# Particle Swarm Optimization Techniques for Estimating Juvenile Salmon Behavioral Parameters in an Enhanced Particle Tracking Model

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# Goals

- Add ‘behavior’ to PTM particles
  - Ability to model fish movement through the Delta
  - Both historical and predictive
  - Can we choose behavioral parameters with a biological meaning?
- Estimate most likely behavioral parameter values
  - Model stochasticity and computational burden make this difficult

# Acoustic Telemetry Data for Analysis

- Data from Acoustic Telemetry Studies
  - USFWS (Delta Action 8)
  - Late-fall Chinook salmon
  - Vemco acoustic telemetry
  - 1,583 Acoustic tagged fish
  - 4 Years (2007 – 2010)
  - 8 unique release groups
  - Migrated between December and February

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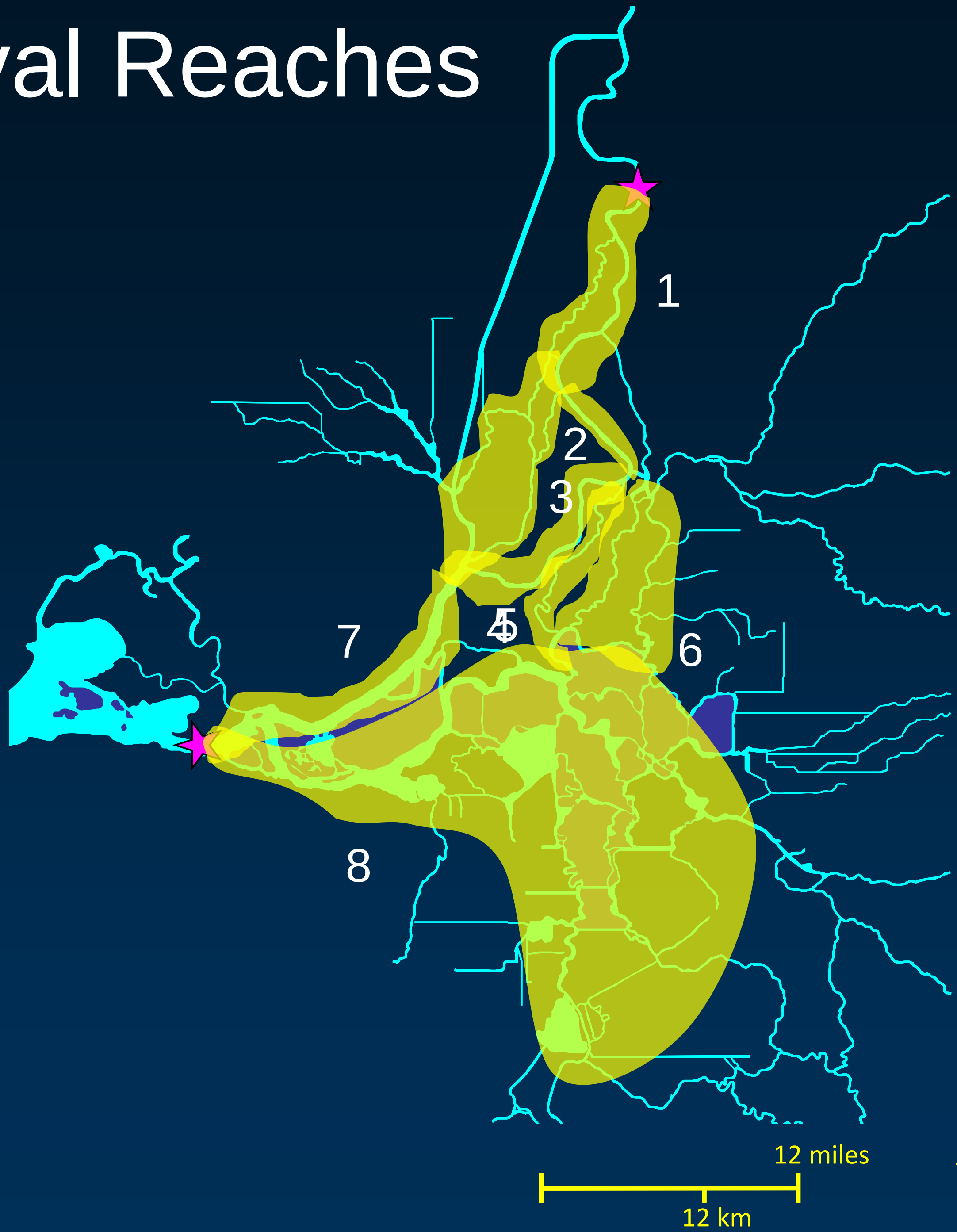
# Survival Reaches

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# Analysis Overview

- Methods for fitting PTM behavior parameters to data
  - Choice of behavioral parameters
  - Simulated Maximum Likelihood
  - Particle Swarm Optimization
  - High Performance Computing
- Results for two models
  - Behavioral parameter estimates and GOF
  - Comparison of observed and simulated travel times

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# Behavioral parameters

- Swim velocity
  - Overall mean velocity among fish
  - Standard deviation in mean velocity (among fish)
  - Standard deviation in timestep velocity (within fish)
- Holding behaviors
  - Probability of migrating during the day
  - Flood tide threshold (STST)
  - ‘Rearing holding’: immediately after release for smolts not ready to migrate
- Directional assessment
  - Probability of mis-assessing downstream, as a function of ratio of tidal variation to mean streamflow

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# Simulated Maximum Likelihood

- Difficulties matching simulation outputs to observed values
  - No closed form likelihood expressing the relationship between input parameter and simulation output
  - Stochasticity in simulation output – the same input parameters will give different outputs from run to run
- Simulated maximum likelihood allows us to estimate input parameters in spite of these difficulties
  - Run the simulation *m* times for a given set of parameters
  - Each simulation corresponds to *n* observations
  - Each of the *m* simulation outputs is matched to the data, and a likelihood value calculated
  - Calculate overall fit by averaging the *m* likelihood values

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# Particle Swarm Optimization

- Traditional optimization routines are not ideal for simulations
  - Number of computations increases exponentially with the number of parameters being estimated
  - Stochastic models are extremely difficult to fit with traditional optimization techniques
- Particle Swarm Optimization
  - Calculate a number of solutions, each at a different set of inputs
  - The ‘swarm’ of solutions has memory and momentum
  - Swarm can quickly find global optimum while not getting stuck at local optima
  - Number of computations increases much more slowly with increasing parameter dimensions

# High Performance Computing

- PSO swarm needs 40 solutions (sets of input parameters) per optimization iteration
- Each solution requires:
  - PTM run for each reach/release combination (9 reaches and up to 8 releases for each reach = 58 reach/release combinations with observed travel times)
  - Each PTM run must simulate *m* datasets
  - 40 x 58 = 2,320 PTM runs; each PTM run takes <1 to 10 minutes
- Once the 40 solutions are calculated, the ‘swarm’ adjusts and repeats, until an optimum is found (~ hundreds of iterations)
- A single model optimization can take on the order of 10,000 hours of CPU time – parallelization and speed are key!

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# Model parameter comparison

| Model A | | | Model B | | |
|---|---|---|---|---|---|
| **Param. name** | **Estimated** | **# param** | **Param. name** | **Estimated** | **# param** |
| Mean velocity | Delta wide | 1 | Mean velocity | Tidal regime | 3 |
| SD velocity (among fish) | Delta wide | 1 | SD velocity (among fish) | Tidal regime | 3 |
| SD velocity (each fish) | Delta wide | 1 | SD velocity (each fish) | Tidal regime | 3 |
| Diel migration probability | Delta wide | 1 | Diel migration probability | Tidal regime | 3 |
| Rearing holding | Single reach | 1 | Rearing holding | Single reach | 1 |
| | | | Flood tide hold threshold | Delta wide | 1 |
| **Total** | | **5** | **Total** | | **14** |

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# Model parameter comparison

| Model A | | Model B | | | |
|---|---|---|---|---|---|
| **Param. name** | **Delta wide** | **Param. name** | **Riverine** | **Transitional** | **Tidal** |
| Diel migration probability | 0.932 | Diel migration probability | 0.497 | 0.883 | 0.949 |
| Mean velocity | 0.28 ft/s | Mean velocity | -0.06 ft/s | 0.62 ft/s | 0.30 ft/s |
| SD velocity (among fish) | 0.72 ft/s | SD velocity (among fish) | 1.02 ft/s | 0.87 ft/s | 0.83 ft/s |
| SD velocity (each fish) | 0.60 ft/s | SD velocity (each fish) | 1.63 ft/s | 0.49 ft/s | 1.15 ft/s |
| | | | **Delta wide** | | |
| Rearing holding | 8.07 hrs | Rearing holding | 9.85 hrs | | |
| | | Flood tide hold threshold | -0.67 ft/s | | |
| **NLL** | **1571.5** | | **1259.1** | | |

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# Model parameter comparison

| Model A | | Model B | | | |
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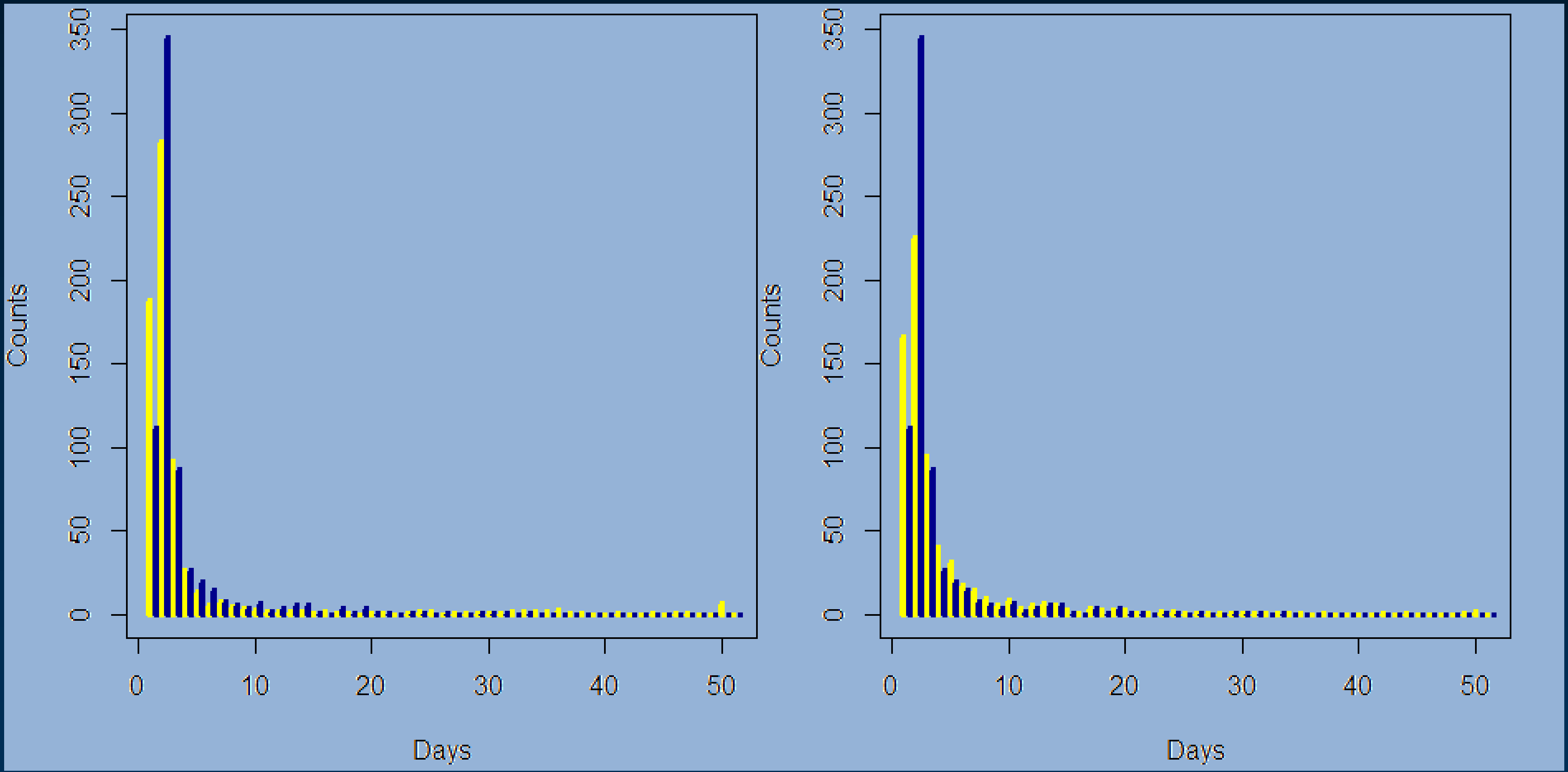
# Model B, Single parameter

# Travel Times:
# Freeport to J1 (Sutter/Steamboat)

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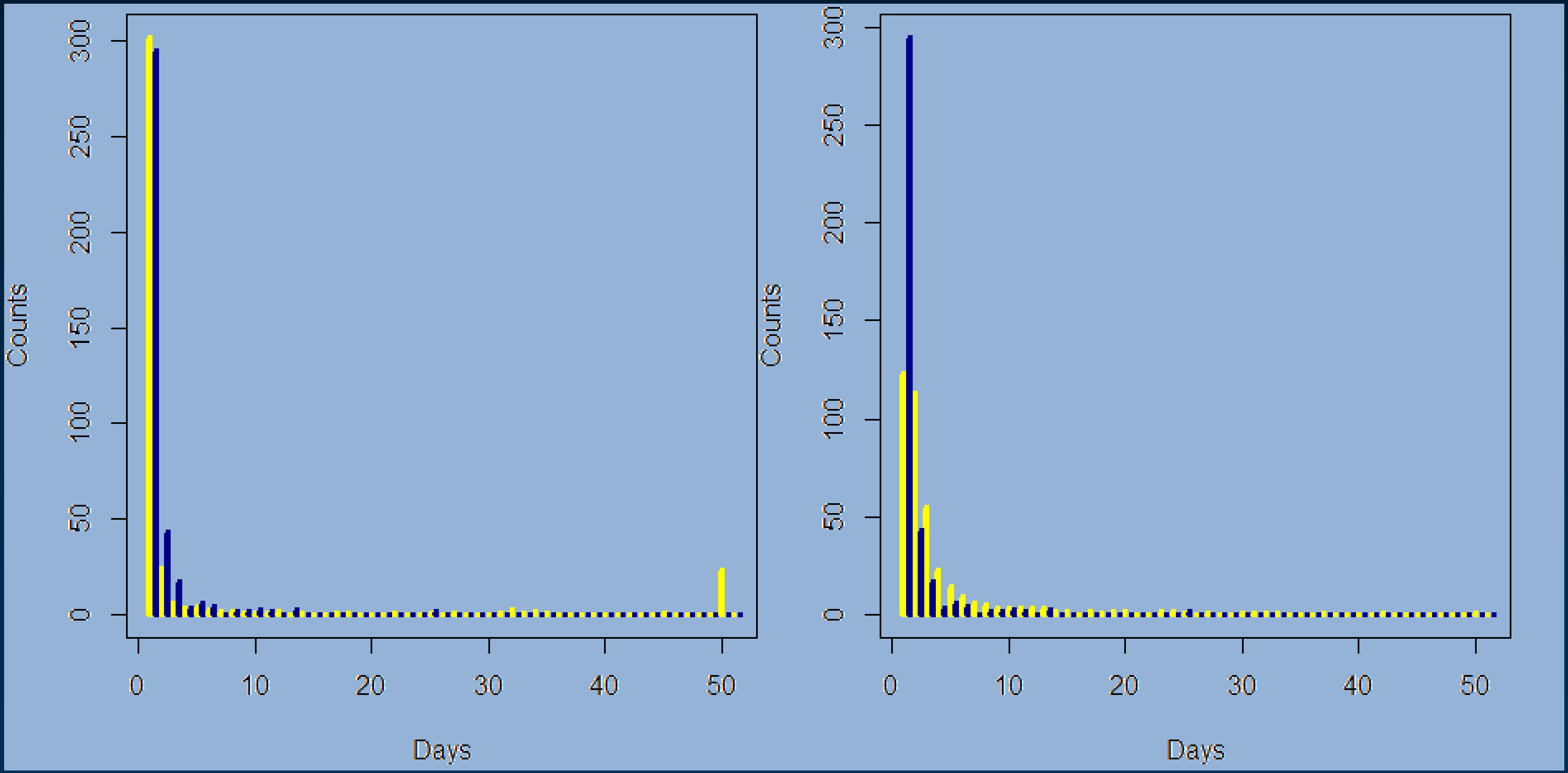
# Travel Times:
# J1 (Sut./Stmbt.) to J2 (Geo./DCC)

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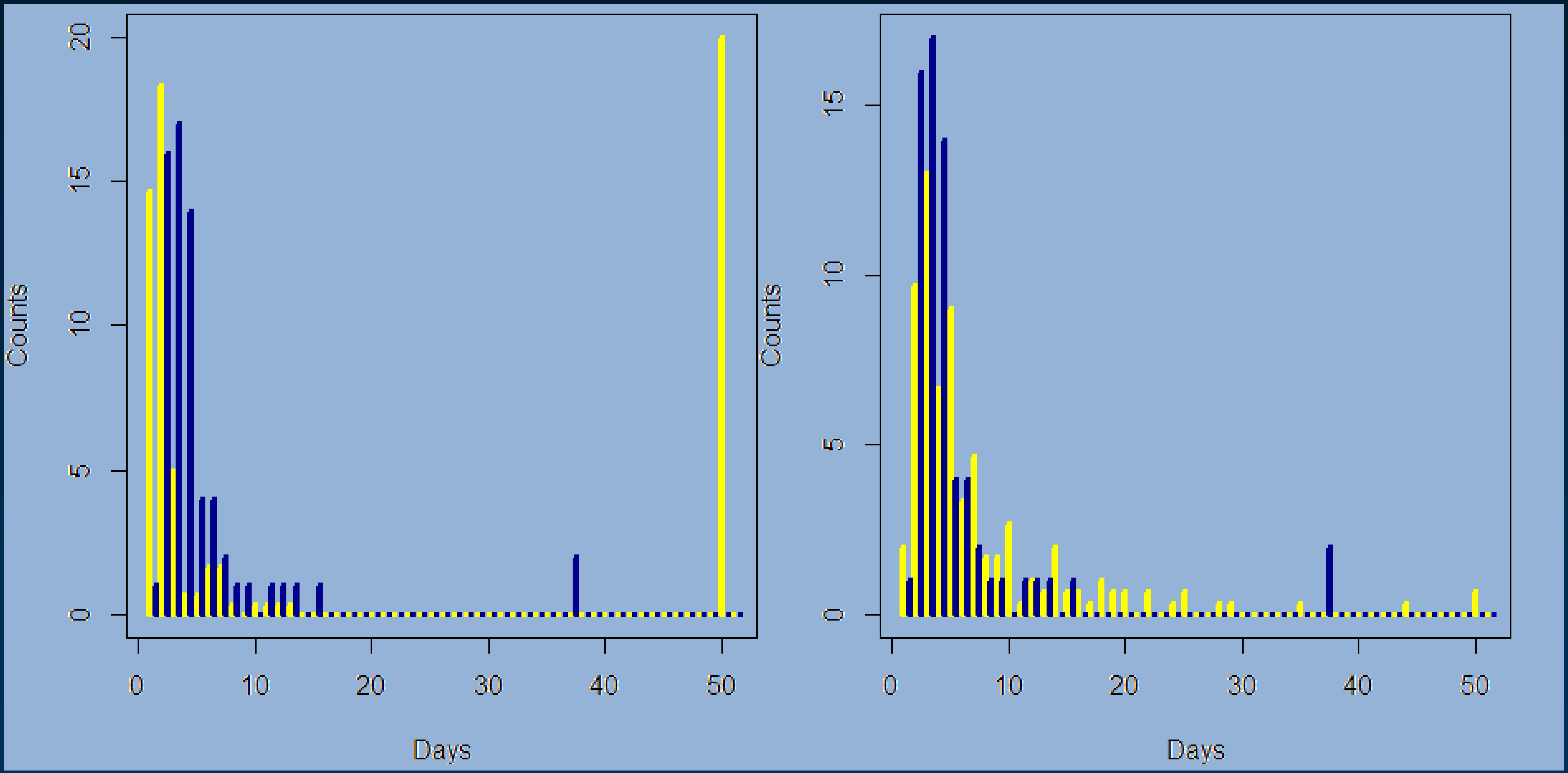
# Travel Times: Sutter Slough

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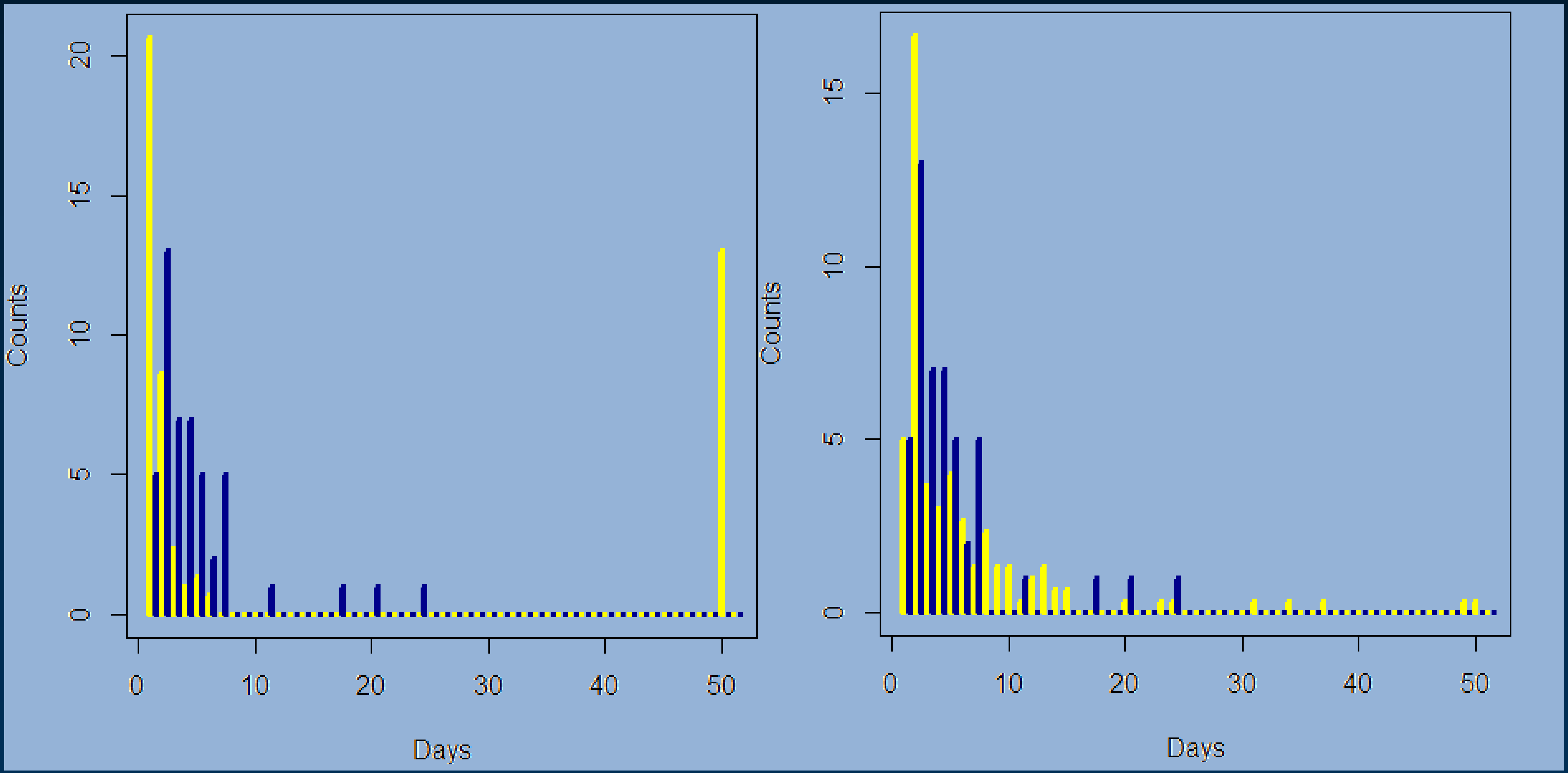
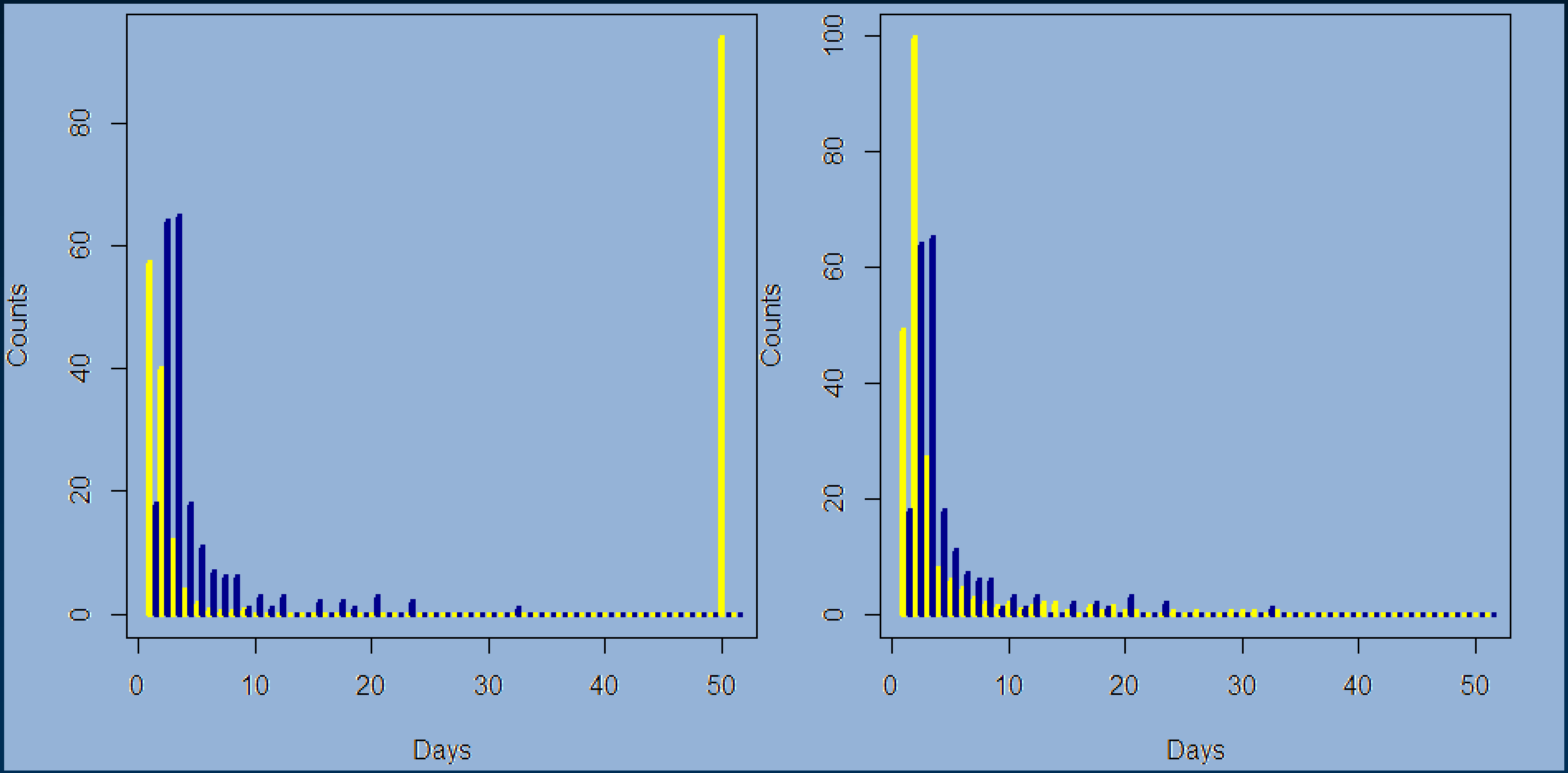
# Travel Times: Steamboat Slough



# Travel Times:
# J2 (Geo./DCC) to Rio Vista

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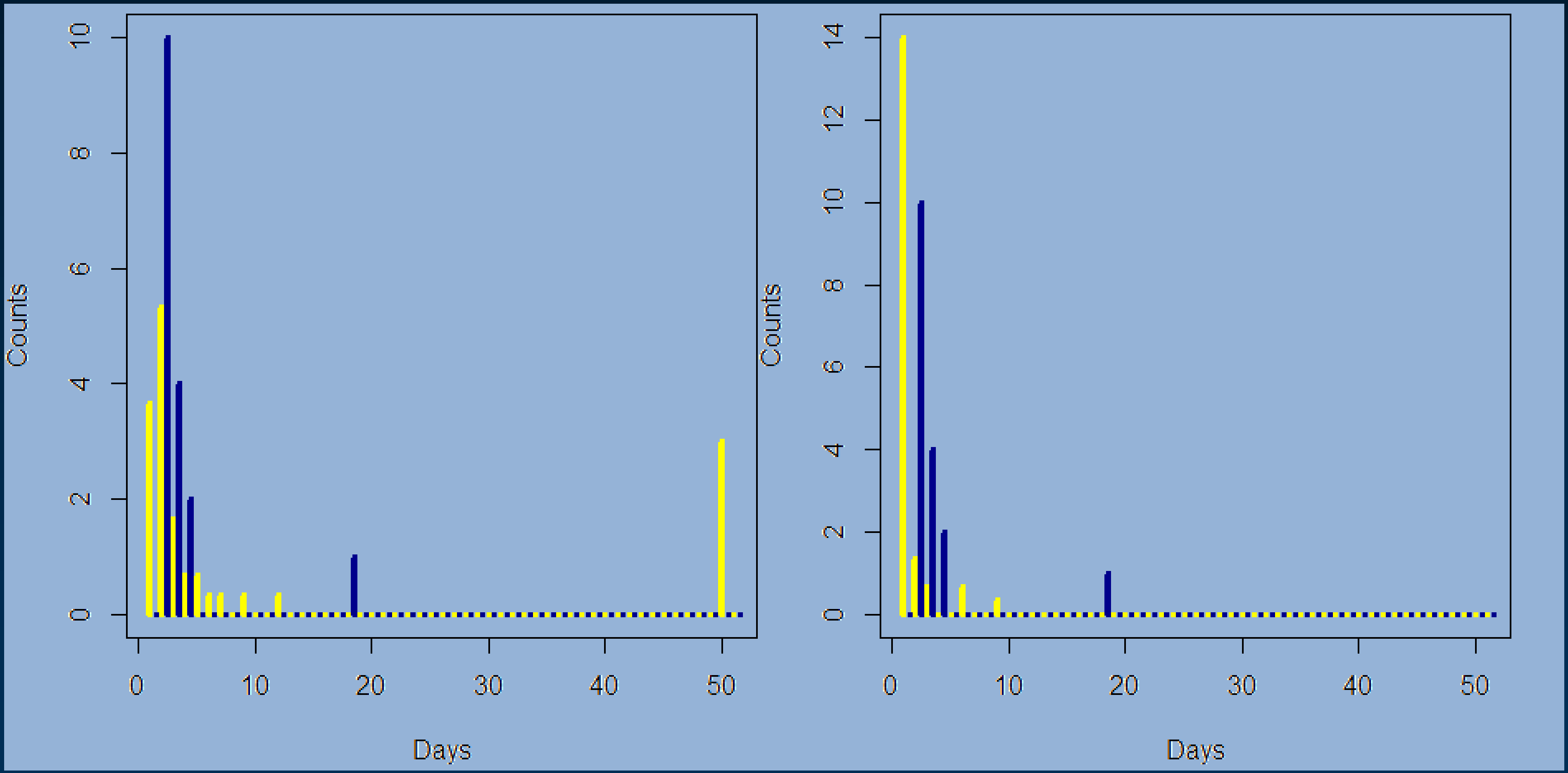
# Travel Times: Georgiana Slough

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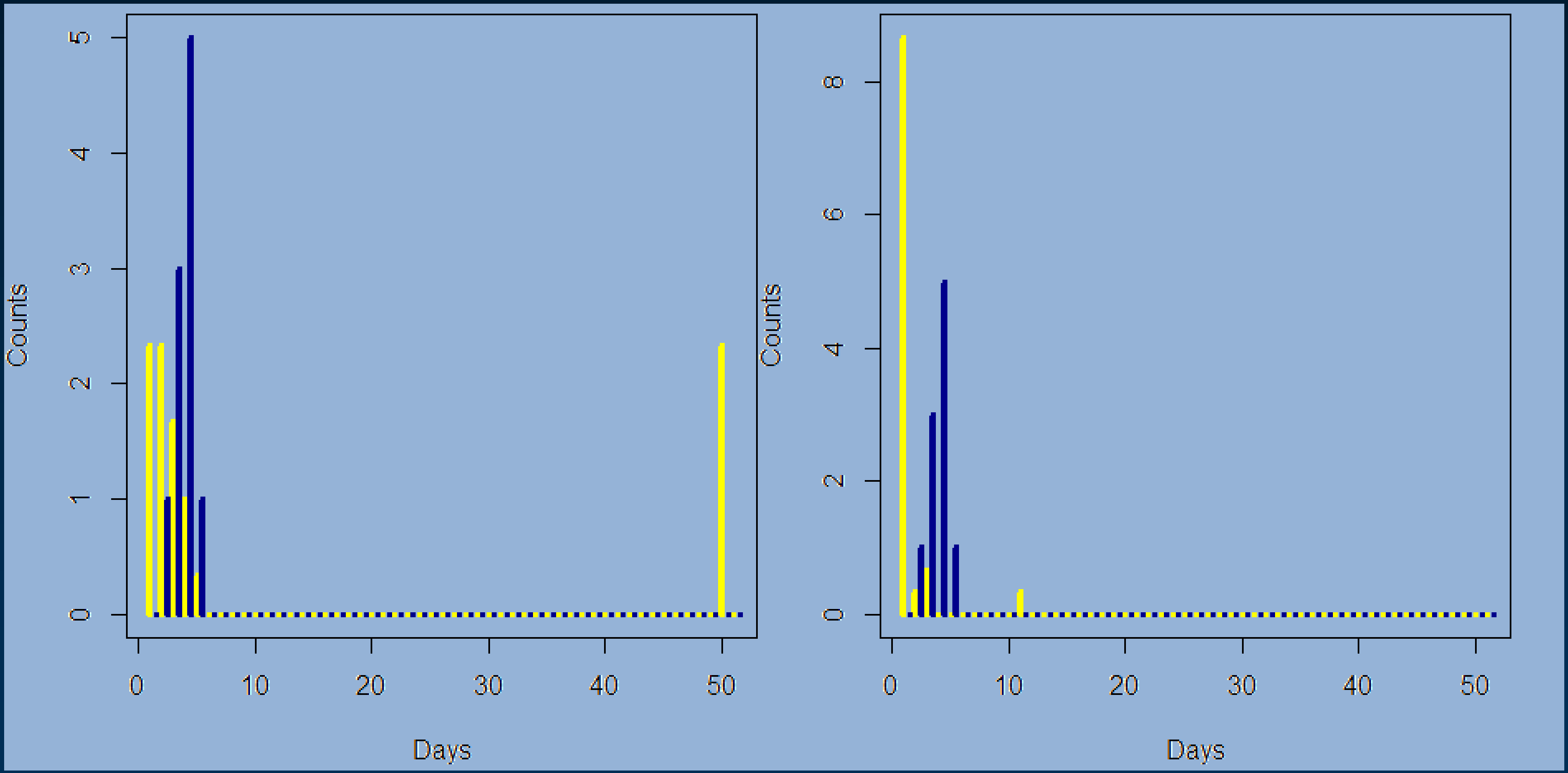
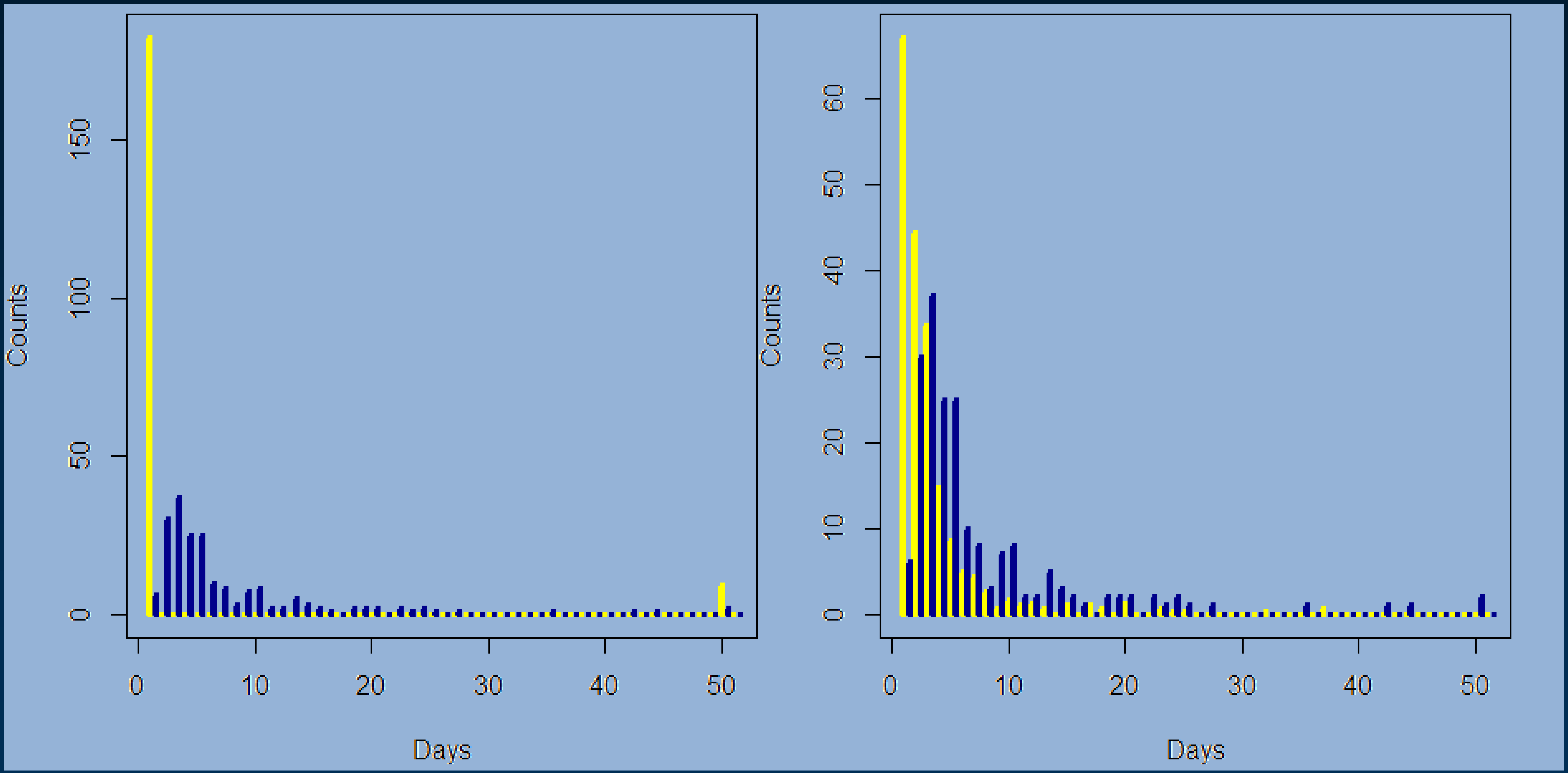
# Travel Times: DCC to Mokolumne



# Travel Times:
# Rio Vista to Chipps Island

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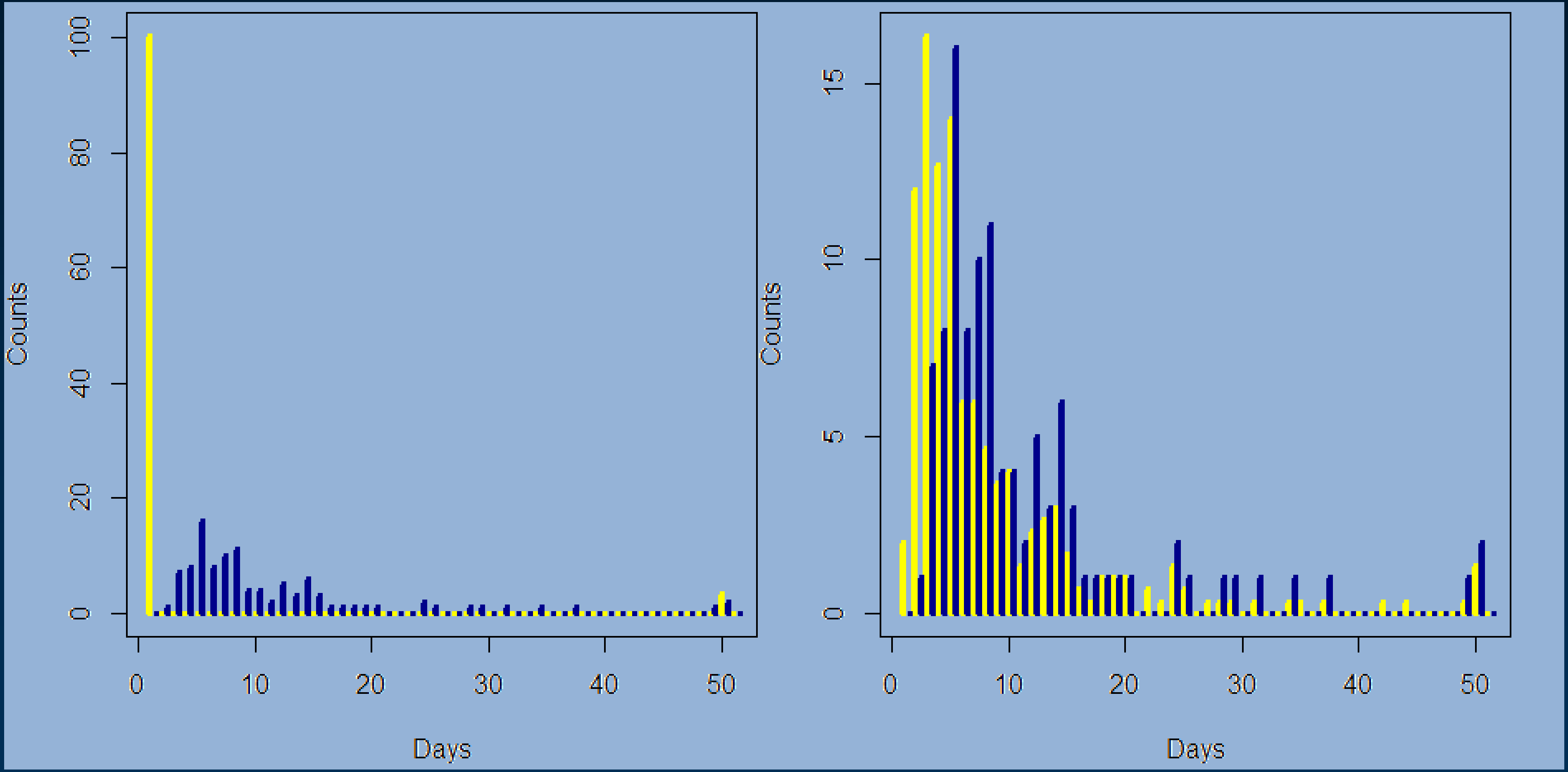
# Travel Times: Interior Delta

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# Conclusions

- Advantages
  - Handles increase in parameter dimensionality
  - Directly uses PTM in optimization
  - Relatively easy to estimate new parameters or change parameter ranges/constraints
- Disadvantages
  - Requires parallelization (access to HPC)
  - Uncertainty is from multiple sources and is difficult to quantify

# Conclusions – Future work

- Fit more models!
  - Allow parameters to vary with reach
  - ‘Turn on/turn off’ varying parameter combinations (STST, directional assessment)
- Explore techniques to propagate uncertainty from PTM and PSO search
- Model other runs, species, regions of the Delta – just need data!