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Survival Analyses in Support of NOAA’s Draft Biological Opinion on California WaterFix

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Overview

- New Bayesian Mark-Recapture Model
  - Overview of methods and results
  - Forms basis for BiOp Analyses

- Using these models for Cal WaterFix
  - Simulating survival under NAA and PA
  - Evaluating NDD Bypass Rules
  - Shaping operations with survival criteria

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Acoustic Telemetry Data for Analysis

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- Data from 2 Acoustic Telemetry Studies
  - NOAA (CALFED) and USFWS (Delta Action 8)
  - Late-fall Chinook salmon
  - Vemco acoustic telemetry
  - 2,170 Acoustic tagged fish
  - 5 Years (2007 – 2011)
  - 17 unique release groups
  - Migrated between late Nov. and early March
  - Sacramento River Flows at Freeport
    - ~6,000 – 77,000 ft^3/s

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Survival Reaches

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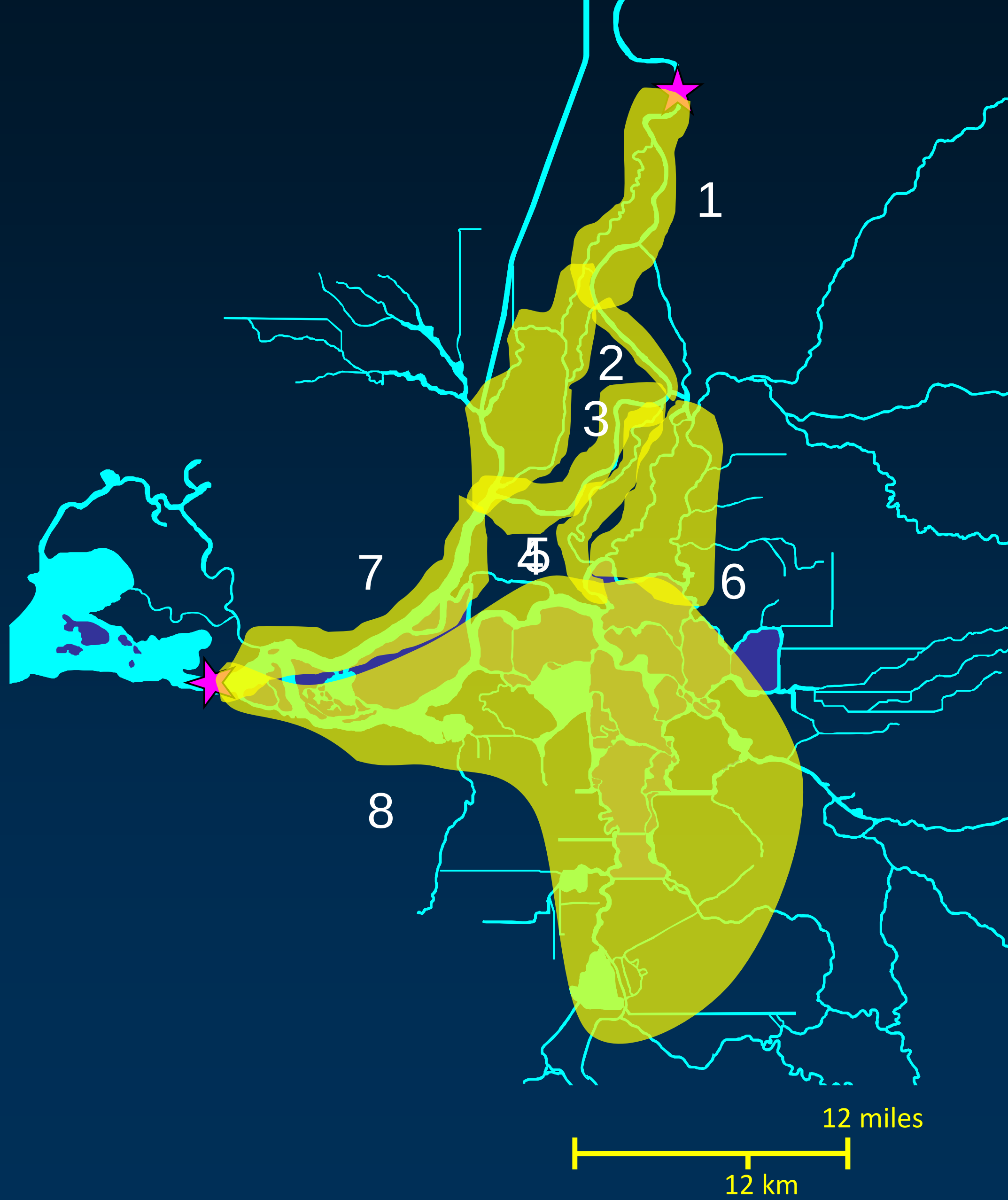

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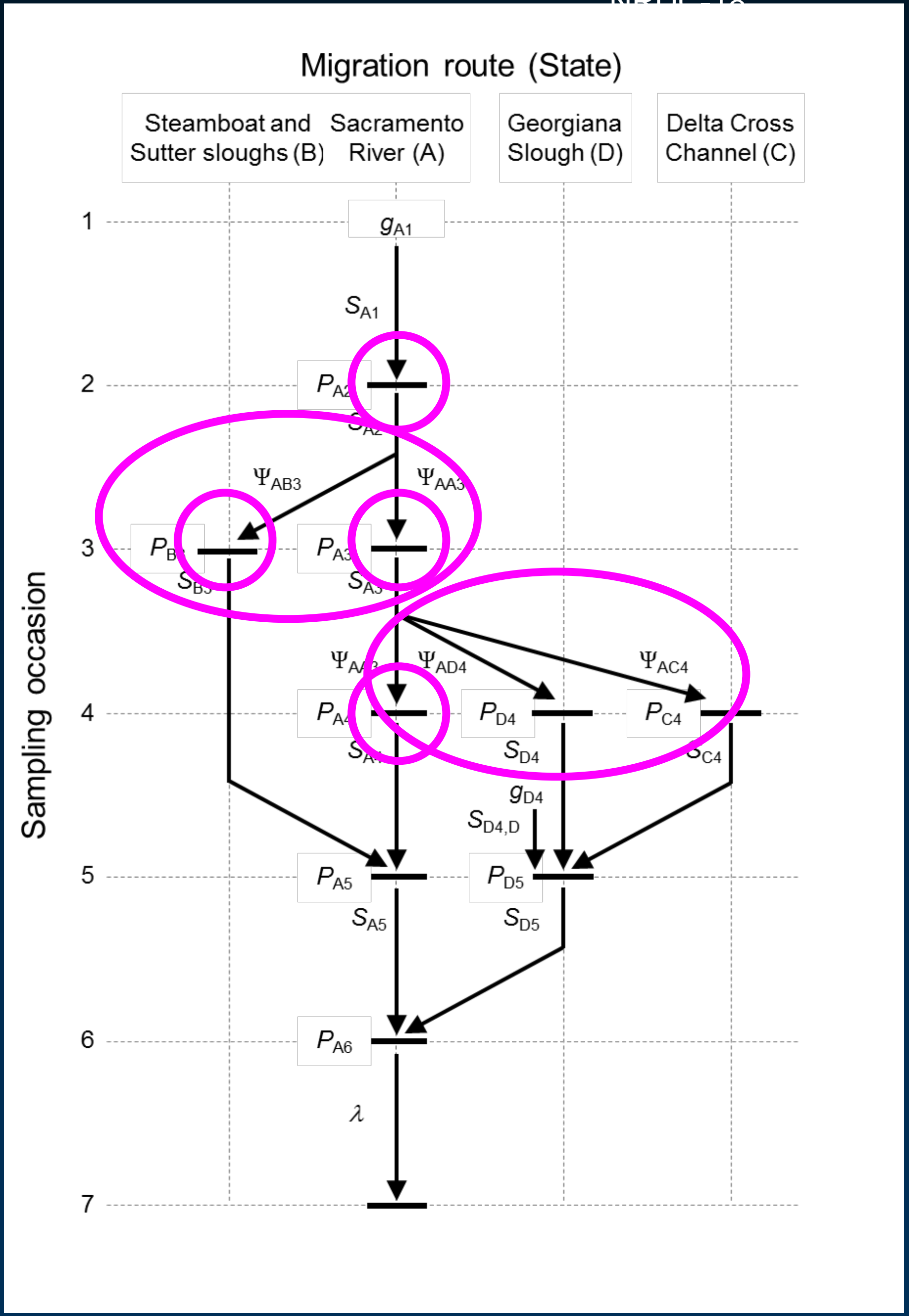
Multistate Model Schematic

3 types of parameters:

p = Detection probability

Ψ = Routing probability

S = Survival probability



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Estimation Framework

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- Time-varying individual covariates
  - Covariate values based on date of reach entry
- Date of entry unknown for undetected fish
  - Need to integrate likelihood over missing data
  - Requires a model for missing data
- Model for reach-specific travel times
  - Estimate parameters from observed travel times
  - Impute missing travel times

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Strength of Bayesian Framework

- Time-varying individual covariates
  - Previous approaches used average values
- Single integrated model
  - Survival and travel time
- MCMC to integrate over missing data
- Random effects
  - Quantify “extra” variation among release groups

Model for Travel Times

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- Assume travel times ($t_{i,j}$) distributed lognormally

$$t_{i,j} \sim \text{lognormal}\left(\mu_j, \sigma_j\right)$$

μ_j = mean of log($t_{i,j}$)

σ_j = standard deviation of log($t_{i,j}$)

exp(μ_j) = median travel time

- Goal is to estimate μ and σ for each reach

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Effect of Discharge on Travel Times

- Relate median travel times to Delta inflows at Freeport

$$\mu_{i,j} = \alpha_{0,j} + \alpha_{1,j} Q_{i,j,d} + \alpha_{2,j} I\left(\mathrm{DCC}_{i,j,d} = \mathrm{open}\right) + \varepsilon_{g,j}$$

α_j = reach-specific slope parameters

$Q_{i,j,d}$ = Freeport discharge on day *d* when *i*th fish entered *j*th reach

$\mathrm{I}(\mathrm{DCC}_{i,j,d} = \mathrm{open})$ = binary indicator for reaches downstream of DCC

$\varepsilon_{g,j}$ = deviation of *g*th release group, ~Normal(0, ξ)

Effect of Discharge on Survival

- Relate survival to Delta inflows at Freeport

$$\text{logit}\left(S_{i,j}\right) = \beta_{0,j} + \beta_{1,j} Q_{i,j,d} + \beta_{2,j} I\left(\text{DCC}_{i,j,d} = \text{open}\right) + \varepsilon_{g,j}$$

β_j = reach-specific slope parameters

$Q_{i,j,d}$ = Freeport discharge on day *d* when *i*th fish entered *j*th reach

$I(\text{DCC}_{i,j,d} = \text{open})$ = binary indicator for reaches downstream of DCC

$\varepsilon_{g,j}$ = deviation of *g*th release group, ~Normal(0, ξ)

Parameter Estimates:
Travel Time

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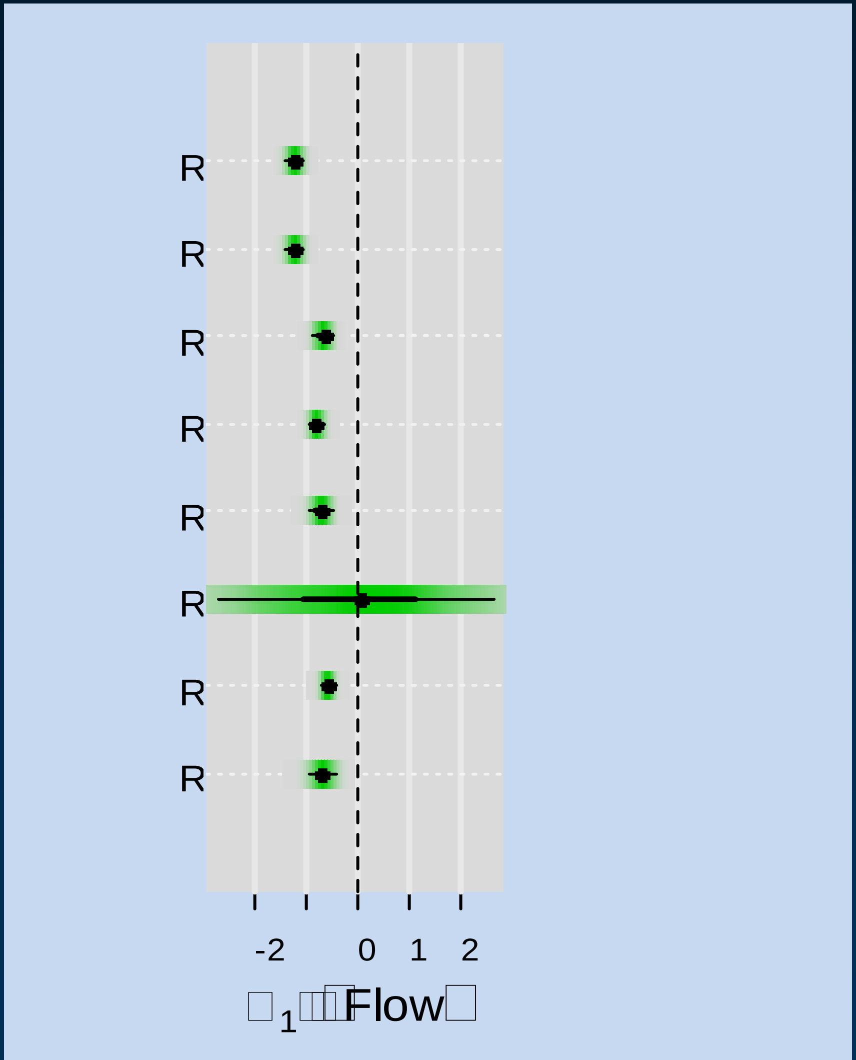
- Negative slopes for all reaches
  - Except DCC (Reach 6)
- Travel time decreases with inflow in all reaches
- DCC effects less certain
  - Except Rio Vista – Chipps (Reach 7)



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Parameter Estimates:

Survival

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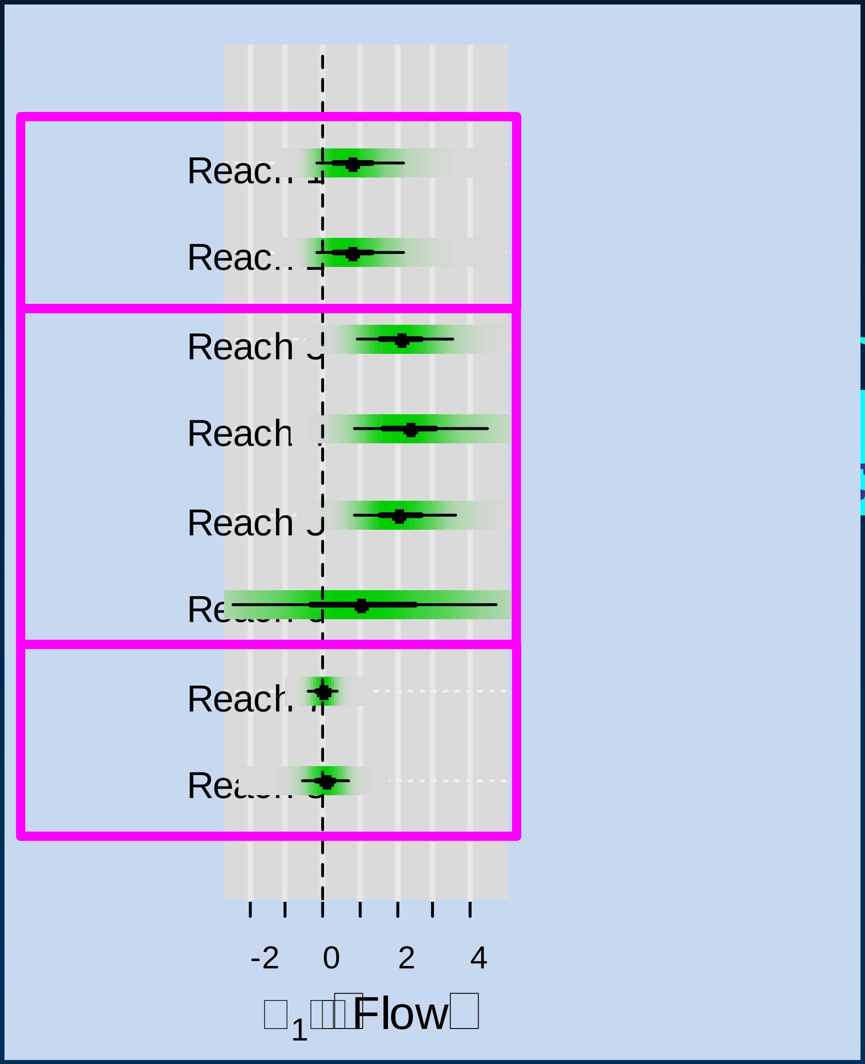

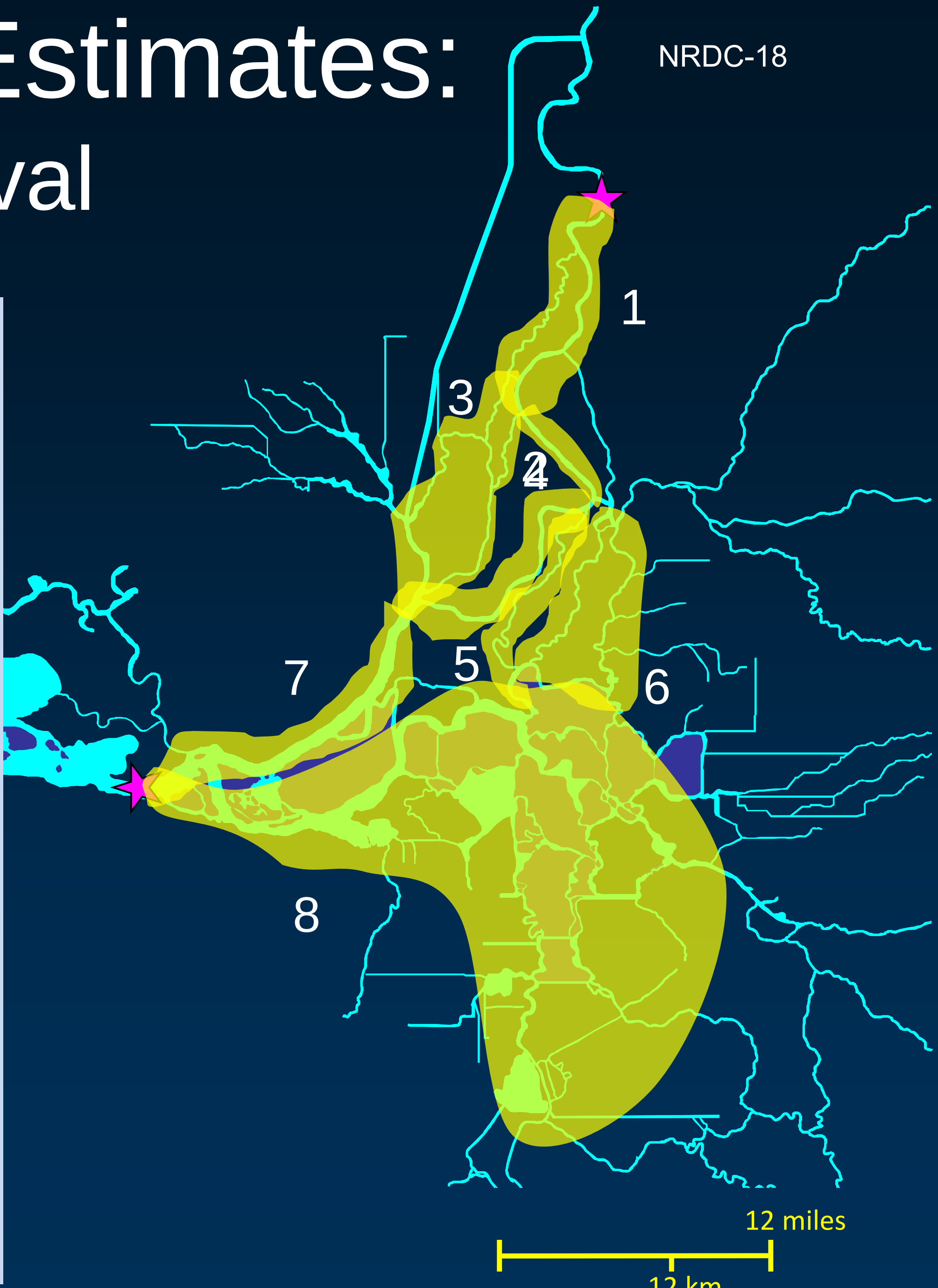

Flow-Survival Relations

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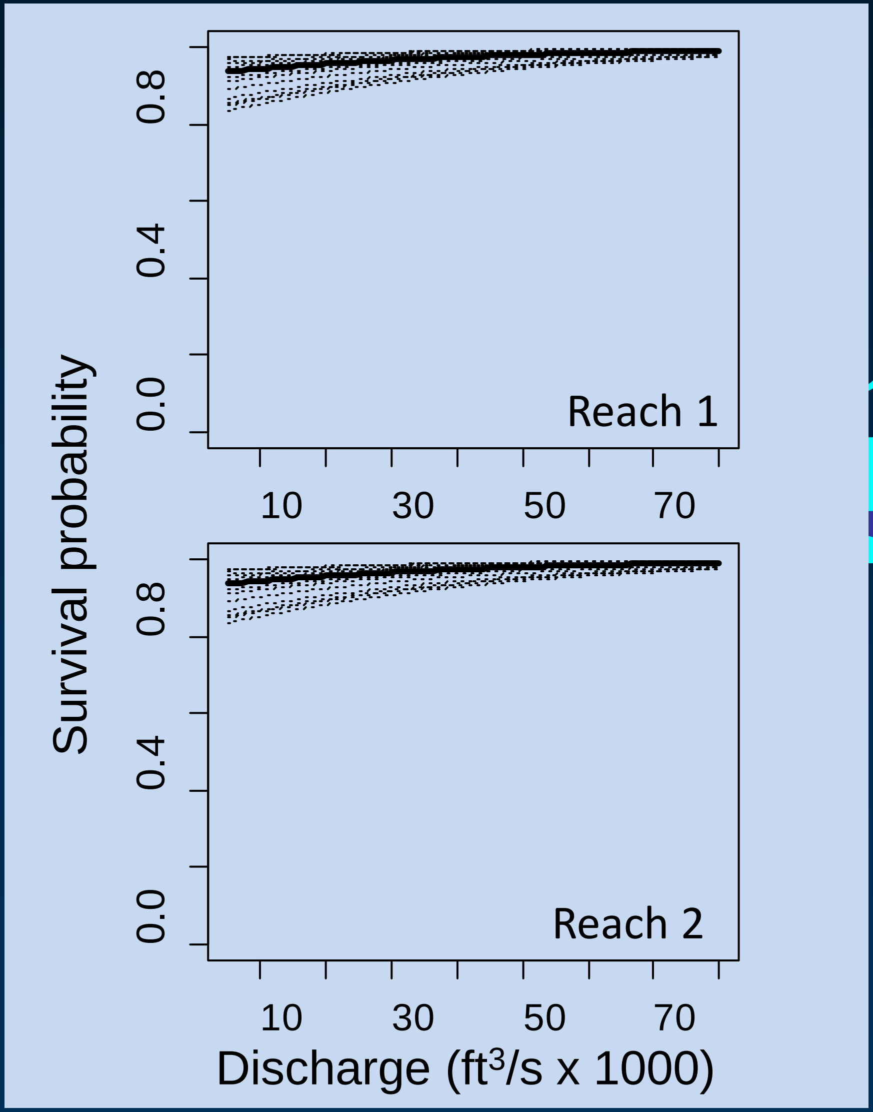

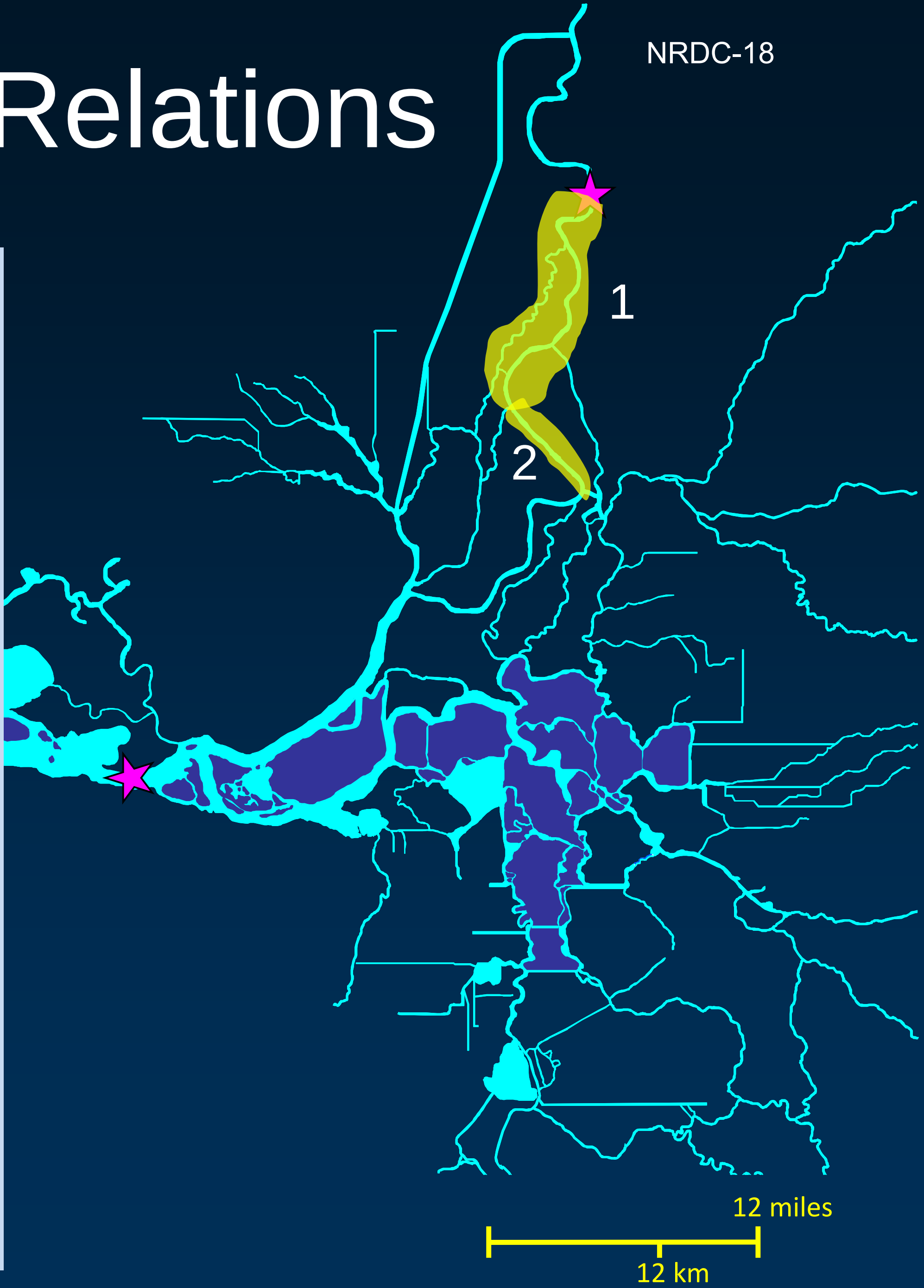

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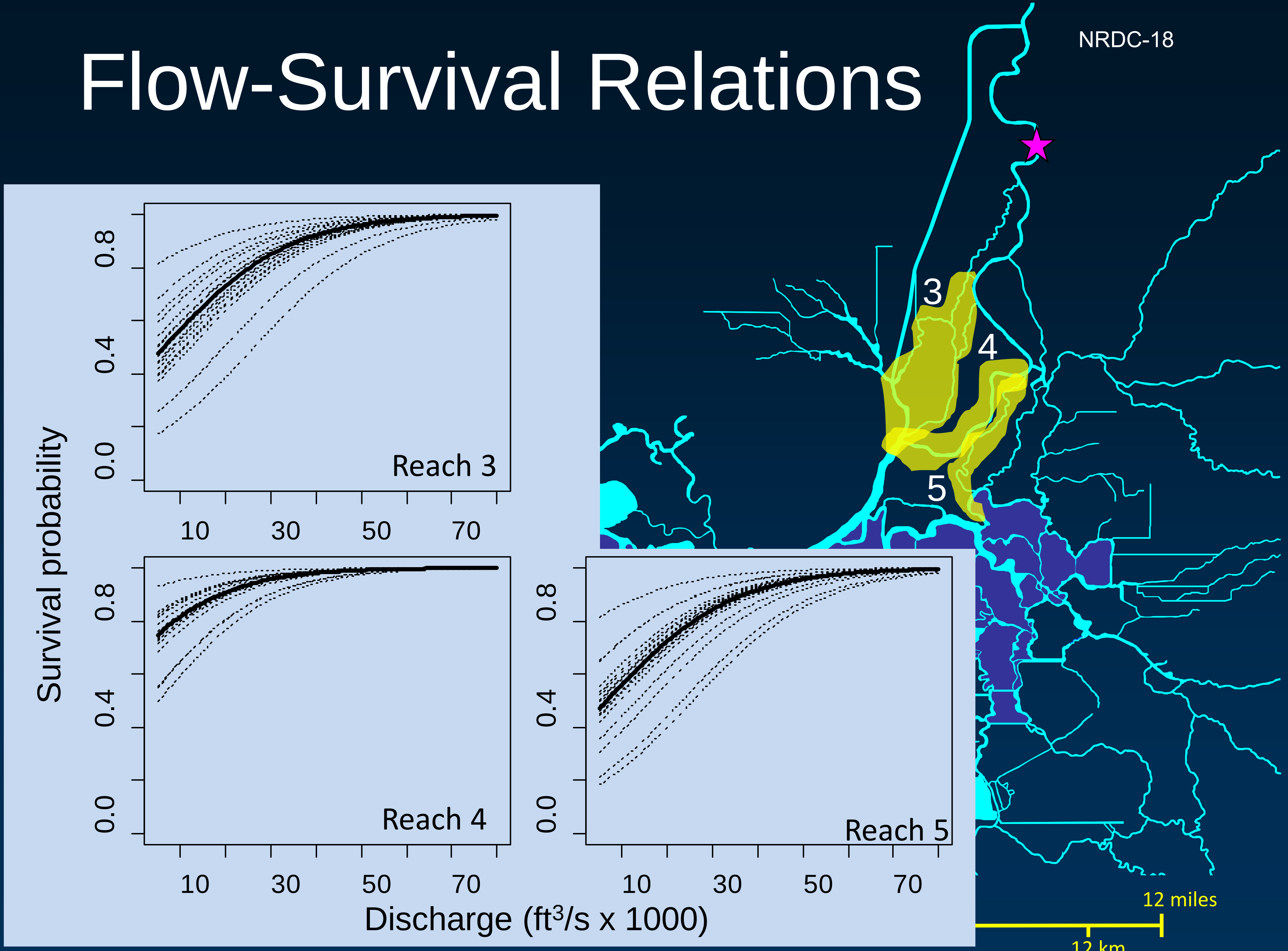
Flow-Survival Relations



Parameter Estimates:
Survival

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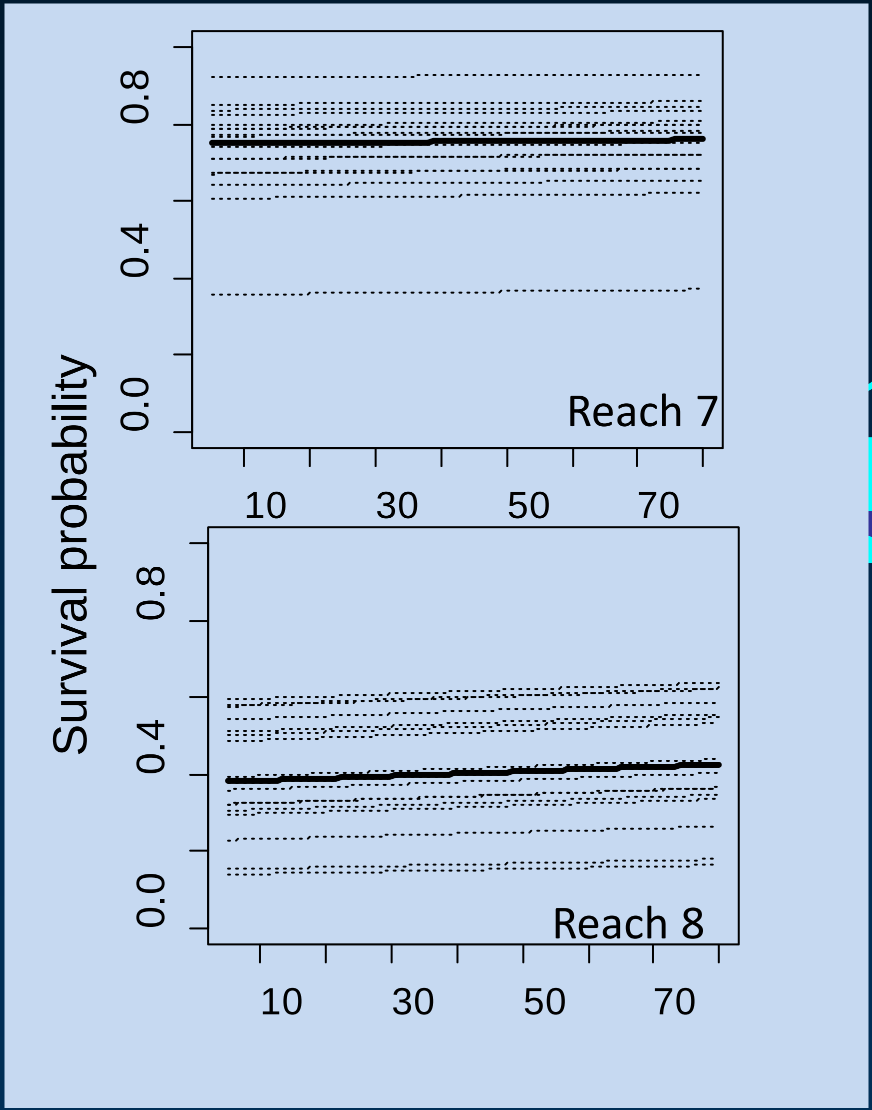
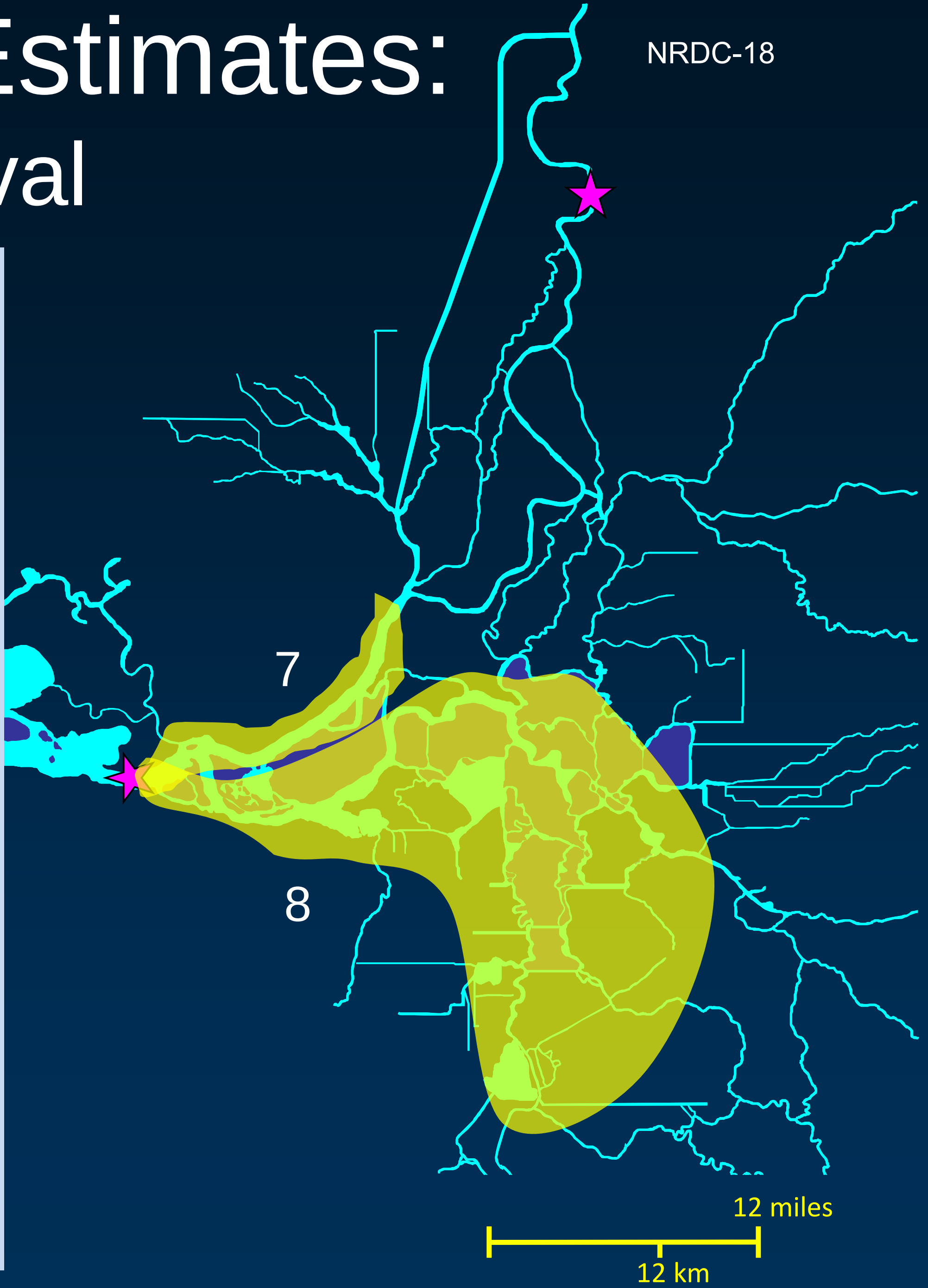
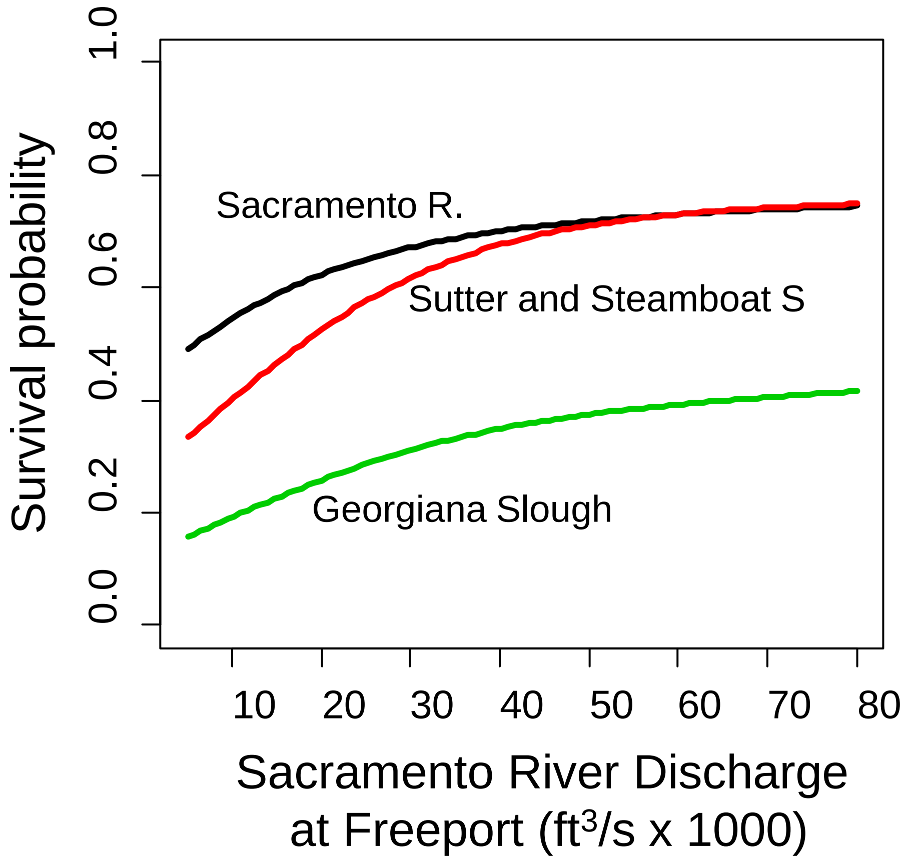
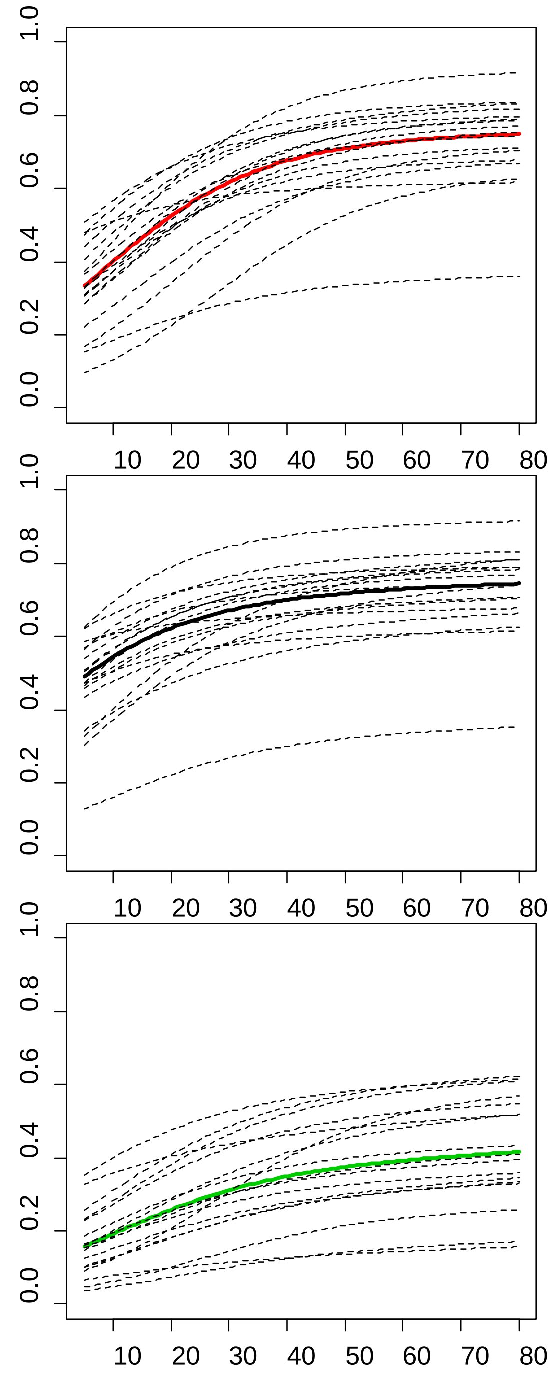


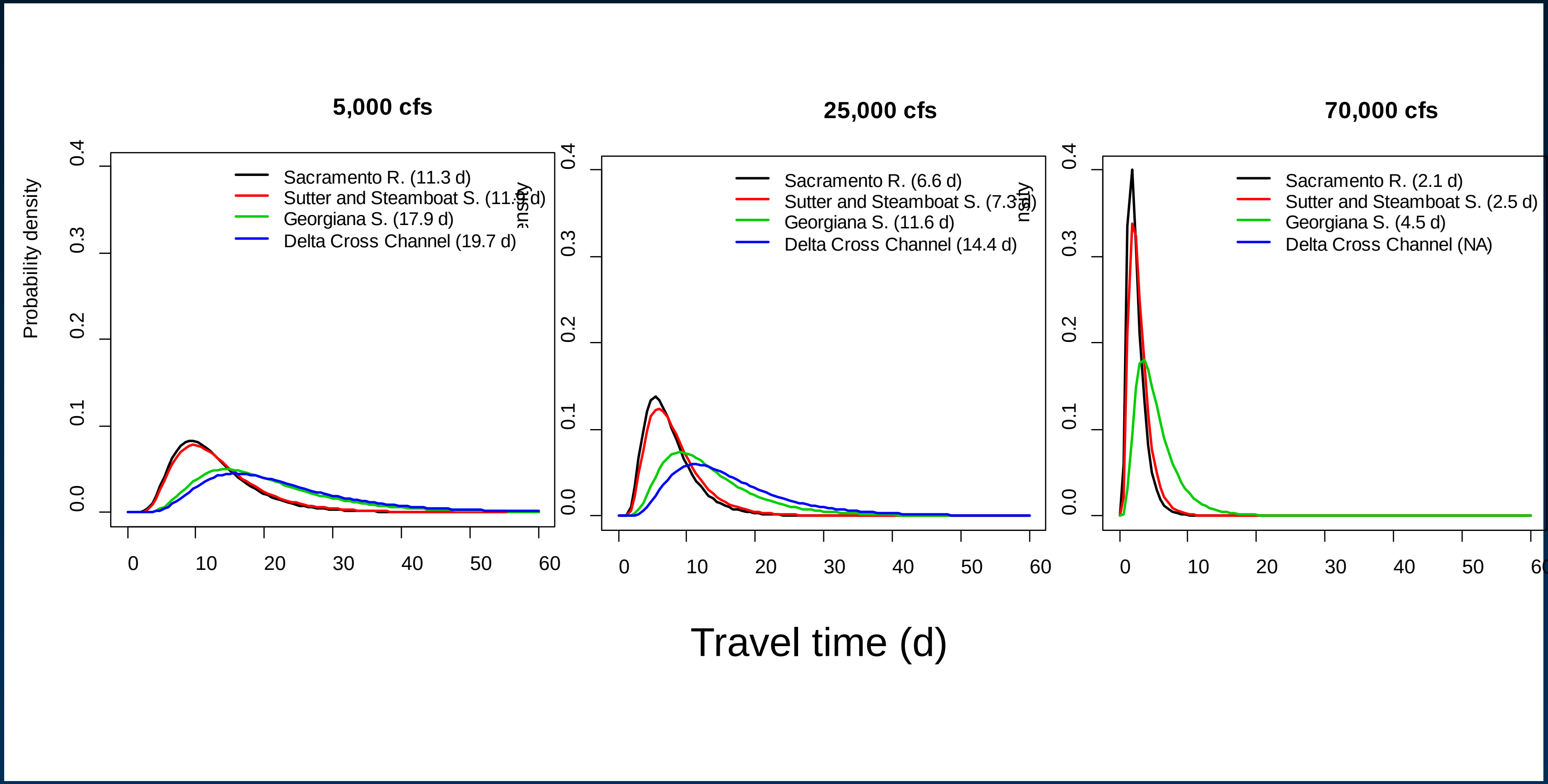


Route-Specific Survival





Route-Specific Travel Times



Summary

- Inflows affect travel times in all reaches
- Inflows affect survival in some reaches
  - Upper reaches: high survival at all flows
  - Transition reaches: strongest flow-survival relations
  - Tidal reaches
    - no evidence of flow effect
    - imposes upper limit on route-specific survival

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Simulating Survival, Travel Time, and Routing for NAA and PA

1. “Release” 10,000 fish at Freeport each day.
2. Reach 1 survival same for all fish.
3. Draw reach 1 travel times as *f*(flow)
   - NAA: flow = Freeport discharge
   - PA: flow = Bypass discharge
4. At junction of Sutter/Steamboat and Sac, draw route as *f*(flow).
5. Reach-specific survival f(flow) at arrival time.
6. Repeat for all subsequent reaches.

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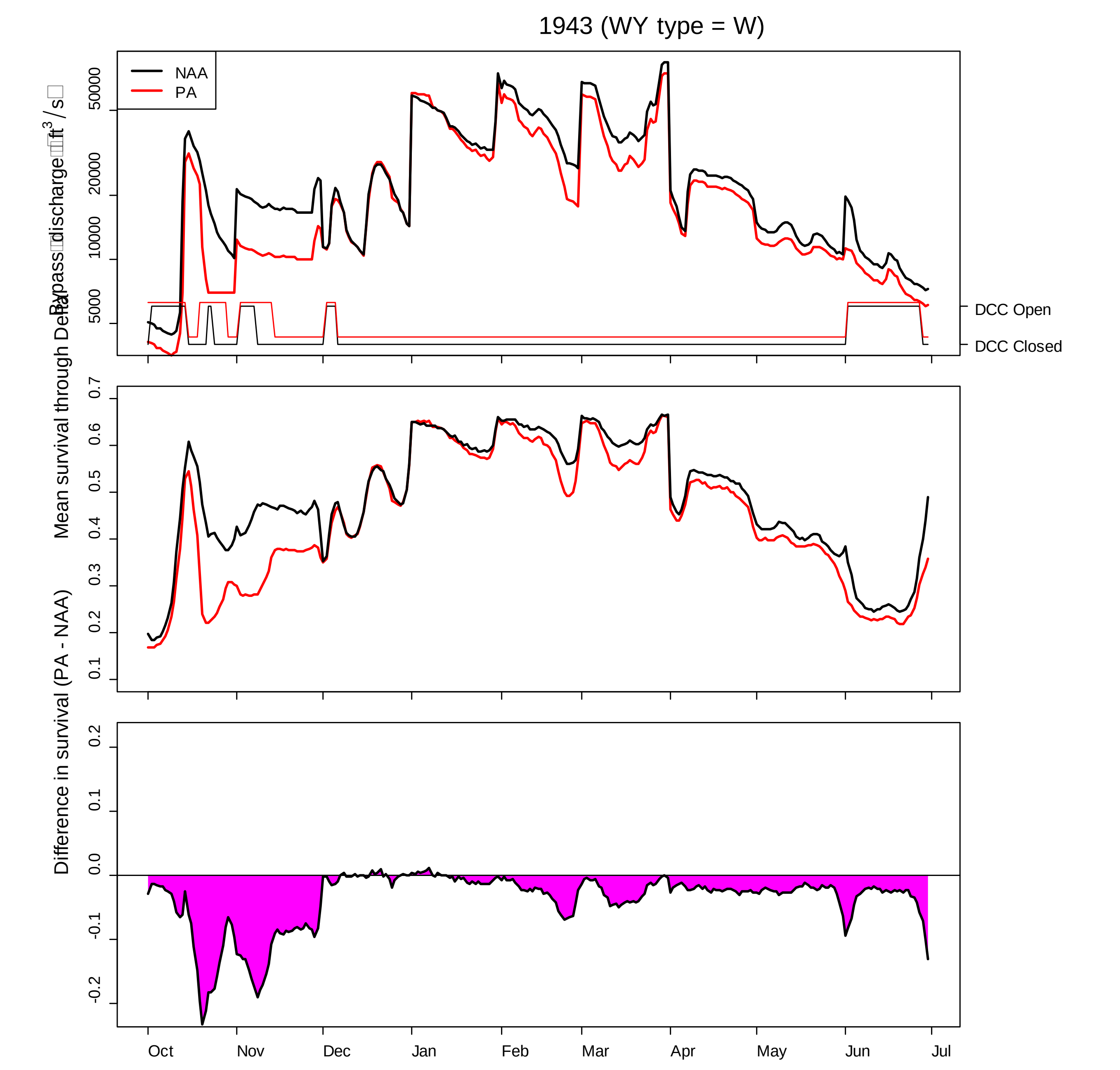
Outputs for Each Year: Survival



Outputs for Each Year: Travel Time

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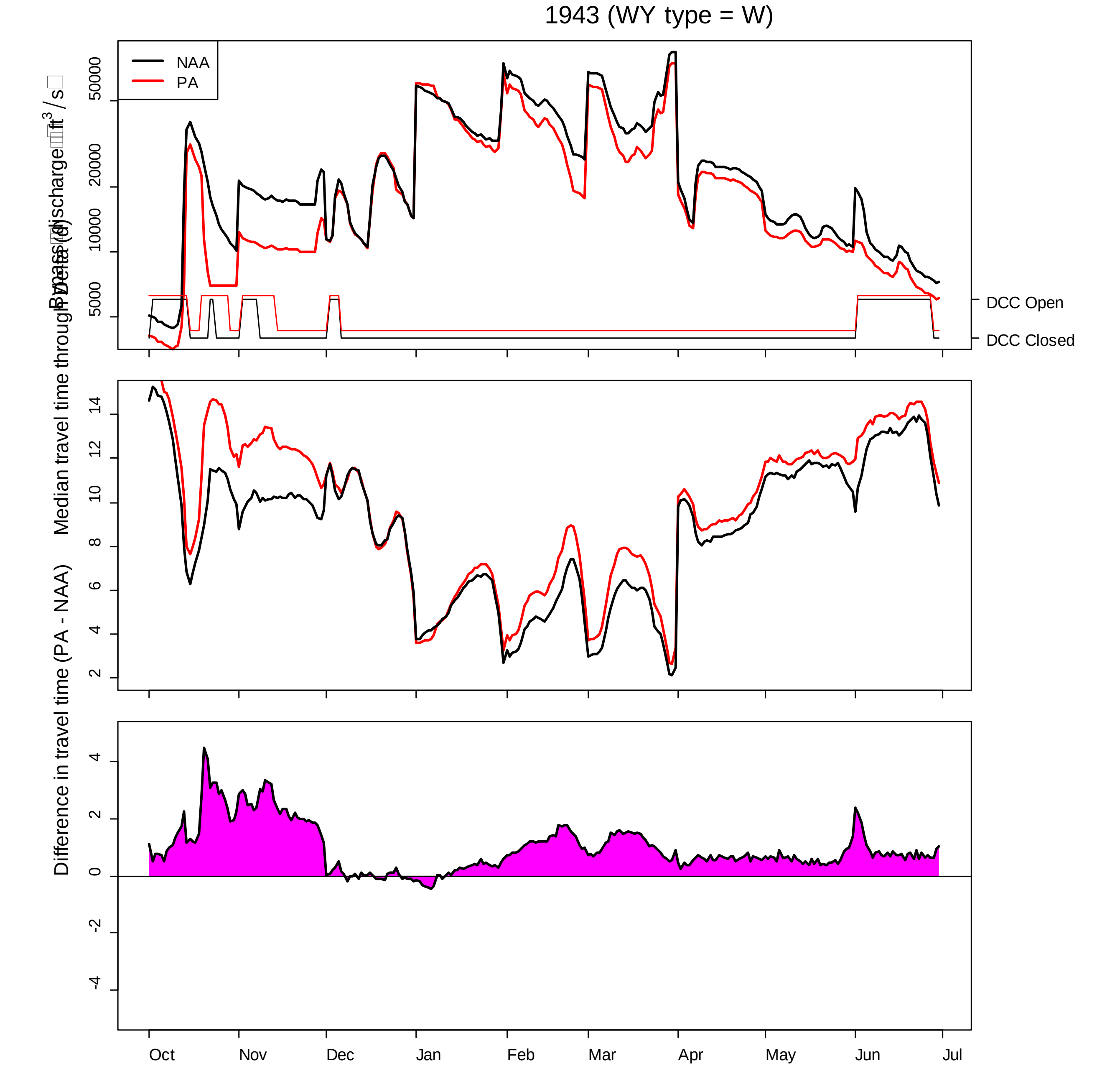

Outputs for Each Year: Routing

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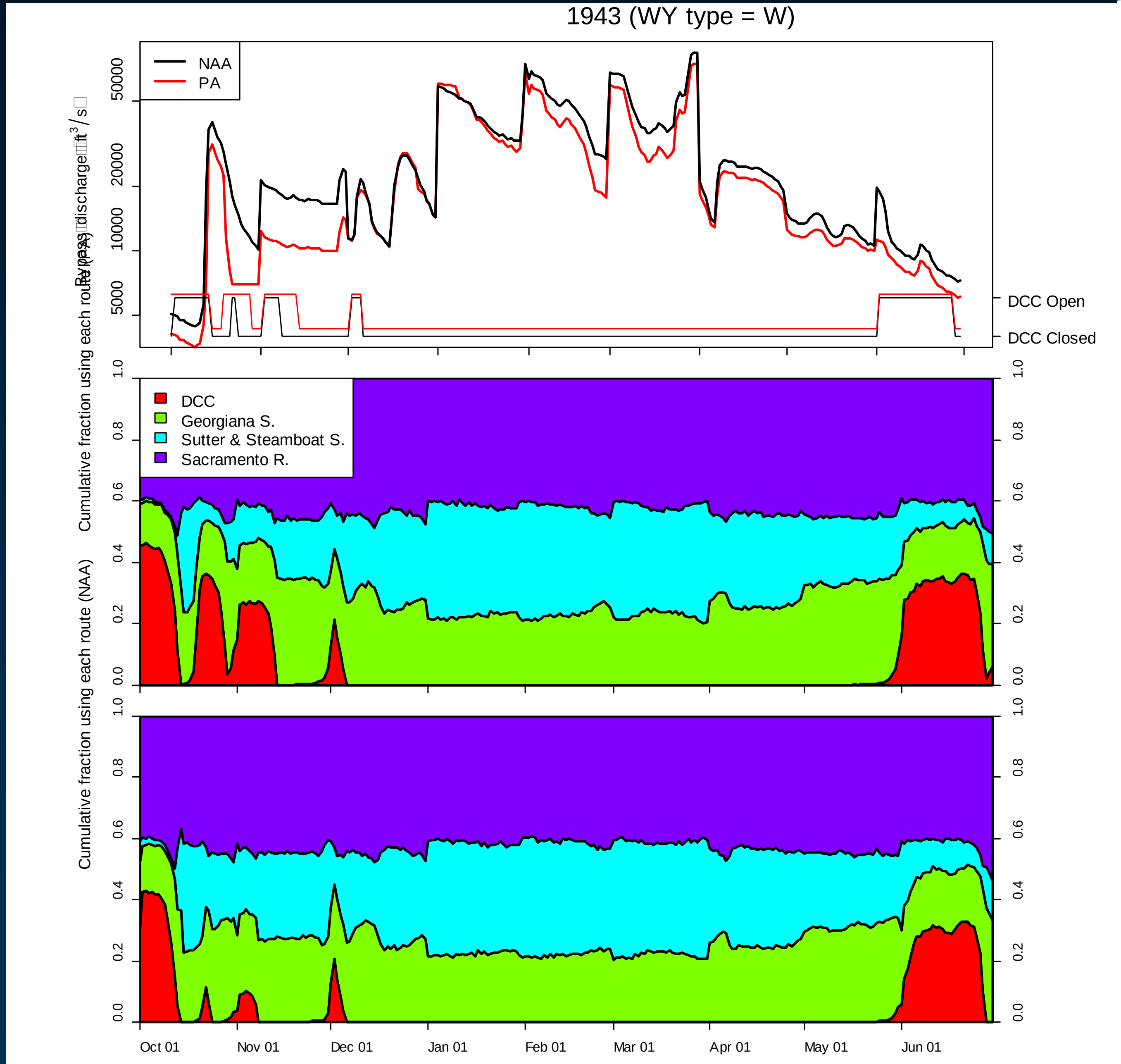
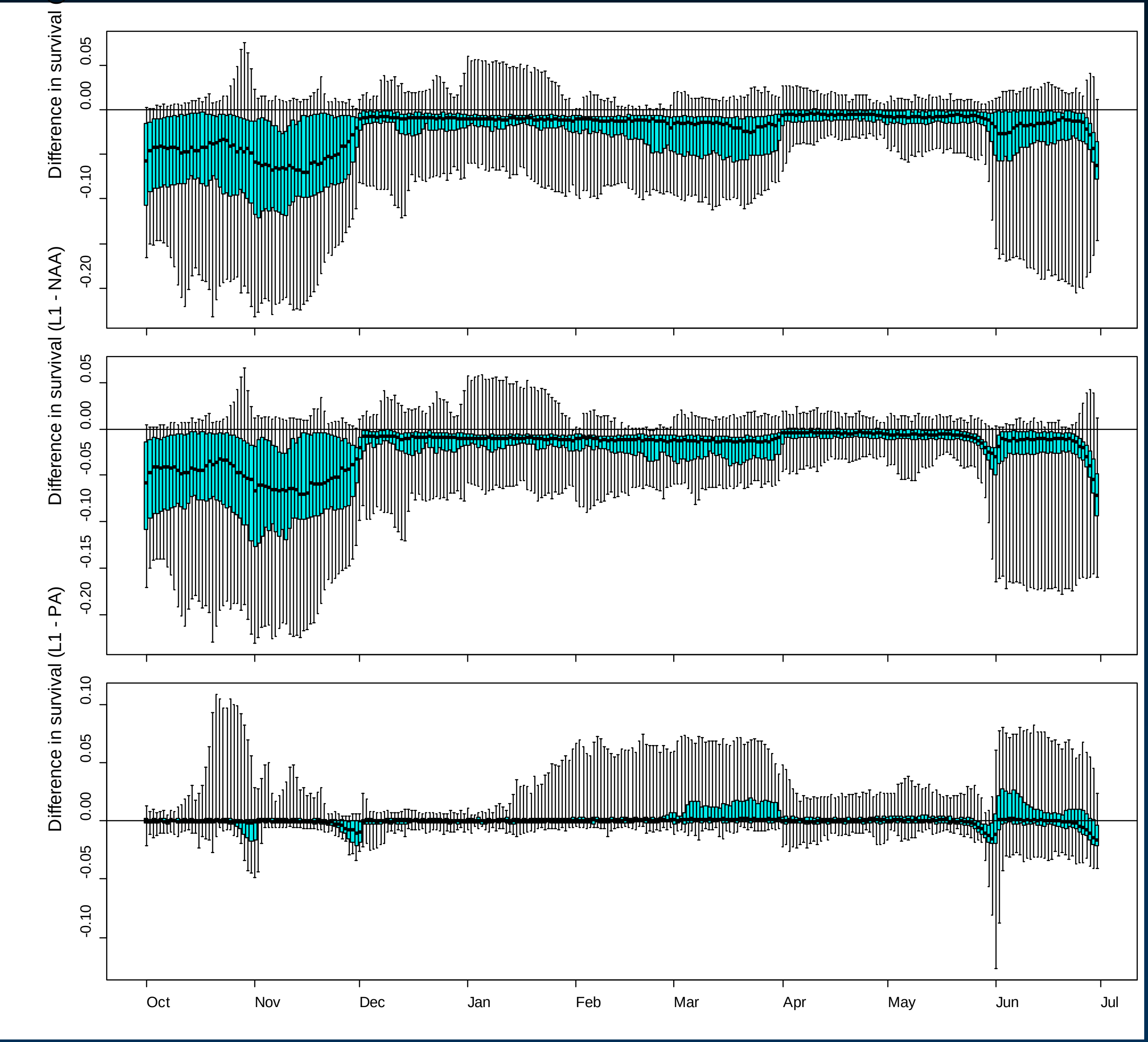


Summarizing Survival Differences



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Evaluating NDD Bypass Rules

- Apply rule sets under "equilibrium" conditions
  - Assume constant inflows and operations for cohort
- Calculate survival with and without diversion
- Evaluate survival differences for each rule set

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Oct.-Nov. Bypass Rules

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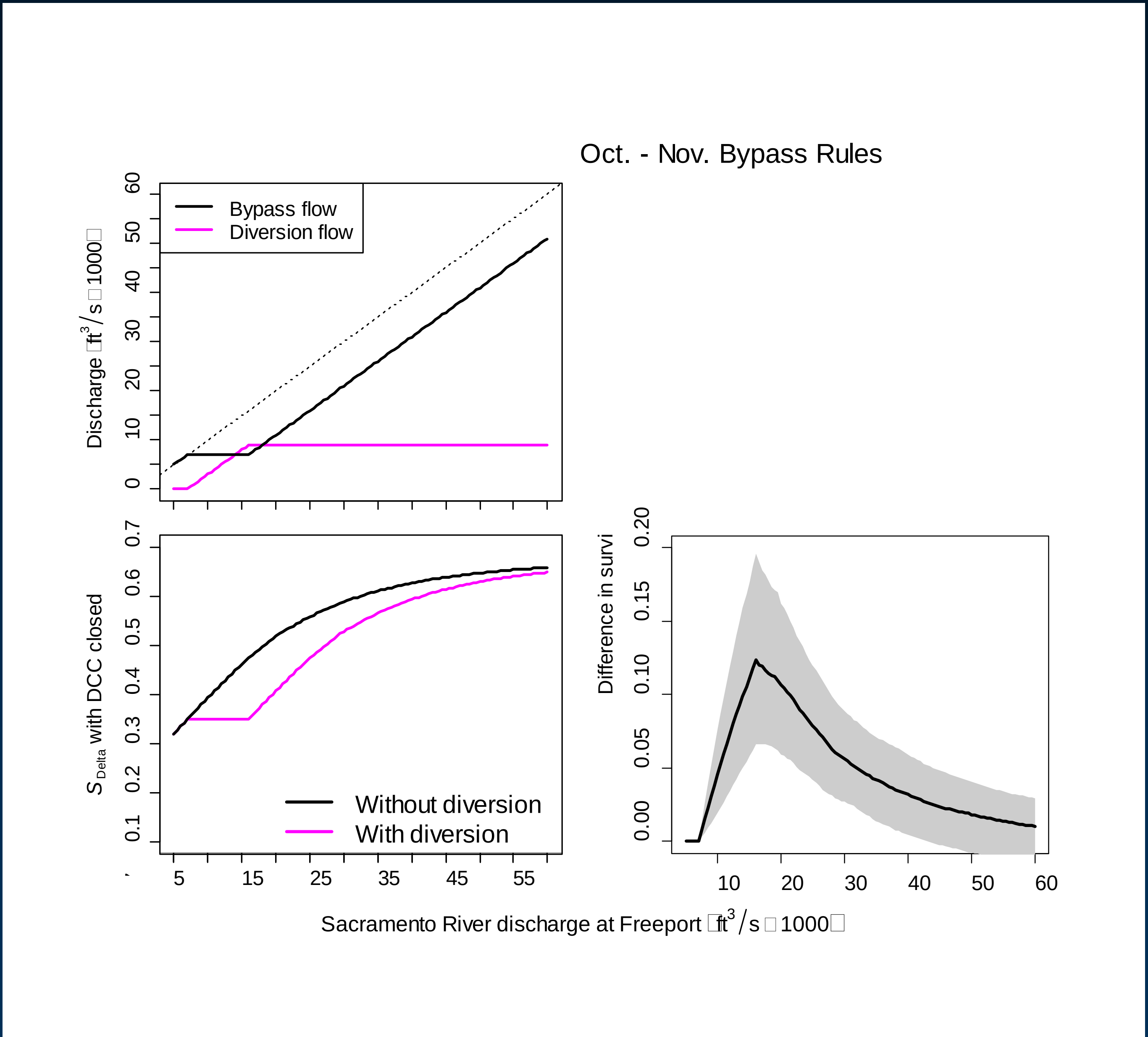

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Constant Low-Level Pumping

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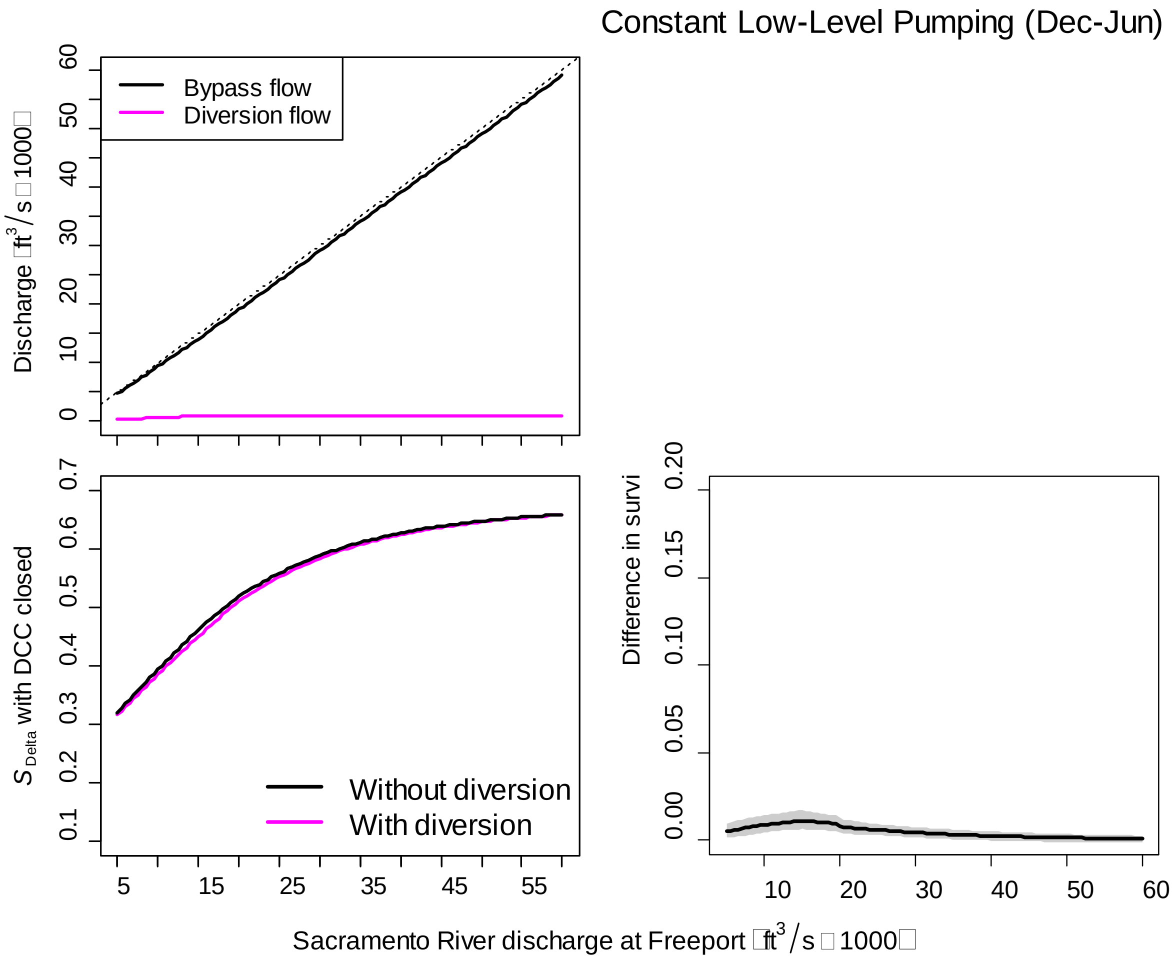

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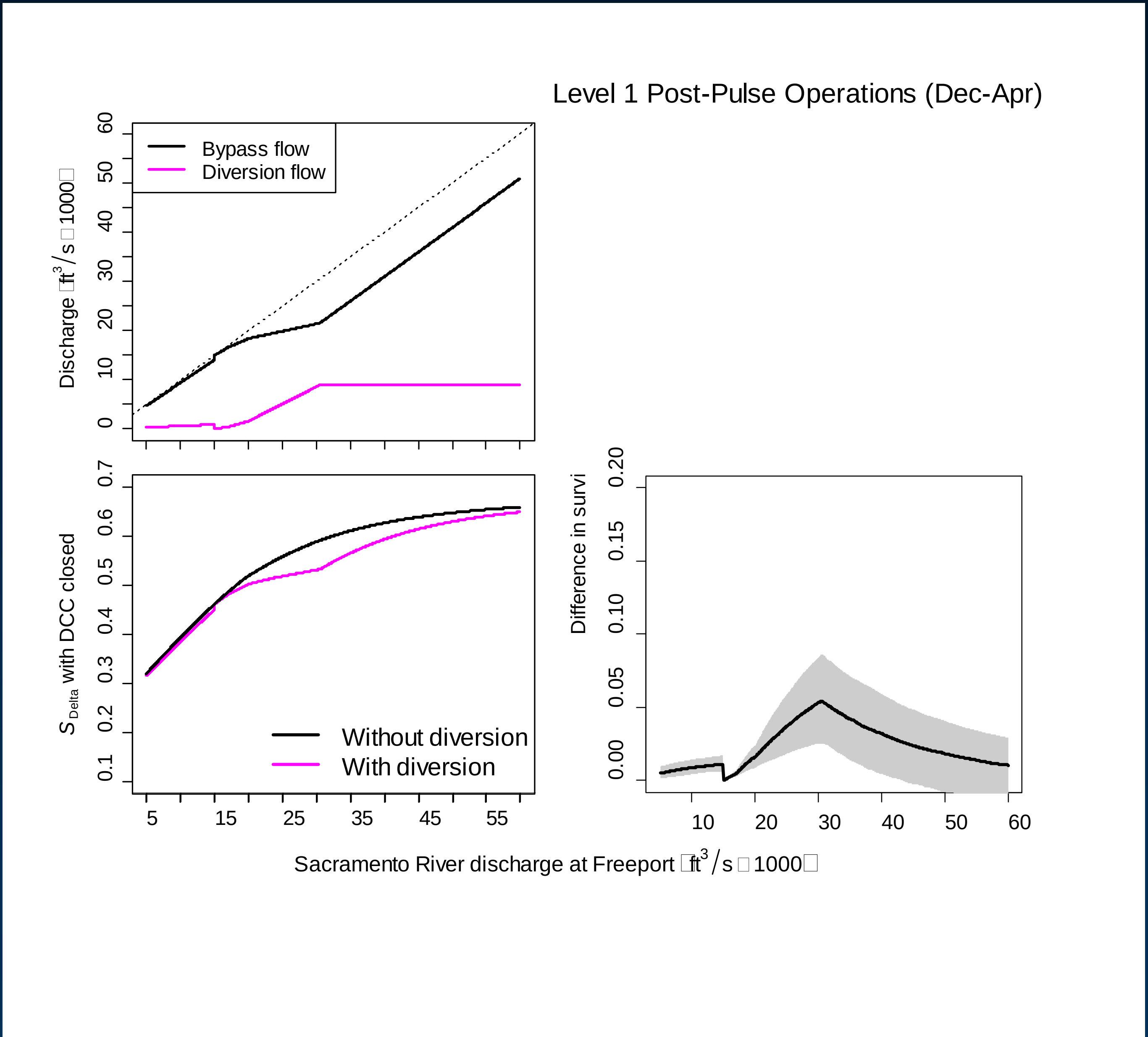
Level 1 Post-Pulse Operations



Summary: NDD Bypass Rules

- Some large survival differences
  - Depends on
    - Bypass flows
    - Rule set
- In CalSim simulations
  - Highlights why larger differences in Oct., Nov., Jun.
- How else might operations be structured?

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Determining Operations based on Maximum Allowable "Take"

- Example criteria
  - No more than a 0.03 decrease in mean survival
  - 90% probability that survival is decreased by no more than 0.03
- Use survival model to identify diversions that satisfy criteria
  - Find by optimization routine

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Diversions Based on Median Survival

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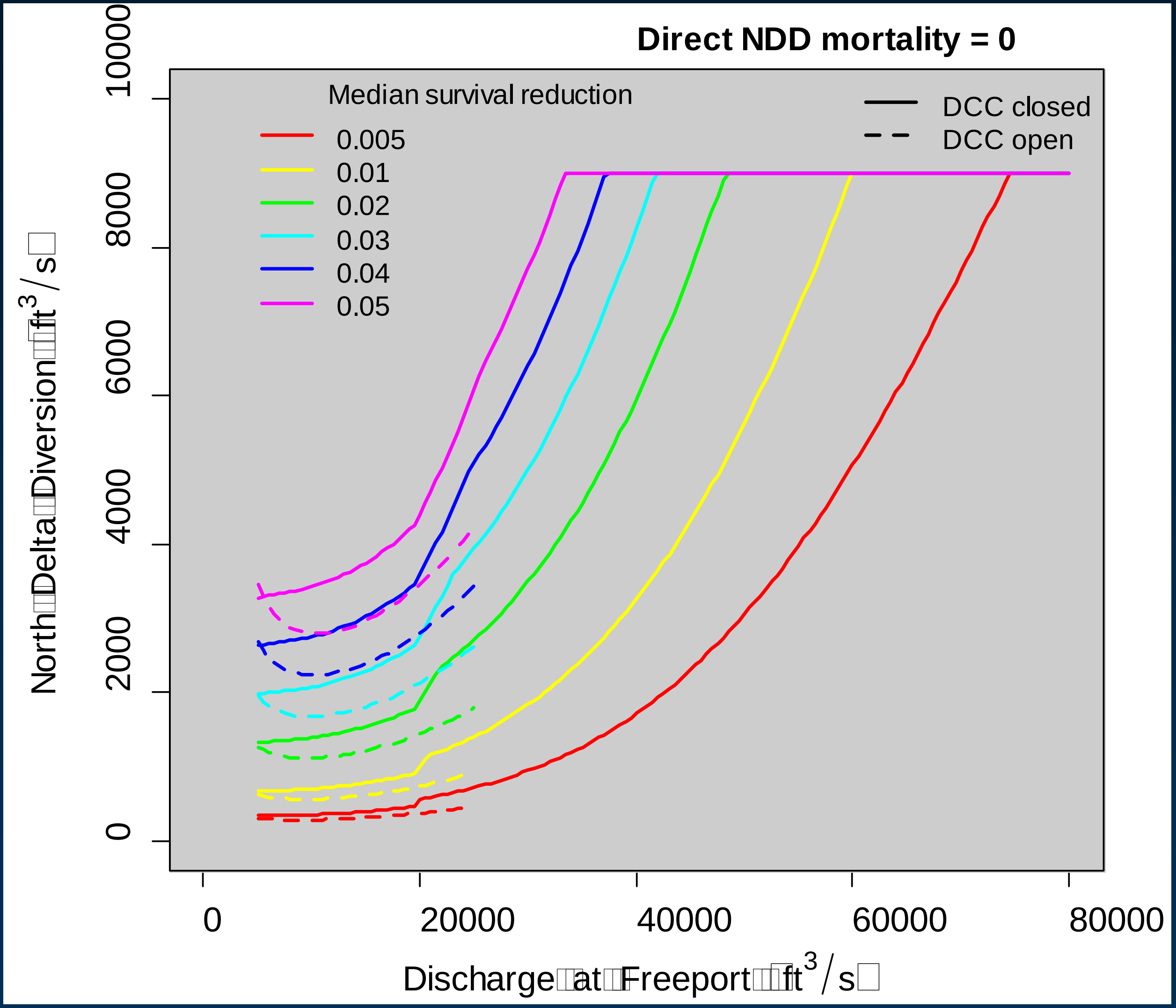

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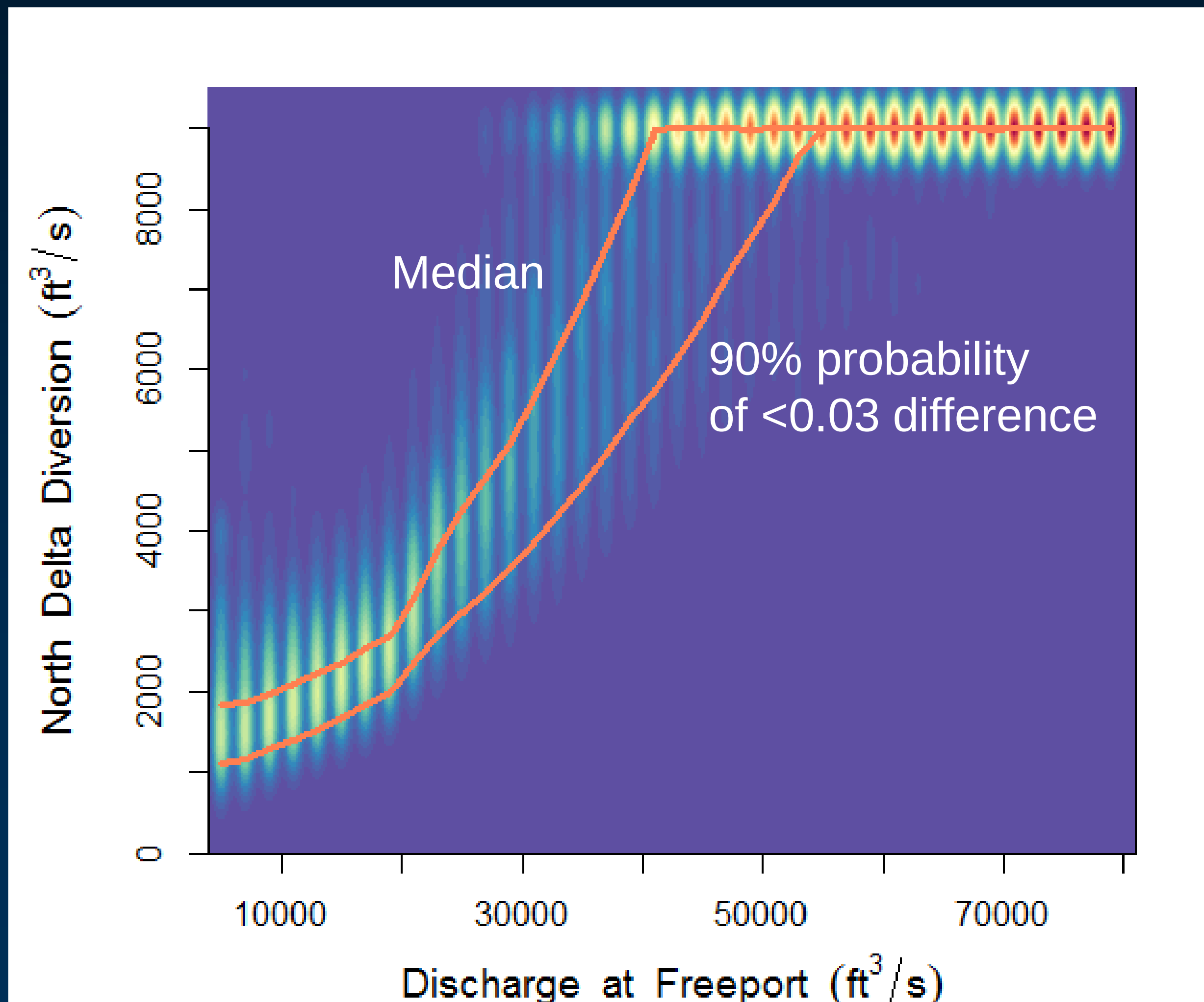
Diversions Based on Full Posterior Distribution for 0.03 survival reduction



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Survival Difference Based on 10th percentile of NDD flows for 0.03 survival reduction

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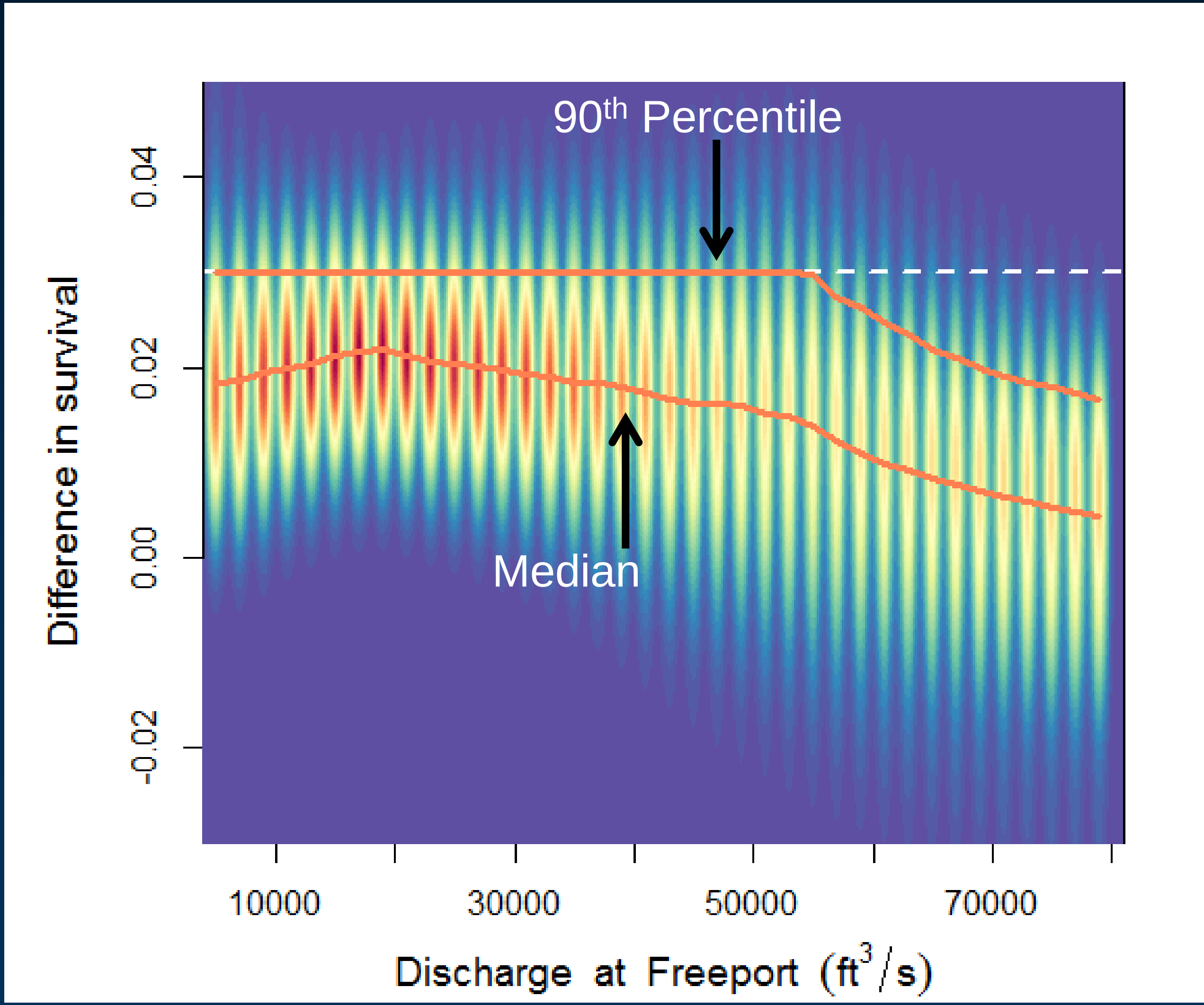

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Summary

- Survival model can help identify operations that meet specific survival criteria
- Variability in survival can explicitly play a role in setting criteria
- New set of operations can be assessed with other models
  - CVLCM, DPM, etc.
  - More robust inferences

Acknowledgments

Delta Stewardship Council

NOAA

DWR

UC Davis

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Important Assumptions

- Extending inferences:
  - Late Fall Chinook = Winter Run?
  - Nov. – Mar. = Apr. – Jun.?
  - Hatchery = Naturally produced?
  - Current system state = future system state?
  - Predicting outside range of observed data?

- Relative vs. Absolute comparisons
  - Relative more robust
    - NAA vs. PA
    - Shape of driving relationships similar

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Diversions Based on Median Survival

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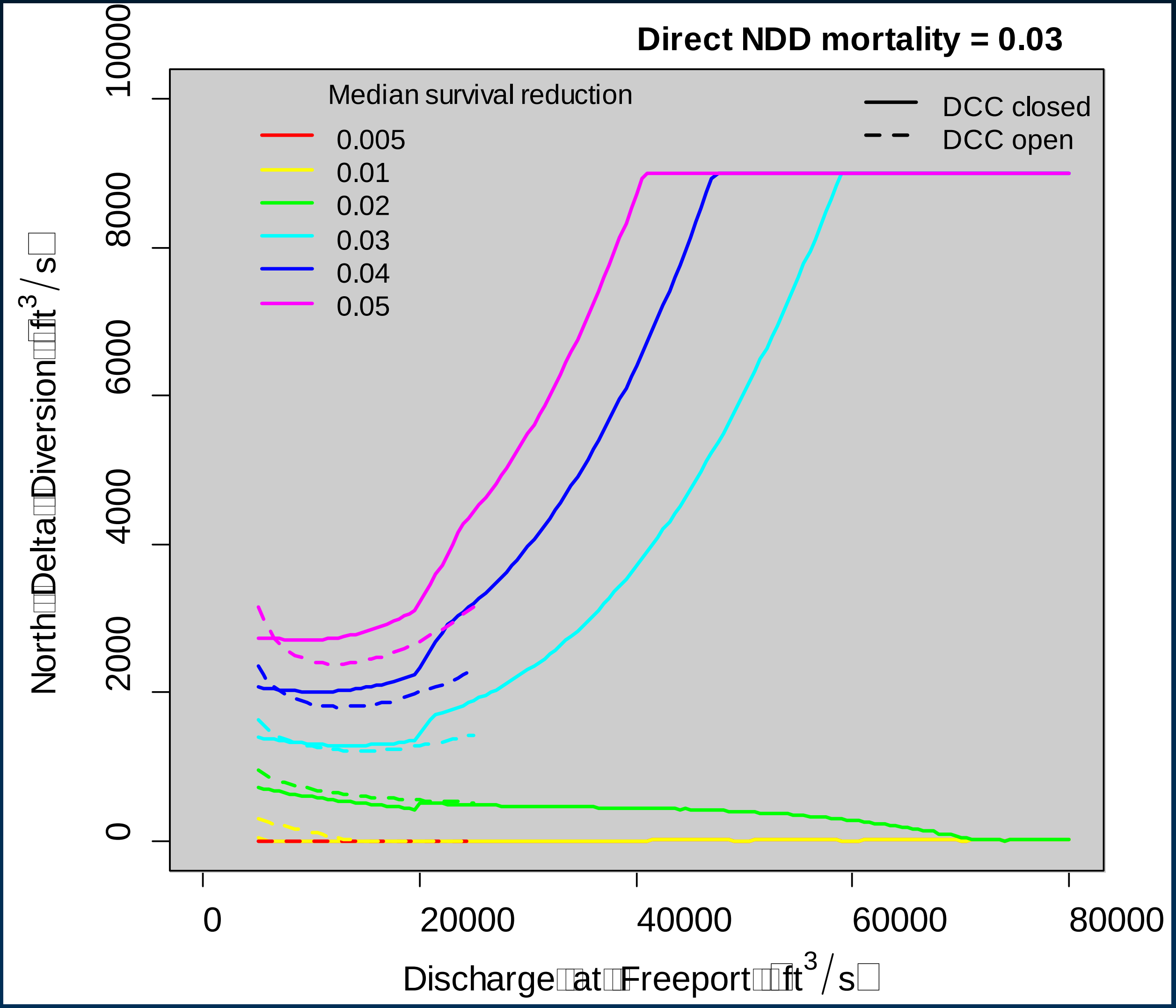

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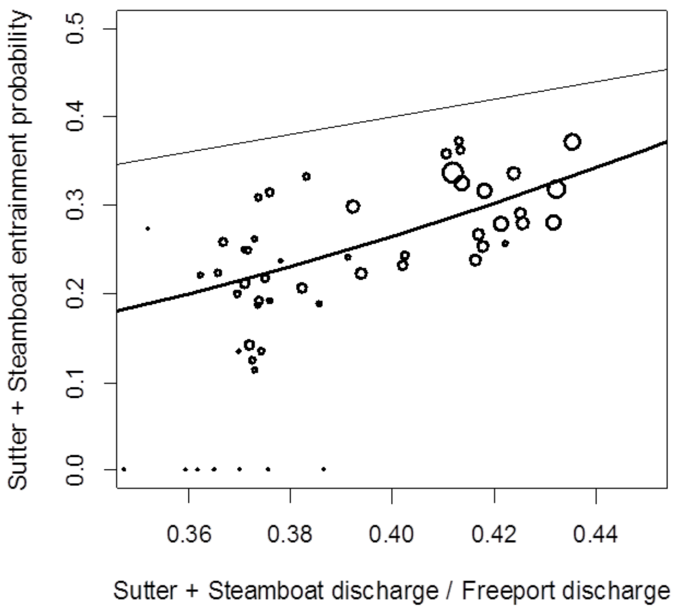
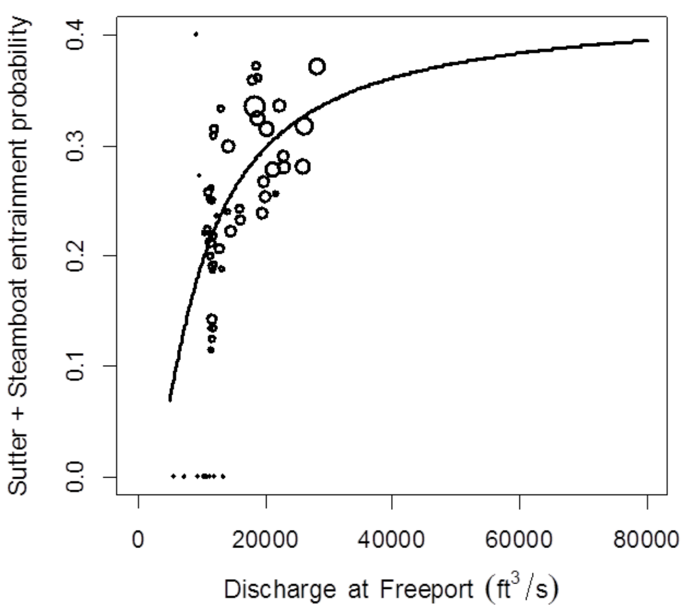
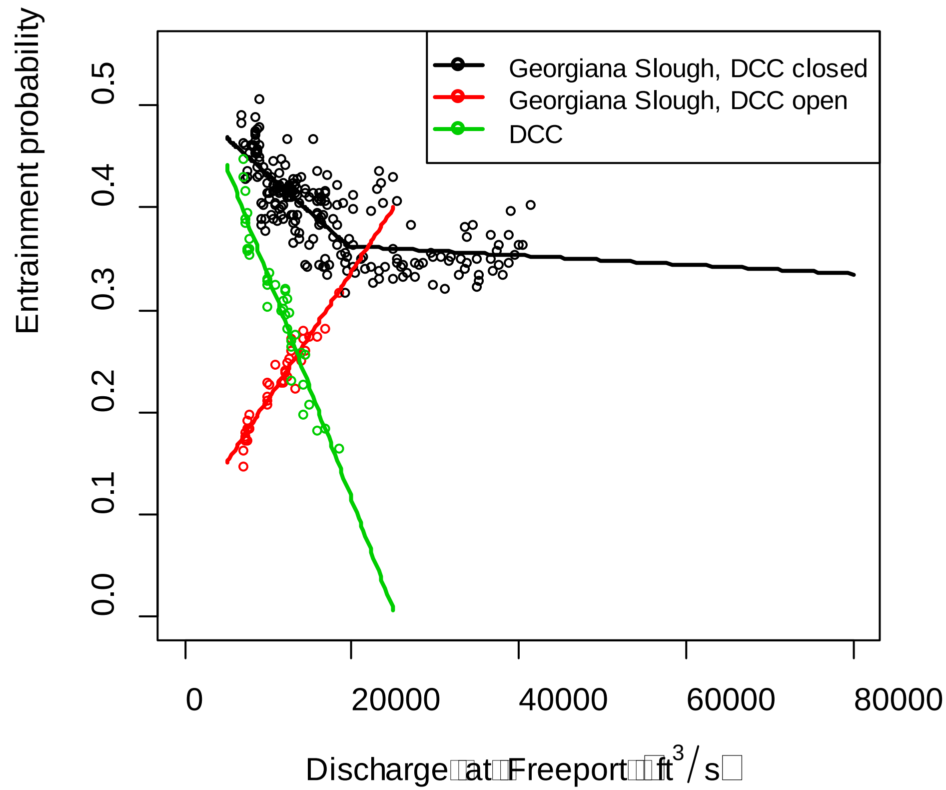

Sutter + Steamboat entrainment probability
0.0
0.1
0.2
0.3
0.4
0.5
0.36
0.38
0.40
0.42
0.44
Sutter + Steamboat discharge / Freeport discharge


Sutter + Steamboat entrainment probability
0.0
0.1
0.2
0.3
0.4
0
20000
40000
60000
80000
Discharge at Freeport (ft3/s)


Entrainment probability
0.0
0.1
0.2
0.3
0.4
0.5
Georgiana Slough, DCC closed
Georgiana Slough, DCC open
DCC
0
20000
40000
60000
80000
Discharge at Freeport ft3 / s