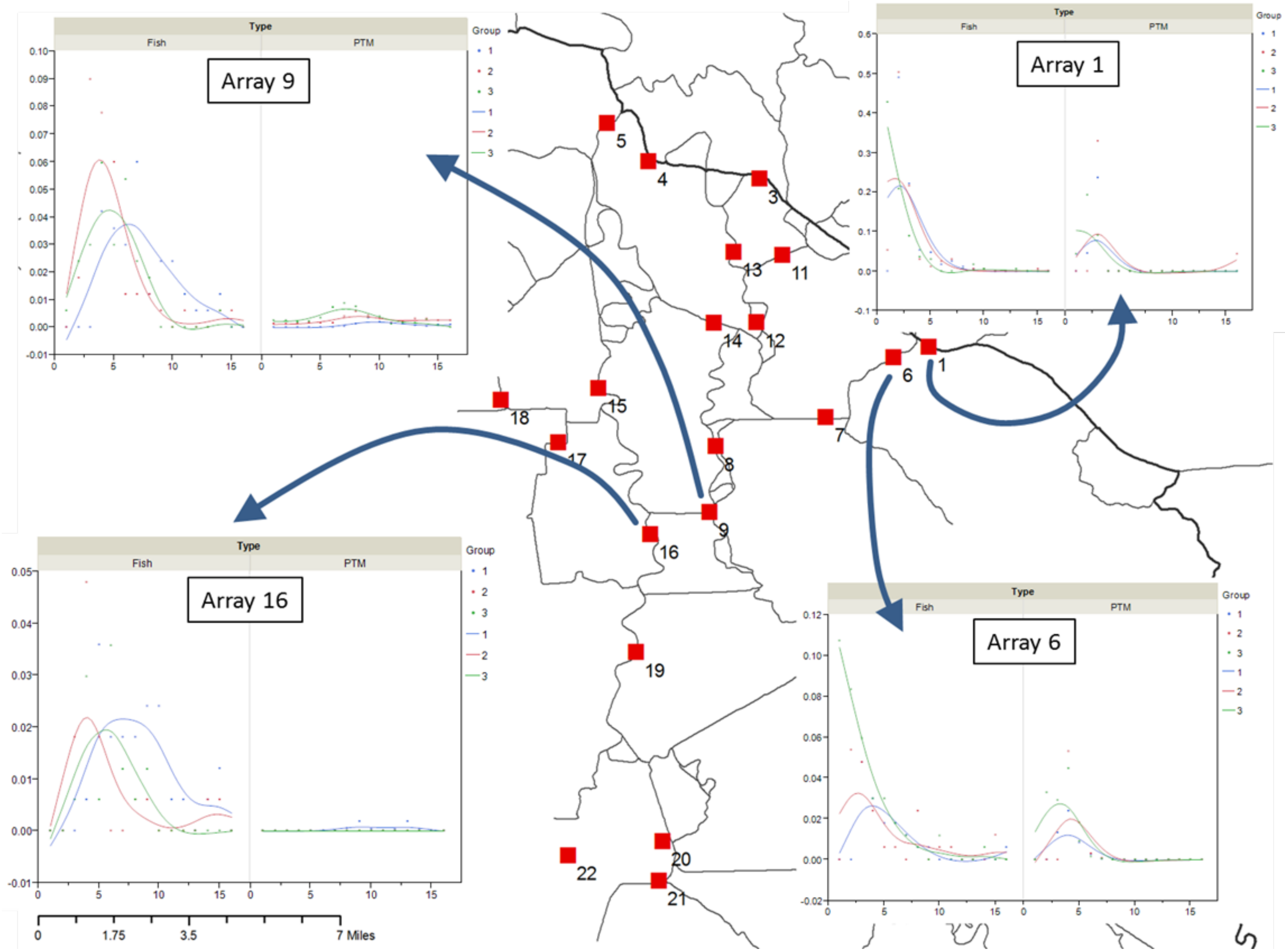

Figure 18. Daily proportion of fish (in days from release) relative to daily proportion of particles for arrays from Turner Cut to Railroad Cut. Results indicate generally similar patterns of tagged fish passage among release groups (colored lines), and demonstrate how particles become increasingly divergent with time and distance from location and time of release.

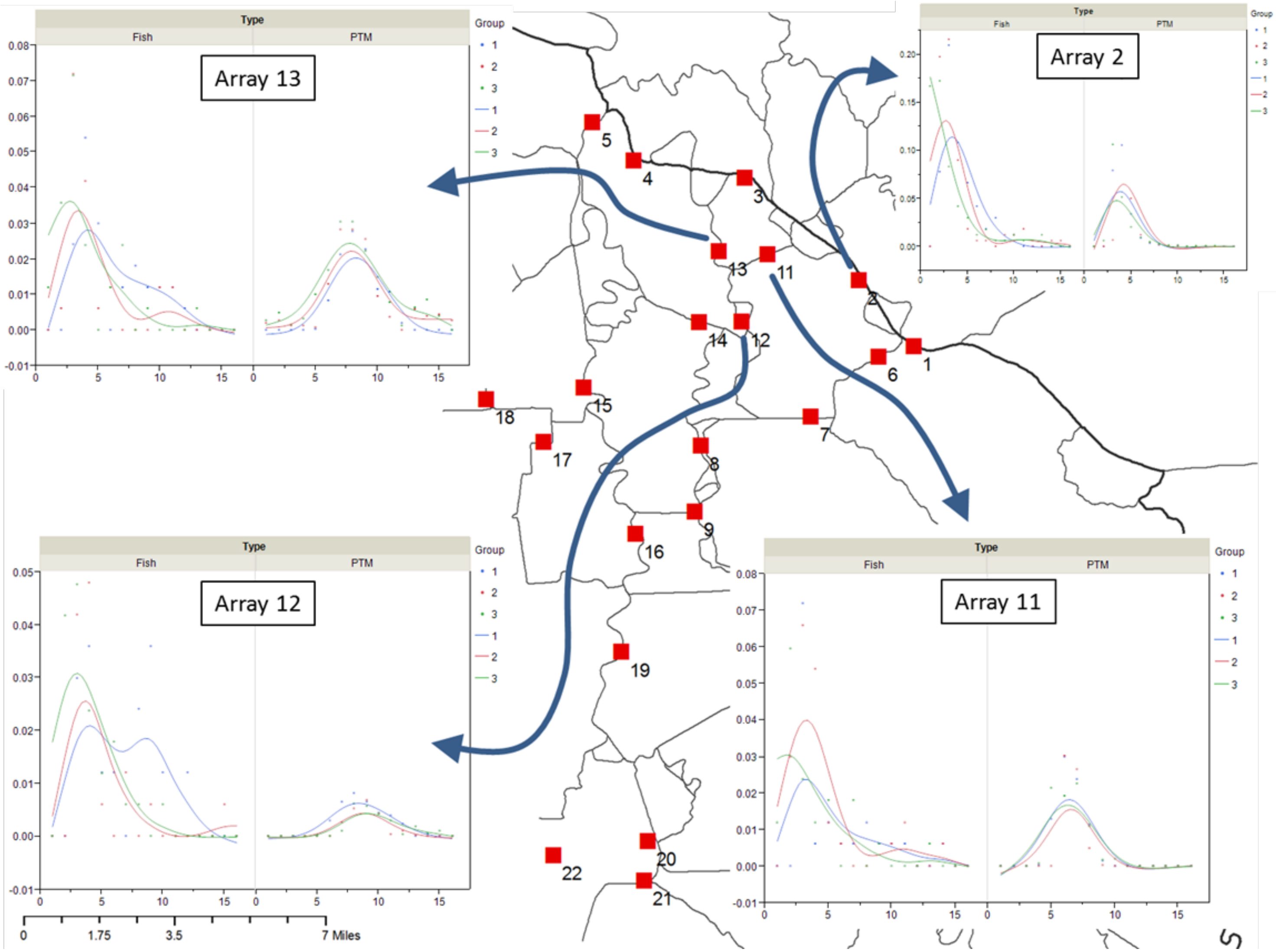

Figure 19. Daily proportion of fish (in days from release) relative to daily proportion of particles for arrays from Colombia Cut and the mouth of Middle River. Results indicate generally similar patterns of tagged fish passage among release groups (colored lines), and demonstrate how particles become increasingly divergent with time and distance from location and time of release.