Delta Real-Time Acoustic Monitoring (DREAM) Program  
Shiny App Demonstration

# Background

On January 17, 2014 Governor Brown issued a proclamation declaring a state of emergency due to prolonged drought conditions, which was then redoubled on April 25, 2014. On December 22, 2014, Governor Brown extended the January 17 and April 25 proclamation through May 31, 2016. The Proclamations direct the Department of Water Resources (DWR) to take specific actions related to evaluating and managing the changing impacts of drought on threatened and endangered species and species of special concern, as well as to conduct specific monitoring actions described in the April 8, 2014 Drought Operations Plan (DOP).

California Central Valley Winter-run chinook (endangered), Spring-run chinook (threatened), Green sturgeon (threatened), Coastal Anadromous Rainbow trout (threatened), Longfin smelt (threatened), and Delta smelt (endangered) are sensitive species affected by the compounding factors of drought such as reduced water flows, sub-optimal water quality, high temperatures, entrainment, and loss to water exports. The ability to monitor the movements and behaviors of these fish species is critical to understanding impacts related to extreme climate conditions and water operations. The use of monitoring technology that can be utilized to inform real-time water operations is critical to the development of both real-time and long-term management strategies to minimize impact to these species. For these reasons implementation of a core real-time acoustic monitoring array in the Delta is critical.

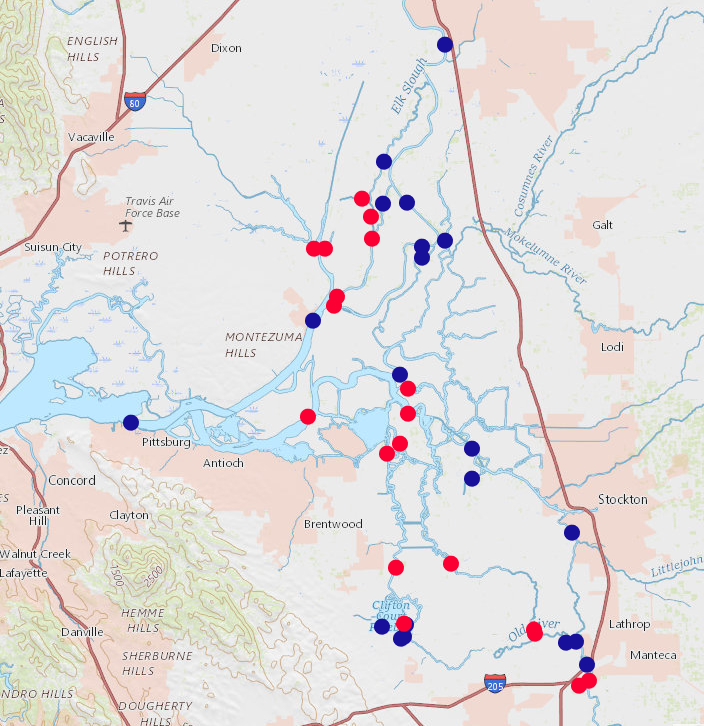
The principal objective of a Delta-wide monitoring array is to provide a common operating platform for monitoring the behavior, route of passage, and survival of tagged fish throughout the Delta. Meeting this objective will form the basis of a real-time reporting program and support additional future efforts. In order for the Delta-wide monitoring array to be run in real-time and year-round, the receivers that make up the array must be deployable so that detection probabilities in the locations they are deployed are near 100% under a variety of hydrologic conditions. The receivers must also be able to transmit data in real-time, be robust and require minimal maintenance, otherwise operational costs will make the array infeasible on a 24 hours a day/ 7 days a week/ 365 days a year basis. Finally, to be consistent with other proposed experiments, the selected technology must have the capacity to collect 2D data. The Juvenile Salmon Acoustic Telemetry System (JSATS) is a technology that could be successfully implemented to meet the real-time demands of a Delta-wide monitoring array.

# What is DREAM?

DWR, in cooperation with the U.S. Geological Survey (USGS), is developing a system to provide daily real-time forecasts of entrainment rates and through-Delta survival estimates for juvenile salmonids in the Sacramento – San Joaquin Delta based on acoustic telemetry data – the Delta Real-time Enhanced Acoustic Monitoring (DREAM) program. The DREAM program has two basic components: (1) an array of telemetry receivers deployed throughout the Delta, known as the CORE array, and (2) Information technology that takes in the real-time data within a Bayesian statistical framework to make near-real-time predictions of reach-specific survival and entrainment rates at junctions.

The foundation of the DREAM project is the CORE array: a network of permanent acoustic telemetry receiver sites designed to provide the data required for statistical mark-recapture models. The raw acoustic tag data acquired by the CORE array will be telemetered to a cloud storage system where the raw data will be processed, filtered, and archived by automated processes. During this step, filtered capture histories for release groups that have completed their outmigration will be placed into the statistical modeling database for use in the Bayesian mark-recapture survival model.

Figure 1: Approximate locations of acoustic receivers proposed for a network of telemetry arrays for a permanent monitoring network of juvenile salmon migration through the Sacramento - San Joaquin Delta. The blue dots represent Tier 1 CORE array sites while red dots represent Tier 2 sites.



The Bayesian mark-recapture survival model is the heart of the DREAM data analysis components. This model uses all of the complete capture histories stored on the DREAM modeling database to estimate route selection and survival model parameters. Scientists can use these parameter estimates to predict release group travel time, survival, and route selection as a function of Sacramento River discharge at Freeport and DCC gate position. Managers can leverage these parameter estimates using the STARS (Survival, Travel Time, and Routing Simulation) model, which allows users to forecast route selection, travel time, and survival in the Delta for operation scenarios or current conditions.

If managers need rapid feedback on survival and routing in the Delta, the DREAM project provides real-time statistical estimates of the route selection and survival of fish as they move through the CORE array. This information can be used to monitor the health of the CORE array, detect a sudden drop in survival, or see how fish respond to gate operations or sudden changes in flow.

## Proposed CORE Array

Two tiers of the core array that can be implemented over time are depicted, each tier defined based on the scientific questions that can be answered based on telemetry data acquired. The “Tier 1” core array defines the “minimal” array required to estimate migration routing and survival for the main migration routes available to juvenile salmon. These migration routes include the Sacramento River, Yolo Bypass (in high flow conditions), Sutter Slough, Steamboat Slough, the Delta Cross Channel, and Georgiana Slough for fish migrating in the Sacramento River. For fish migrating in the San Joaquin River, major migration routes include the mainstem San Joaquin, Paradise Cut (in high flow conditions), Old River, Middle River, Turner Cut, and transport from either of the water export facilities.

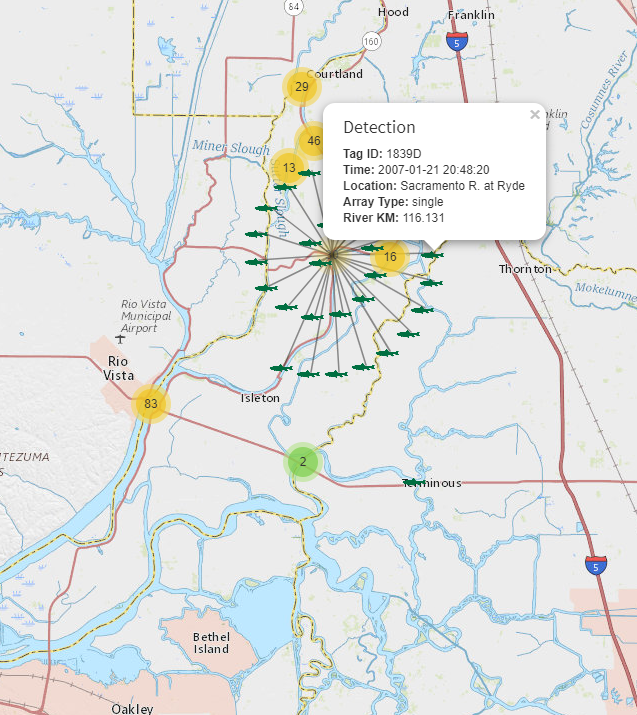
The Tier 2 core array adds receiver locations that further break down migration routes into key reaches within routes. While route-specific survival estimates through the Delta are obtainable with only Tier 1 infrastructure, certain locations within the Delta may be of heightened interest for finer-resolution survival and routing estimates. The Tier 2 core array attempts to identify some of these key monitoring locations and reaches.

# Shiny App

The Shiny App is a demonstration of a possible user interface for exploring raw acoustic telemetry data in real-time, as well as survival and migration routing estimates from Bayesian mark-recapture probability models. This is a prototype only for demonstration purposes, and it is not intended at this stage to be a management tool or publicly available. The Shiny App summarizes the output of each daily cohort for the current water year to display (1) overall survival and median travel time through the Delta between Freeport and Chipps Island, (2) route-specific survival and median travel time, and (3) the proportion of fish using each unique migration route. In addition to median travel time, users may also examine travel time distributions of daily cohorts or animate how travel time distributions change over time.

## Simulation of real-time in-season data access

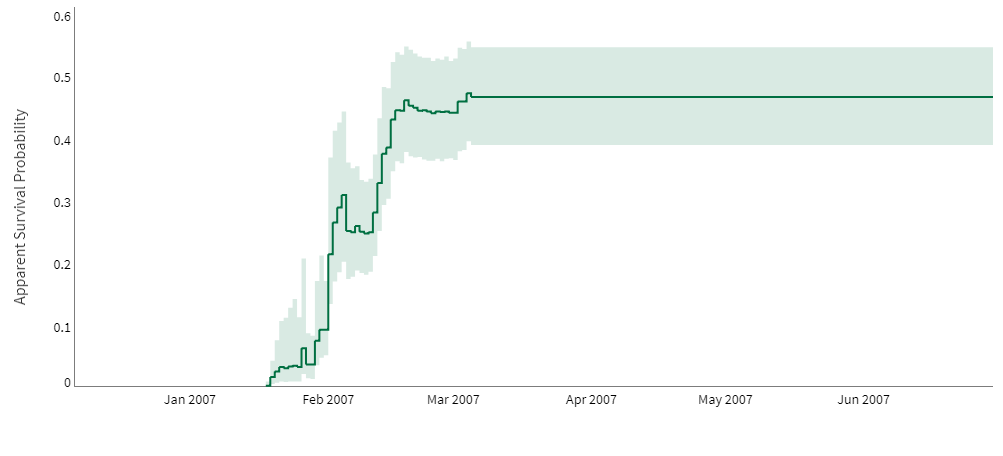
Figure 2: This map displays releases and detections at acoustic receiver arrays for acoustic telemetry studies of juvenile Chinook salmon survival and migration routing through the Sacramento River Delta conducted from the USFWS January 2007 Study.



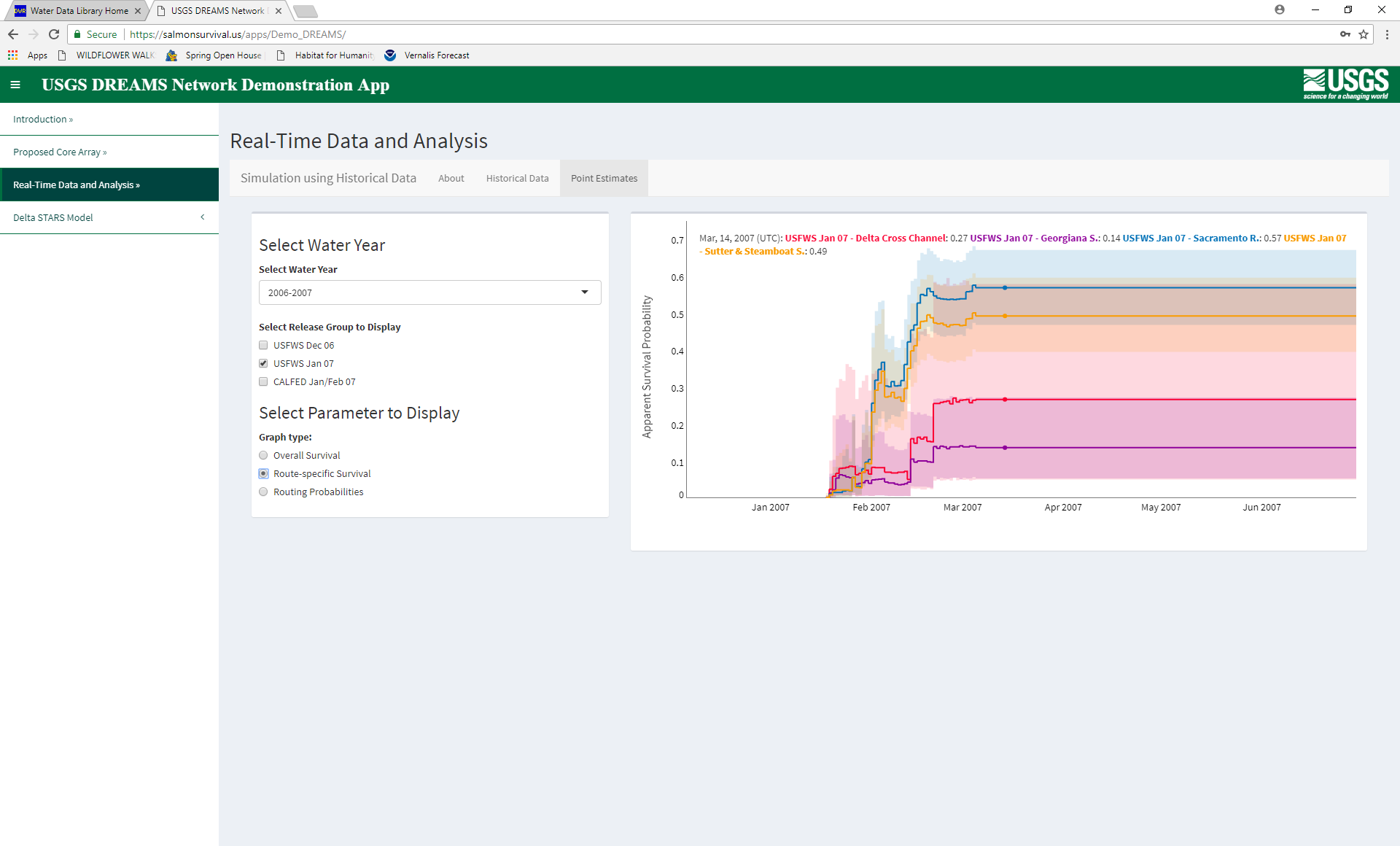
The Bayesian survival model generates route selection and survival parameter estimates, and the STARS model gives managers a means of using these estimates to predict survival and routing for a flow scenario. However, the STARS model does not provide information on the survival and routing of individual release groups. Additionally, because of the STARS model is computationally intensive, the model does not provide rapid feedback on changes in survival rates within the Delta. To overcome these limitations, the DREAM system includes real-time access to capture history data and real-time point estimates of survival and routing within the Delta.

The Shiny App includes a Real-Time Data and Analysis section that simulates some of the ways in which the data can be accessed and used in real-time. As an example, historical data from acoustic telemetry studies conducted during the winters of 2007 through 2011 by CALFED and by USFWS are presented in the demonstration. In this section, data on the release and detection of individually tagged fish is displayed. Detections represent the first detection per fish per receiver after QA/QC and predator filtering.

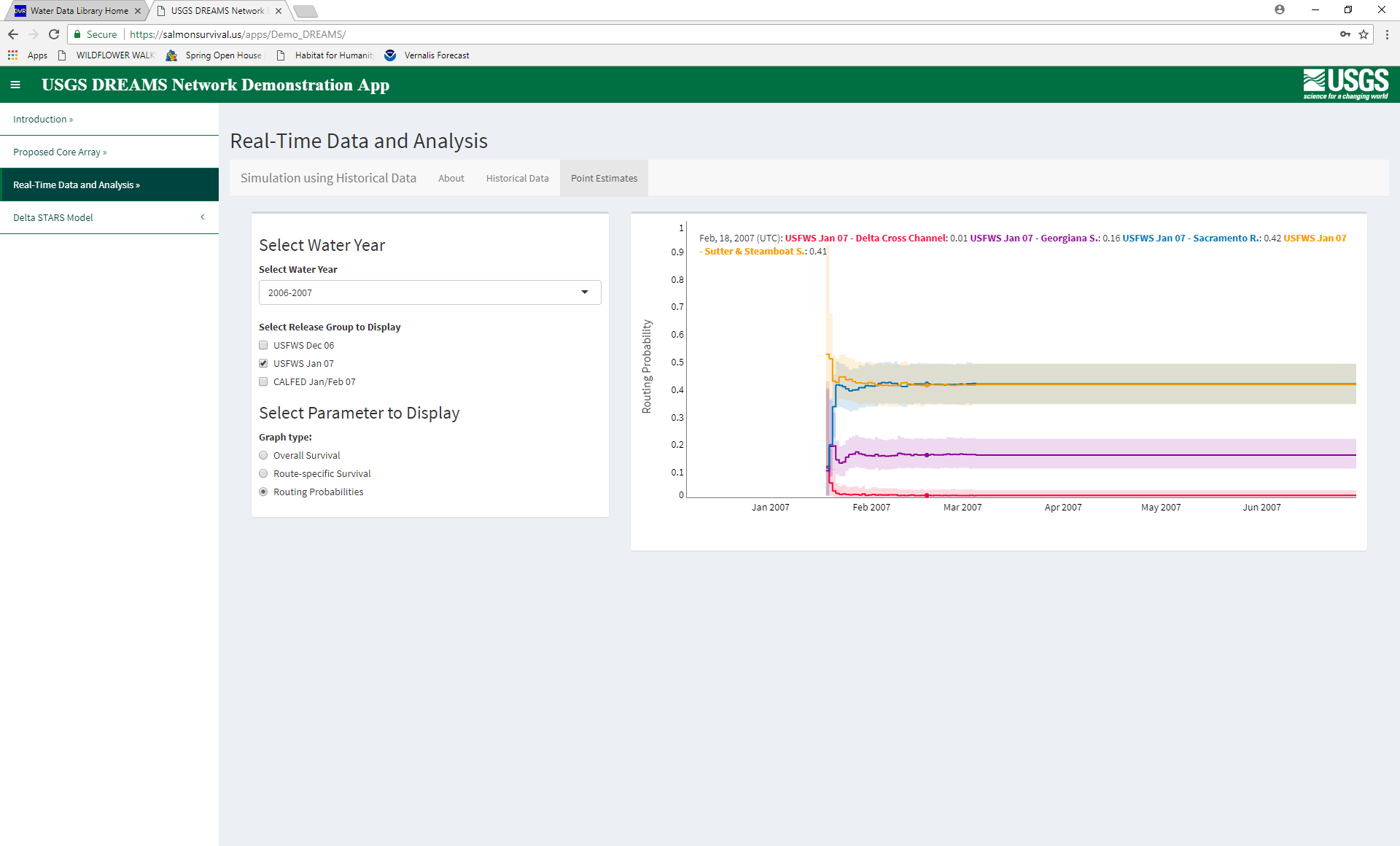
The App also simulates the process of providing point estimates of the fundamental parameters of survival and route selection probabilities for each release group in real-time. Point estimation begins on the first day after the last fish in a release group has been released. Initially, shortly after release, few fish will have migrated through the study area, which ends at Chipps Island.



Consequently, apparent survival probabilities represent the joint probability of surviving and migrating through the study area. Overtime, as fish migrate past Chipps Island, the apparent survival probability will increase until the last surviving fish is detected passing Chipps Island. At this point, the apparent survival probability will remain unchanged through time, and this asymptotic survival probability will represent the final estimate of true survival for a given release group. In contrast to apparent survival, routing probabilities represent the mean proportion of fish using each migration, conditional on fish having passed a given river junction.



Consequently, routing probabilities can be interpreted at 'face value' immediately after release. However, mean routing probabilities may be imprecise and fluctuate considerably shortly after release owing to few fish having yet migrated past key river junctions that divide the Delta in alternate migration routes. As with apparent survival, after all surviving fish pass Chipps Island, routing probabilities will stabilize to a constant 'final' value.



## Delta STARS Model

The Delta STARS (Survival, Travel Time, and Routing Simulation) Model is an individual-based simulation model that predicts survival, travel time, and routing of juvenile salmon migrating through the Delta. The model's structure and parameters are based on a recent analysis ([Perry et al. in press](http://www.nrcresearchpress.com/doi/abs/10.1139/cjfas-2017-0310#.WtT9zjZPqmQ)) that relates individual survival, travel time, and routing of late-fall Chinook salmon to daily [Sacramento River flows at Freeport](https://waterdata.usgs.gov/ca/nwis/dv/?site_no=11447650&agency_cd=USGS&referred_module=sw) and [Delta Cross Channel operations](https://www.usbr.gov/mp/cvo/vungvari/Ccgates.pdf).

The STARS model simulates travel time, routing, and survival of individuals in a daily cohort as they migrate through eight unique reaches of the Delta. A daily cohort is defined as all fish that enter the Delta on a given day at Freeport. Because travel time, routing, and survival depends on river flow when an individual enters a given reach, overall survival of a daily cohort depends on the entire time series of daily flows during their migration time through the Delta. For example, two cohorts may enter the Delta at the same discharge, but their overall survival will differ if one cohort enters during an ascending hydrograph and the other enters when it descending.

It is important to note that the STARS model is based on a set of relationships fitted to hatchery-origin late-fall Chinook salmon that migrated through the Delta between late November and mid-March over a five-year period (2007 - 2011). Therefore, model output should be thought of as a “historical expectation”. That is, the model provides predictions about survival based on what we know about a particular race that migrated through the Delta during a particular time of year under the environmental, operational, and physical characteristics of the Delta that occurred between 2007 and 2011.

Output from the model can be useful when used in conjunction with real time telemetry data to help understand what we might expect to occur based on what we have seen in the past. When real-time data and in-season observations deviate from our “historical expectation”, such deviations provide an important opportunity to learn about system dynamics.

The following pseudocode describes how travel time, survival, and routing are simulated given a daily time series of discharge and Delta Cross Channel gate operations:

1. Select parameter set i from the joint posterior parameter distribution (see Perry et al. in press for details).
2. Initiate the simulation with 1,000 fish at Freeport on day t.
3. Calculate survival in reach 1 given discharge on day t and parameter set i.
4. Draw individual travel times through reach 1 from a log-normal distribution where the mean of the distribution depends on parameter set i and discharge on day t. This yields a distribution of arrival times at the junction of Sutter and Steamboat Slough with the Sacramento River.
5. Draw the route taken by each fish from a Bernoulli distribution where the probability of entering Sutter and Steamboat Slough is a function of discharge on the day each fish arrives at the junction.
6. Calculate the survival probability of each individual for the next reach downstream (Sacramento River or Sutter and Steamboat Sloughs) given the discharge on the day each fish entered the next reach.
7. Draw travel times for each individual for the next downstream reach given the discharge on the day each fish entered the reach.
8. For fish remaining in the Sacramento River, draw the route taken by fish at the junction of the Sacramento River with the Delta Cross Channel (DCC) and Georgiana Slough from a multiple Bernoulli distribution where the probability of entering each route depends on the position of the DCC gates and discharge on the day each fish arrived at the junction.
9. Repeat steps 6 and 7 for all remaining reaches.
10. Repeat steps 2-9 for all days in the simulation.
11. Repeat 1-10 for all iterations of the joint posterior distribution.

### Survival and Routing

This simulation yields a posterior distribution of reach-specific survival probabilities, reach-specific travel times, and routing histories for a cohort of 1,000 individuals entering the Delta at Freeport on each day of the daily time series. Currently, if a fish's arrival time in a reach is later than the last date of available flow data, then the model assumes that flow remains constant based on the last date of available flow data. In the future, we would like to incorporate river flow forecasts so that the model provides more realistic real-time survival predictions.

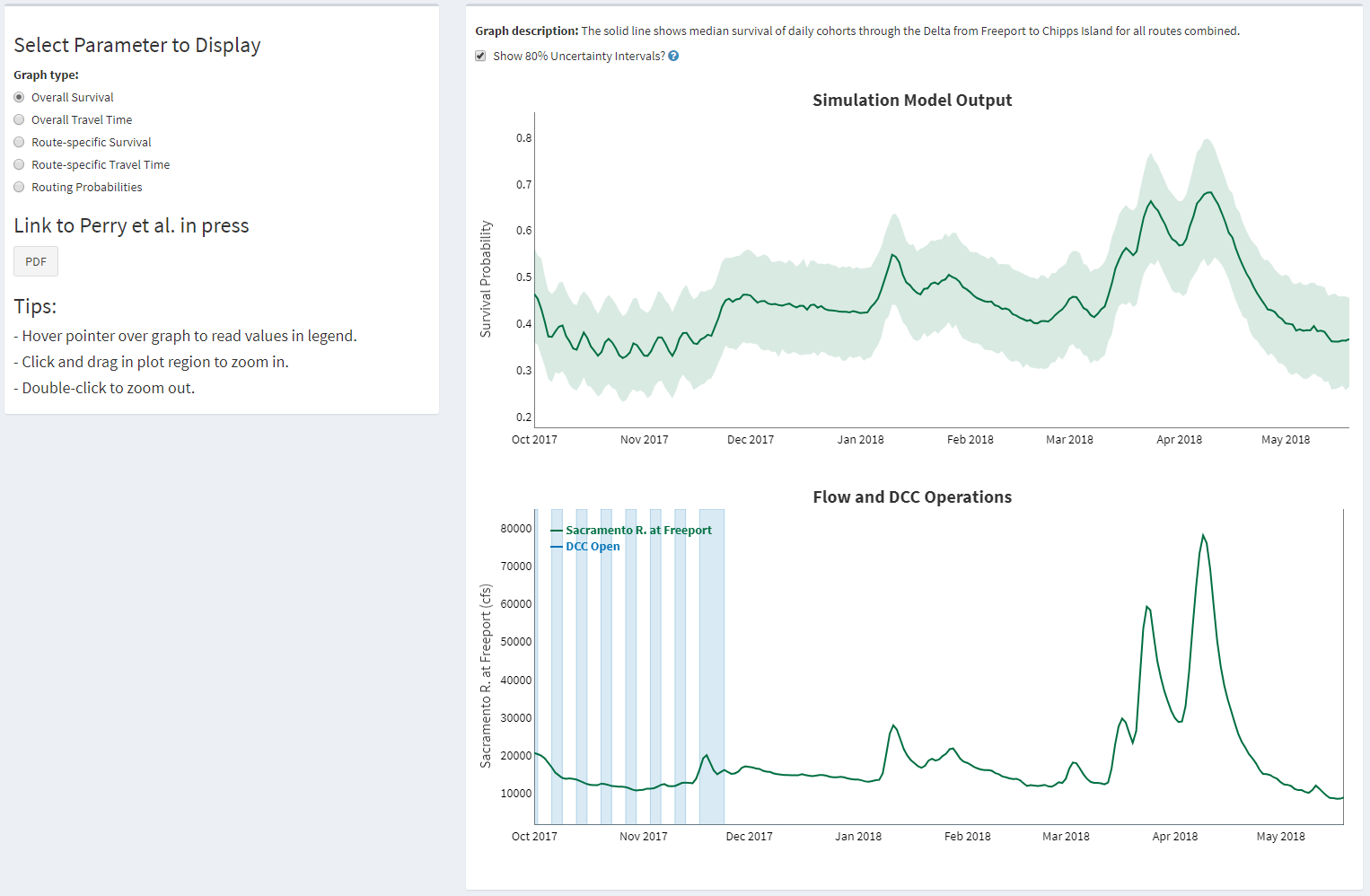


Figure 3: Simulation model output showing overall survival

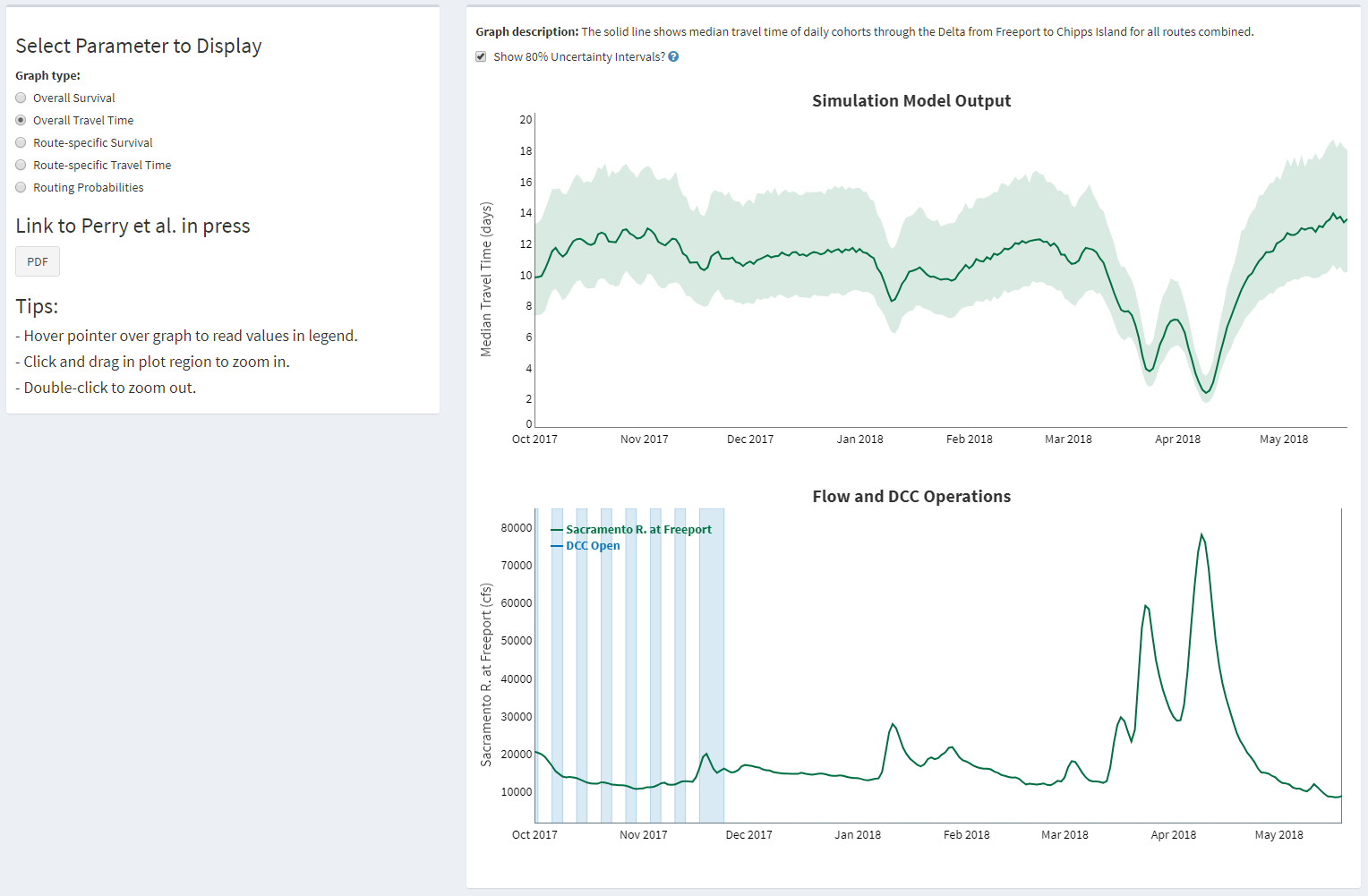


Figure 4: Simulation model output showing overall travel time

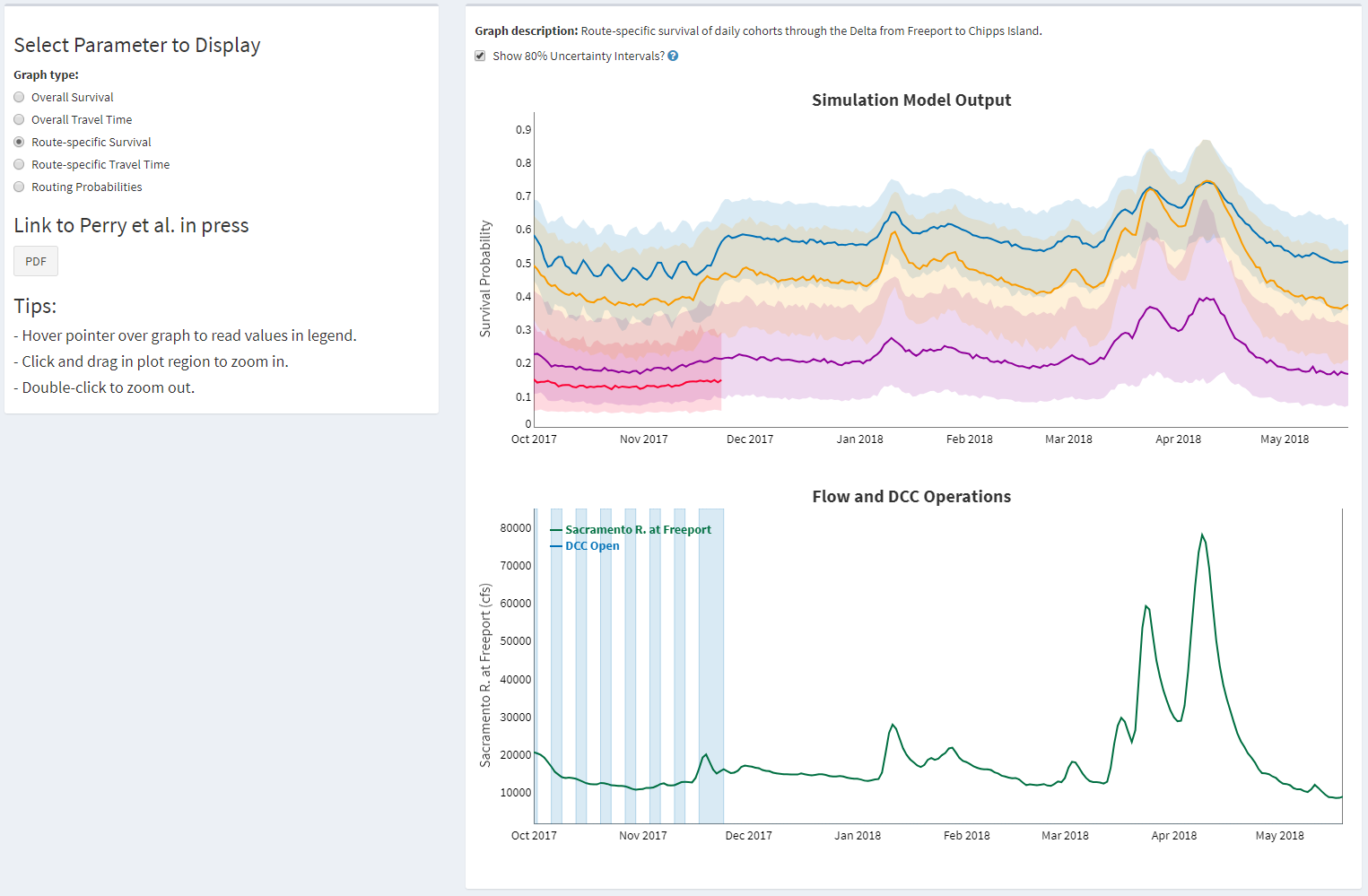


Figure 5: Simulation model output showing route-survival

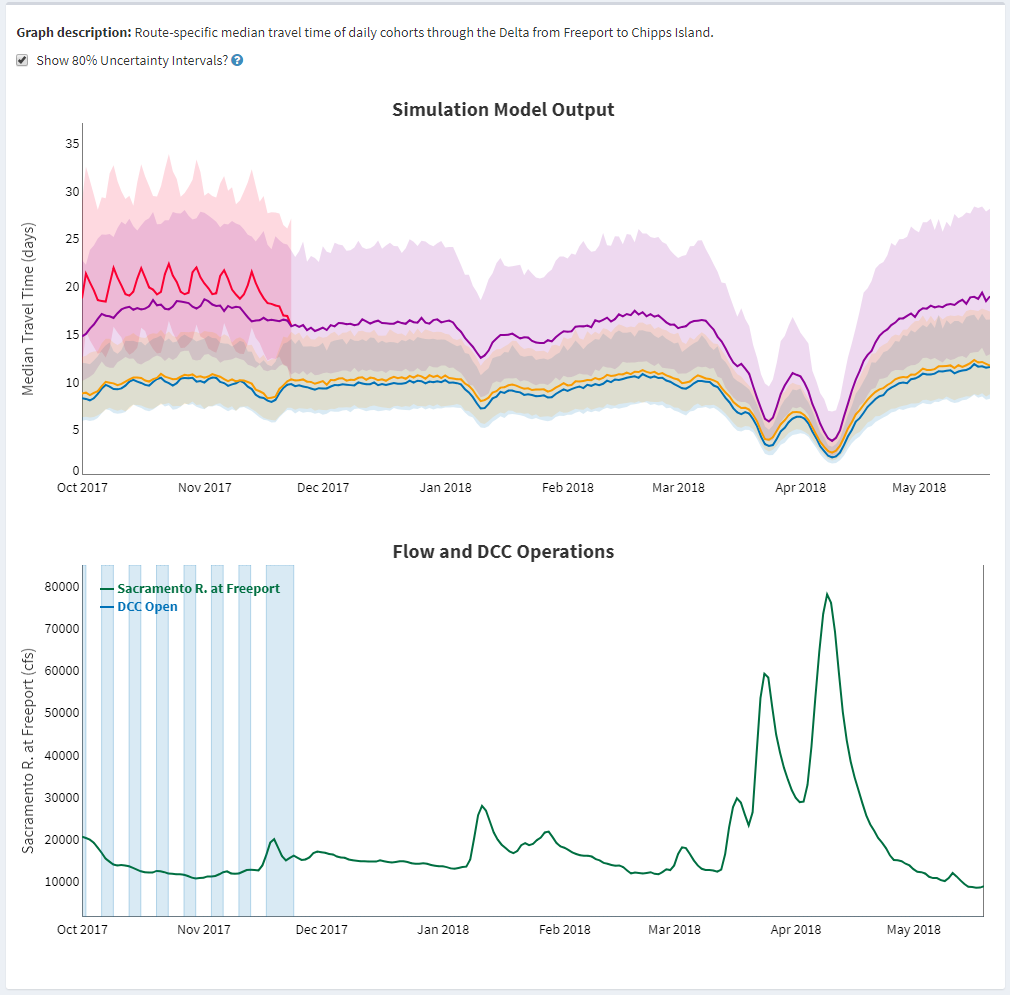


Figure 6: Simulation model output showing route-specific travel time

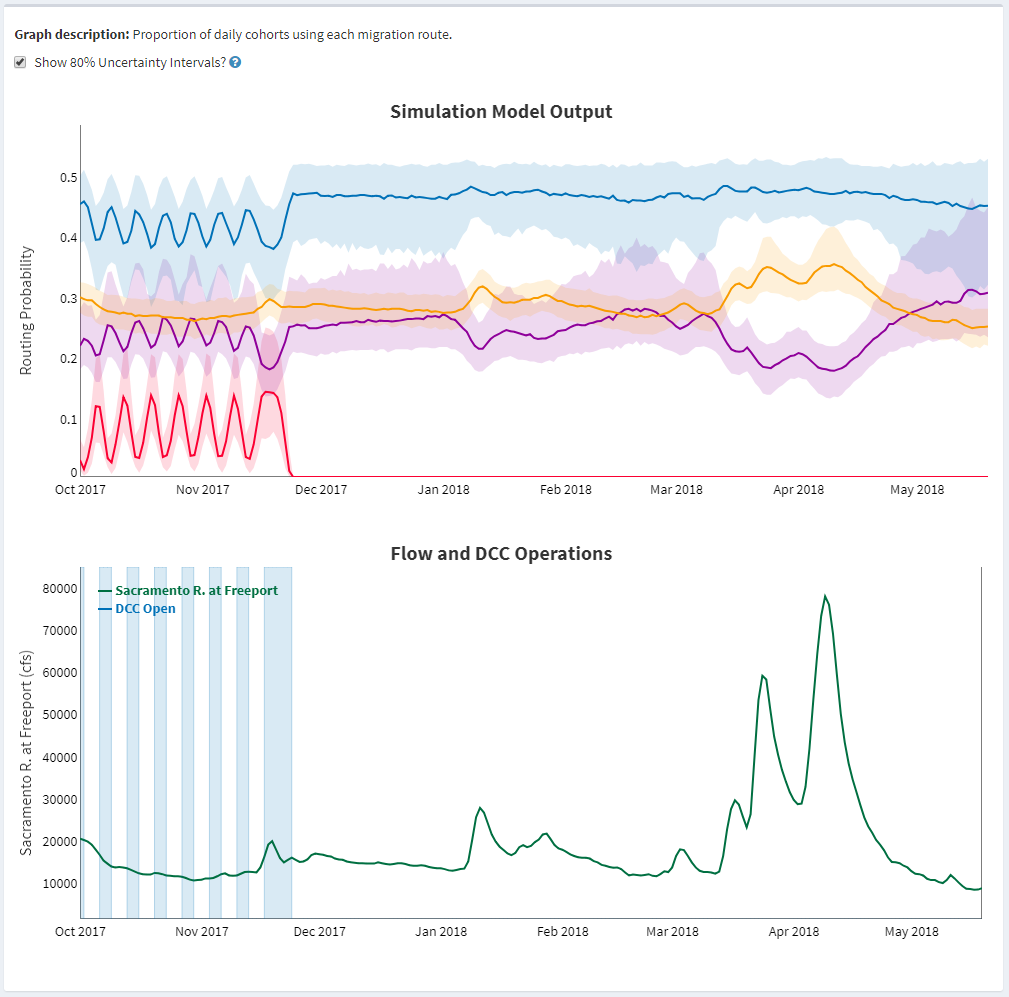
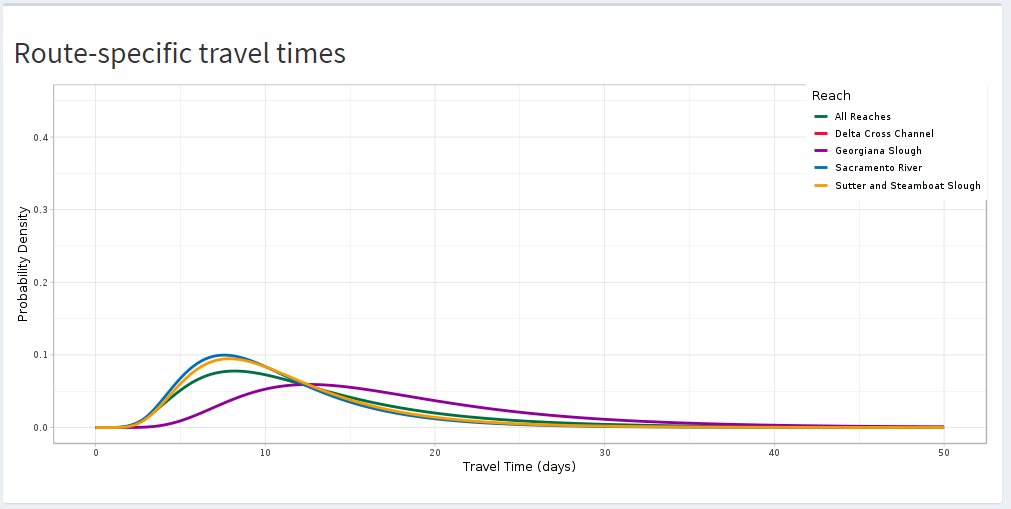
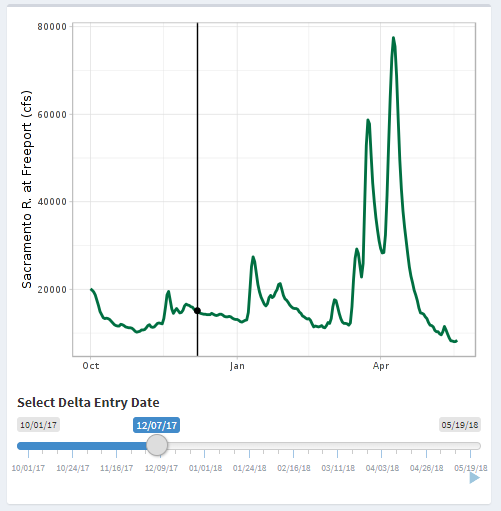


Figure 7: Simulation model output showing routing probabilities

### Travel Time Distributions



The graph above shows expected travel time distributions between Freeport and Chipps Island for a cohort of fish entering the Delta on the given date shown by the vertical line in the graph on the left.

# Contact

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