Combining Models of the Critical Streak Line and the Cross-Sectional Distribution of Juvenile Salmon to Predict Fish Routing at River Junctions

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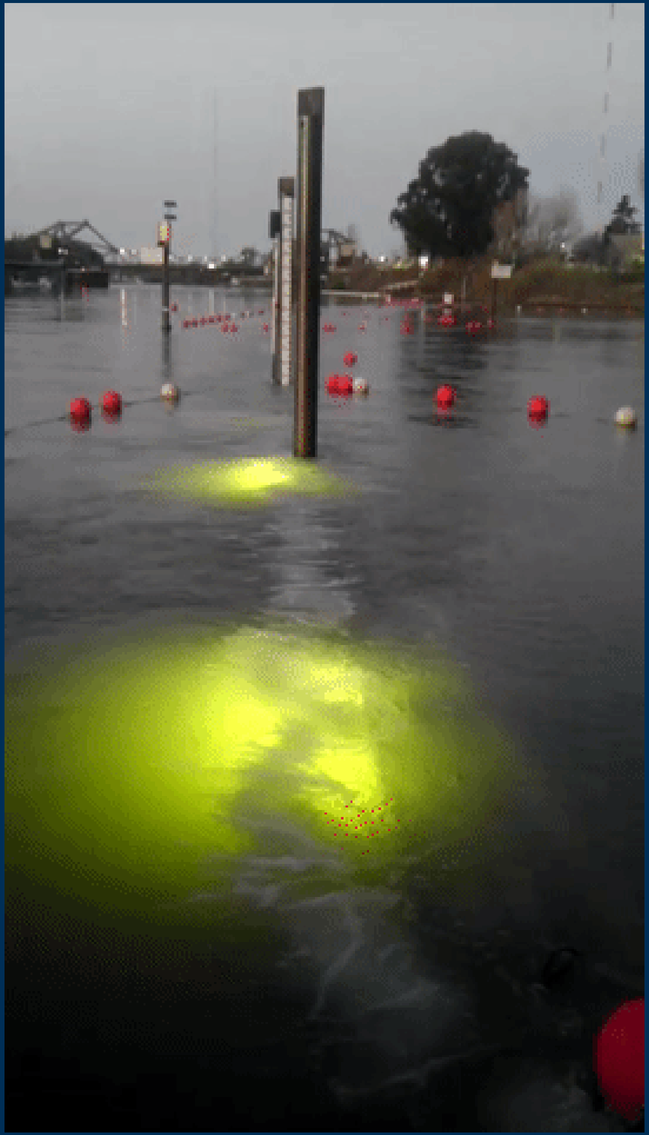
A Quick Review: Migration Routing at Georgiana Slough

- Bio-Acoustic Fish Fence (BAFF)
  - Barrier reduced entrainment, but was only one factor

- Other Factors:
  - Streamflow Above Junction
  - Day/Night
  - Critical Streakline Position
  - Cross-stream Position of Fish



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Perry et al. (2014) “Using a non-physical behavioral barrier to alter migration routing of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta”, River Research Applications, 30: 192–203.

Entrainment Zones and the Critical Streakline

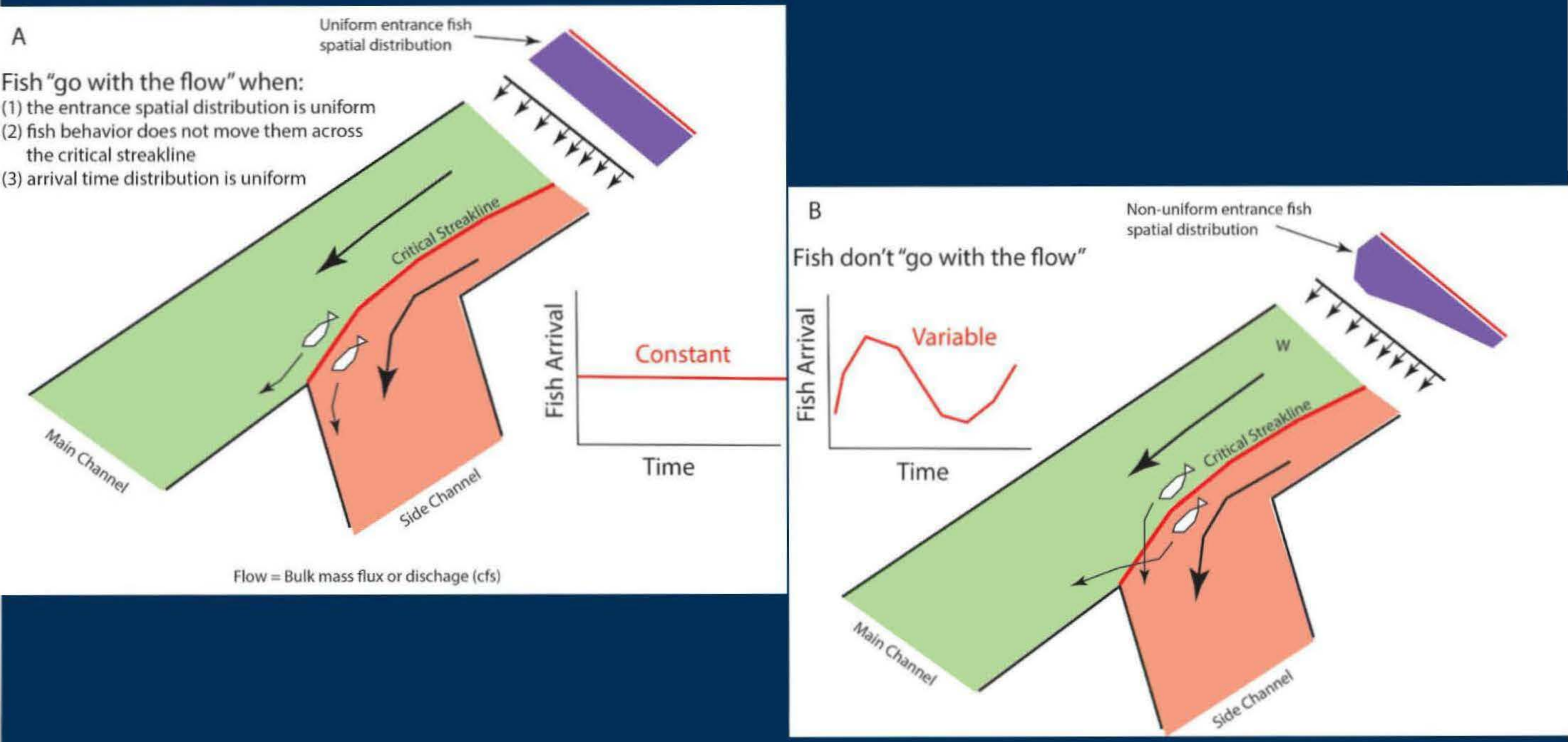

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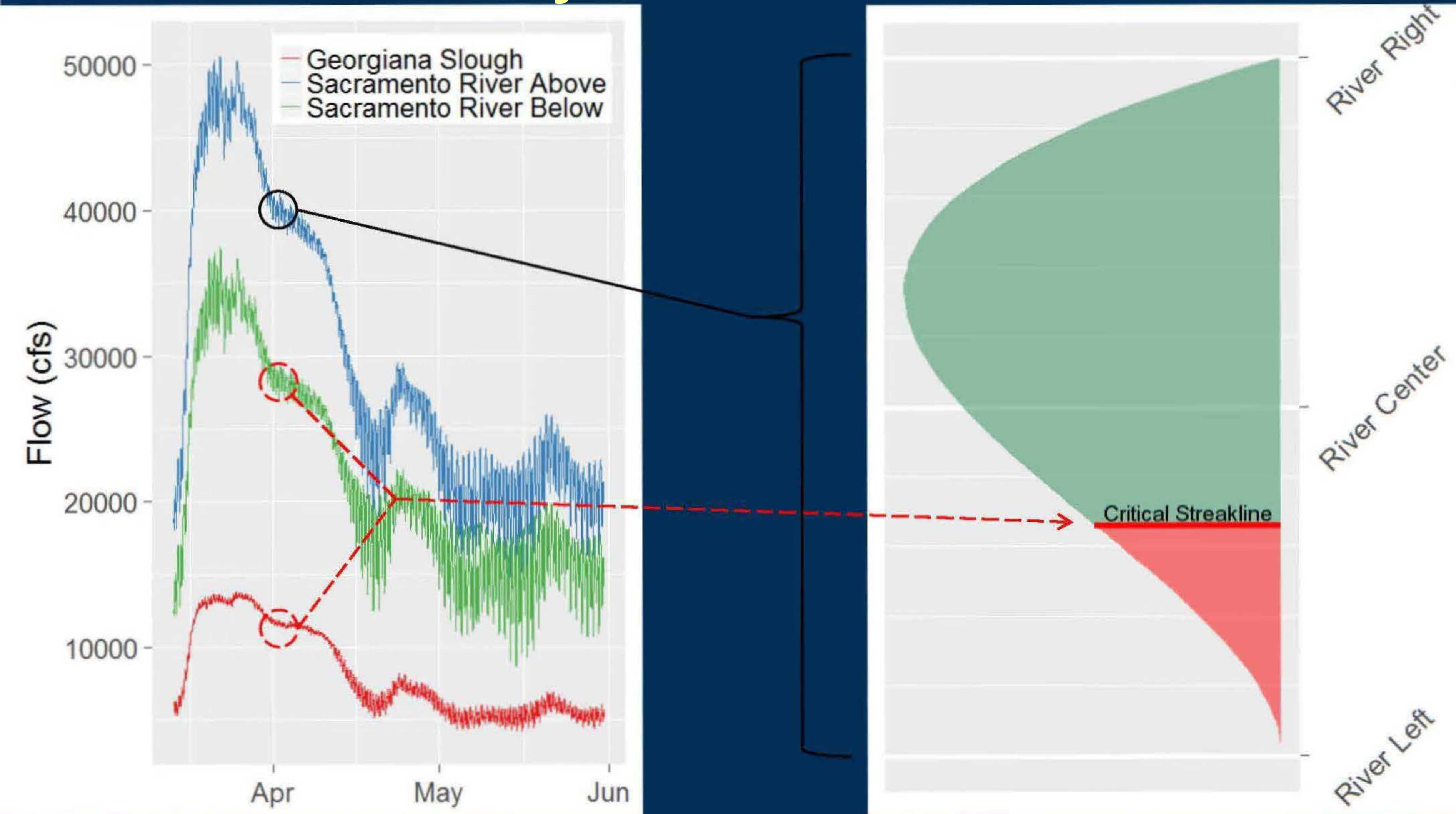
Figure Courtesy Jon Burau; In: Perry et al. (2016) "Anadramous Salmonids in the Delta: New Science 2006 – 2016" , San Francisco Estuary and Watershed Science, 14(2)

Predicting Entrainment: What is Necessary and Sufficient?



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Objectives

- Estimate cross-sectional fish distribution upstream of junction
  - Environmental conditions
  - BAFF operations
- Estimate entrainment probability based on fish position relative critical streakline
- Identify whether cross-sectional fish distribution and critical streakline position are sufficient to predict entrainment probability

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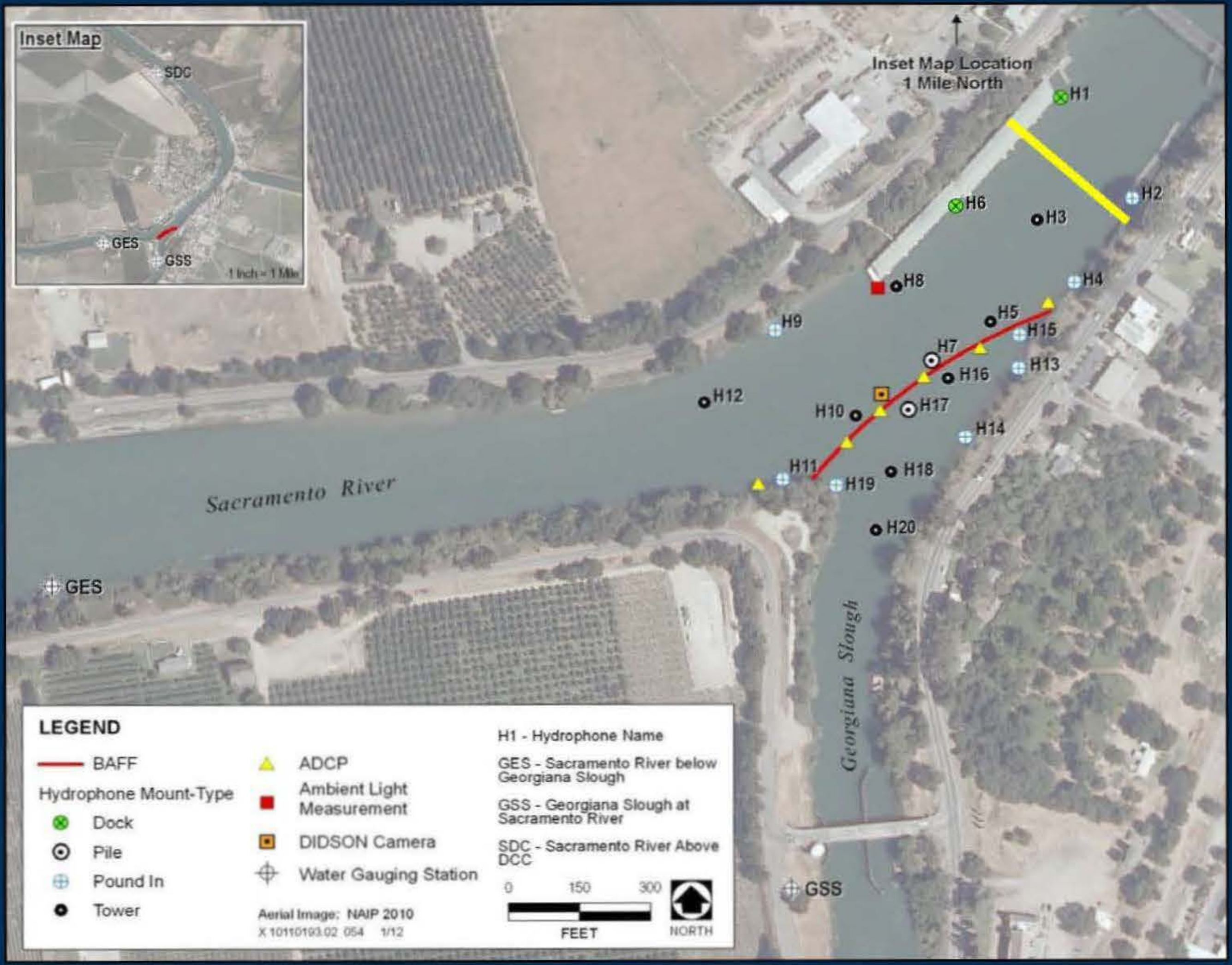
Methods: Study site



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Methods: Fish Tagging and Release

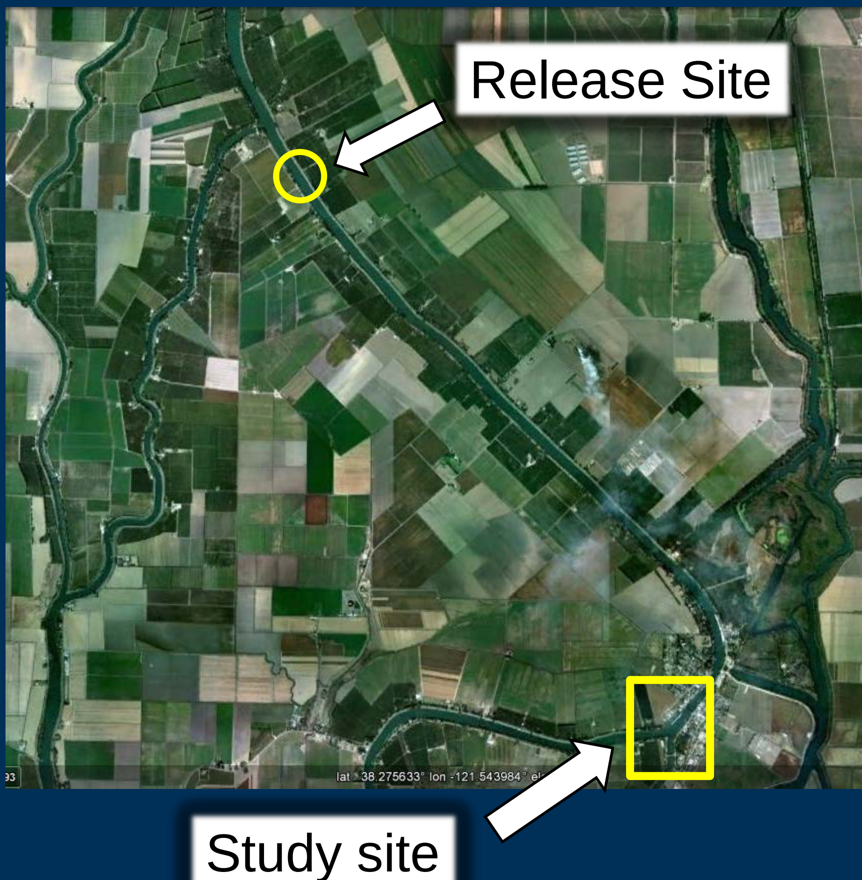
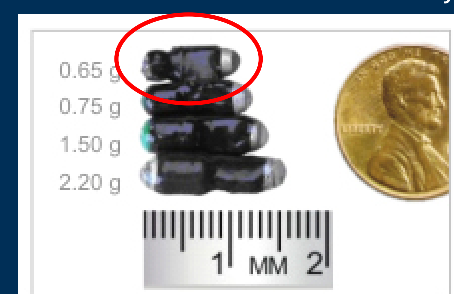


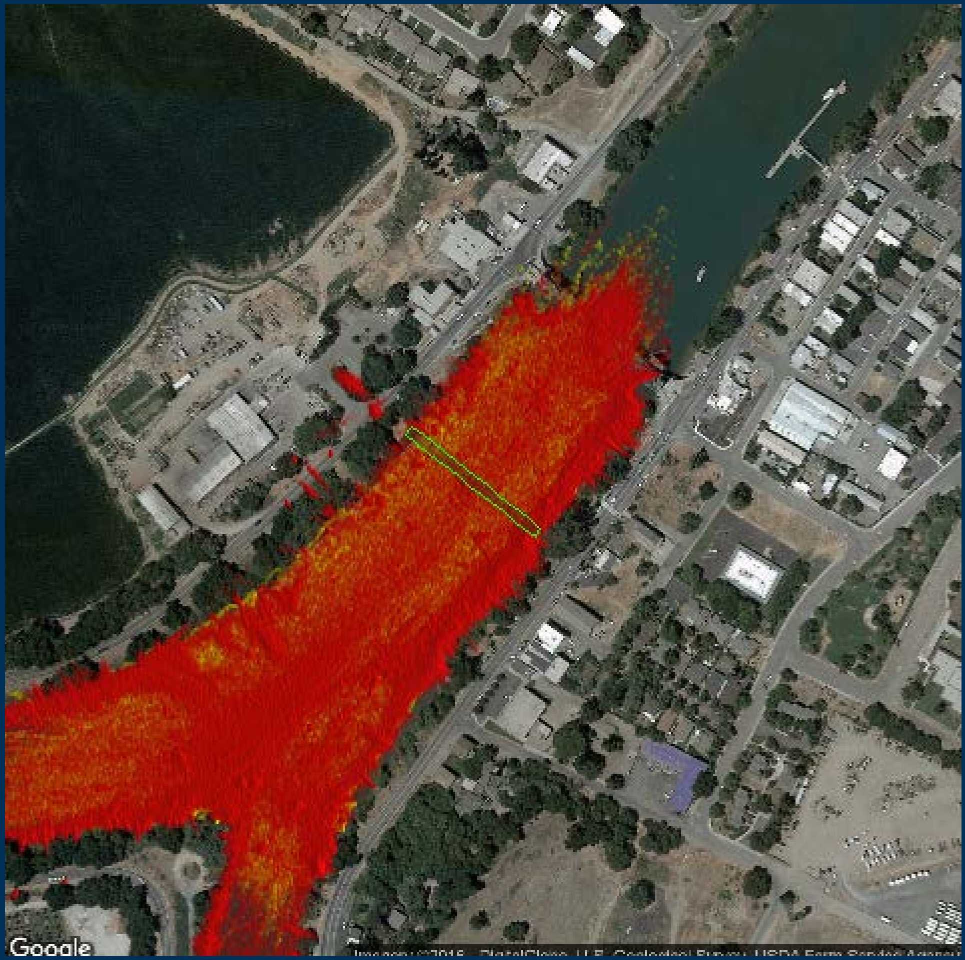
Photo courtesy of AECOM



http://www.htisonar.com/acoustic_tags.htm

Methods: Data Preparation

- Removed all tracks suspected of predation
- Restricted analysis to detections within single transect upstream of junction
- Discharge, BAFF operations, and Night/Day assigned based on timestamp of detections



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Methods: Beta Regression

$$f(y;\mu,\phi) = \frac{\Gamma(\phi)}{\Gamma(\mu\phi)\Gamma((1-\mu)\phi)} y^{\mu\phi-1}(1-y)^{(1-\mu)\phi-1}, \quad 0 < y < 1,$$

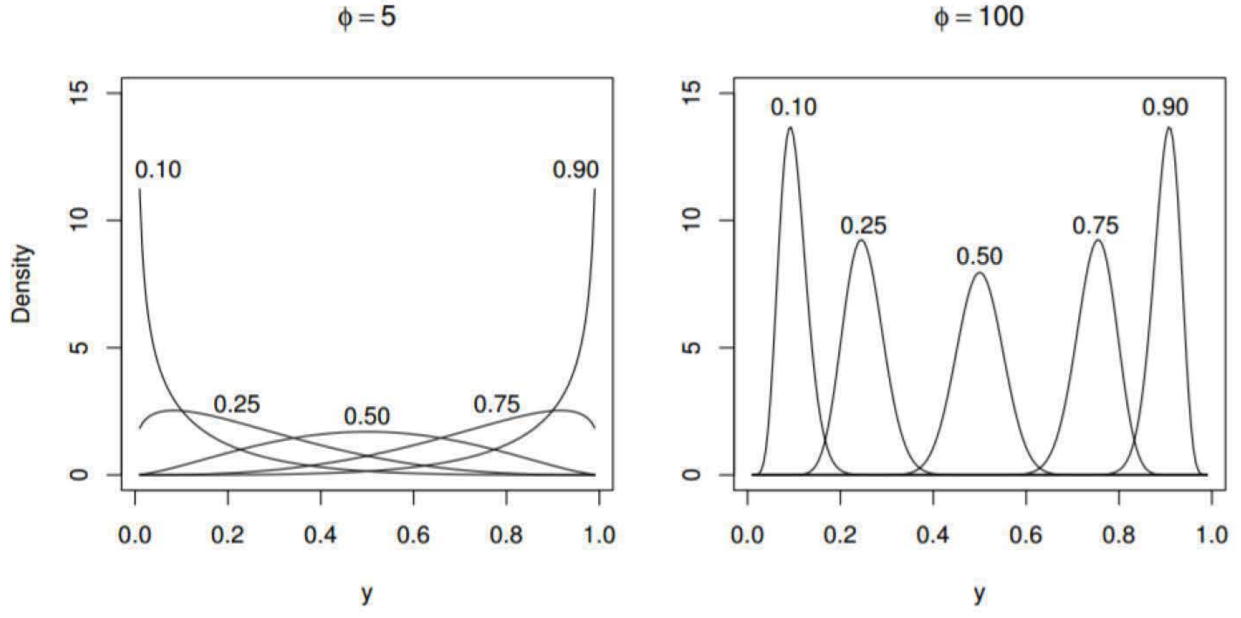

Figure 1: Probability density functions for beta distributions with varying parameters $\mu = 0.10, 0.25, 0.50, 0.75, 0.90$ and $\phi = 5$ (left) and $\phi = 100$ (right).

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Figure from Cribari-Neto F, Zeileis A (2010). "Beta Regression in R." Journal of Statistical Software, 34(2), 1–24. URL http://www.jstatsoft.org/v34/i02/

Methods: Beta Regression

$$y_i \sim \mathrm{B}(\mu, \phi)$$

- y is cross-stream position normalized to (0,1) scale with 0 left-bank and 1 right-bank

$$\mathrm{logit}(\mu_i) = X_i * \beta$$

- X are covariates of interest for mean term, β are corresponding parameters

$$\log(\phi_i) = Z_i * \gamma$$

- Z are covariates of interest for precision term, γ are corresponding parameters

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Methods: Logistic Regression

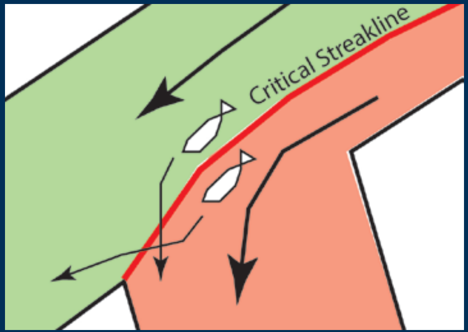
$$F_i \sim \text{Bernoulli}(p_i)$$

- F is the fate of the i^{th} fish with 1 for fish entrained and 0 other

$$\text{logit}(p_i) = \alpha_0 + S_i * \alpha_1 + B_i * \alpha_2 + S_i * B_i * \alpha_3$$

- α_0 is logit-mean probability of entrainment if BAFF is off and fish is on Sacramento side of streakline
- S_i is 1 if fish is on Georgiana side of streakline
- B_i is 1 if BAFF is on as fish approaches junction

$$\text{Streakline} = \frac{Q_{Georgiana}}{Q_{Georgiana} + Q_{Sacramento\ Below}}$$



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Methods: Model Fitting

- Models fit in Stan (mc-stan.org)
- All combinations of covariates for mean and precision considered
- Model selection conducted using leave-one out cross-validation
  - Model for precision term selected first using full model for mean term
- Model fit assessed using posterior predictive check

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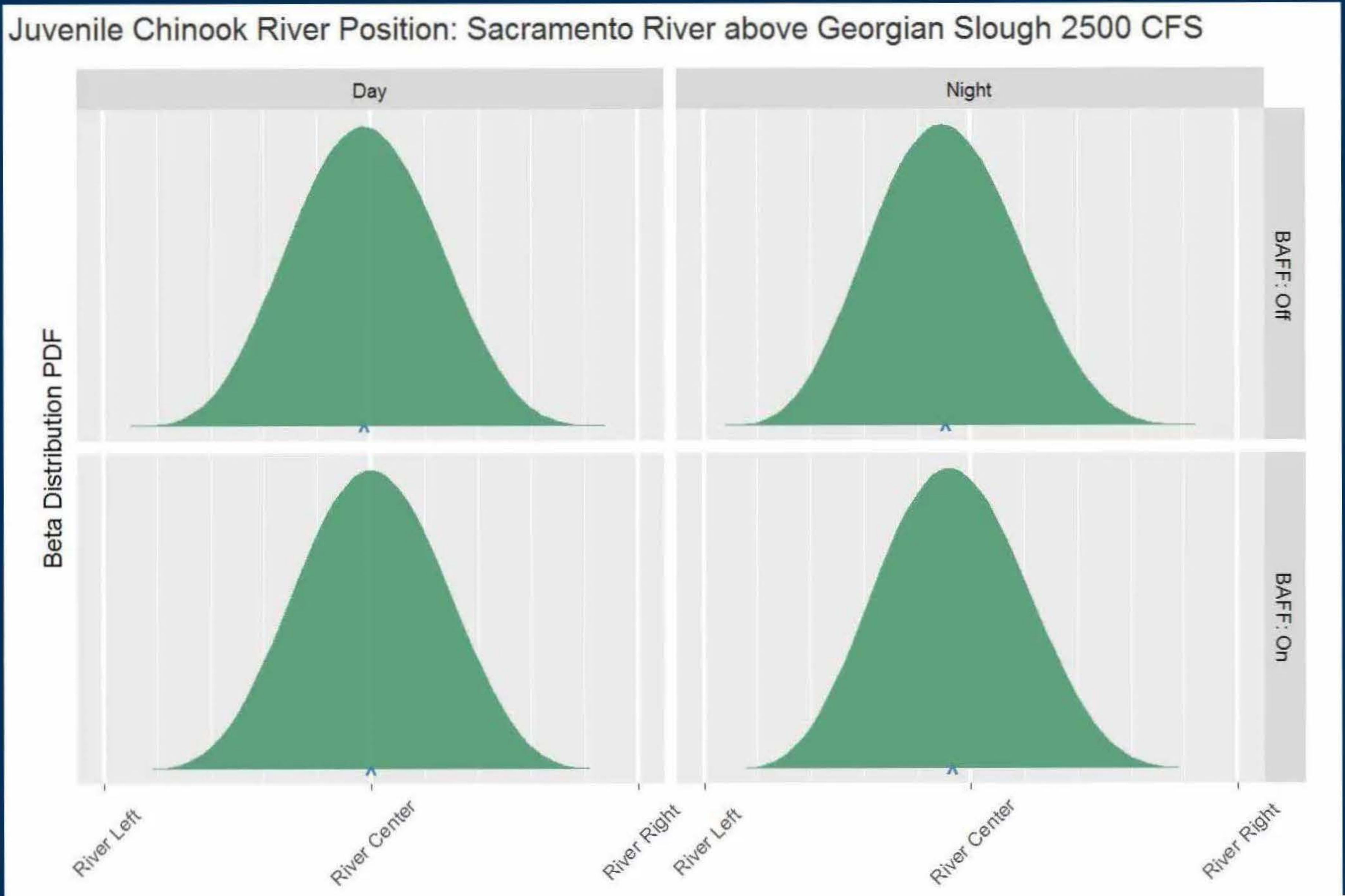
Results: Beta Regression - μ and ϕ

Parameter Estimates for the Best-fit Model			
μ		**ϕ**	
Variable	**Estimate**	**Variable**	**Estimate**
Intercept (Day, Off)	≈0.5	*Q*	+
Q	≈0.0		
BAFF	+		
Night	-		
*Q*Night*	+		

Results: Beta Regression



Results:
Critical Streakline Logistic Regression

Condition	Probability of Entrainment [90% CI]
BAFF Off, Sacramento Side	0.18 [0.15, 0.21]
BAFF On, Sacramento Side	0.10 [0.09, 0.11]
BAFF Off, Georgiana Side	0.62 [0.53, 0.71]
BAFF On, Georgiana Side	0.58 [0.52, 0.64]

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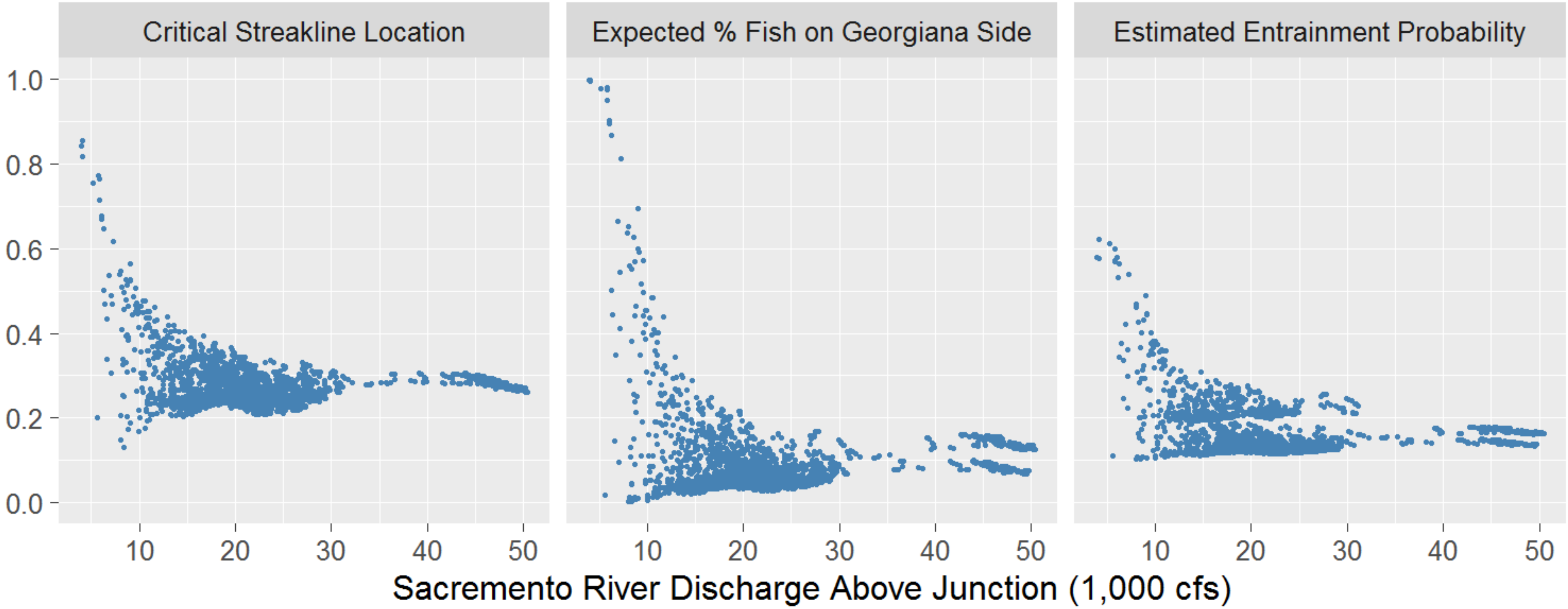
Results: Combined Models

BAFF	N	Observed Entrained	Expected Entrained [90% CI]
On	1981	282	282 [258, 306]
Off	569	136	132 [118, 149]



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Conclusions

- Cross-stream fish distribution upstream of the junction was previously found to be a major determinant of entrainment in Georgiana Slough

- Cross-stream fish distribution can be modelled based on environmental conditions, especially discharge

- Fish on different sides of streakline* have markedly different probability of entrainment

- Combining models of fish distribution and entrainment probability can predict overall entrainment rates

Acknowledgements

HTI

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

Fish Guidance Systems

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U.S. DEPARTMENT OF THE INTERIOR
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Thank you
Questions?

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