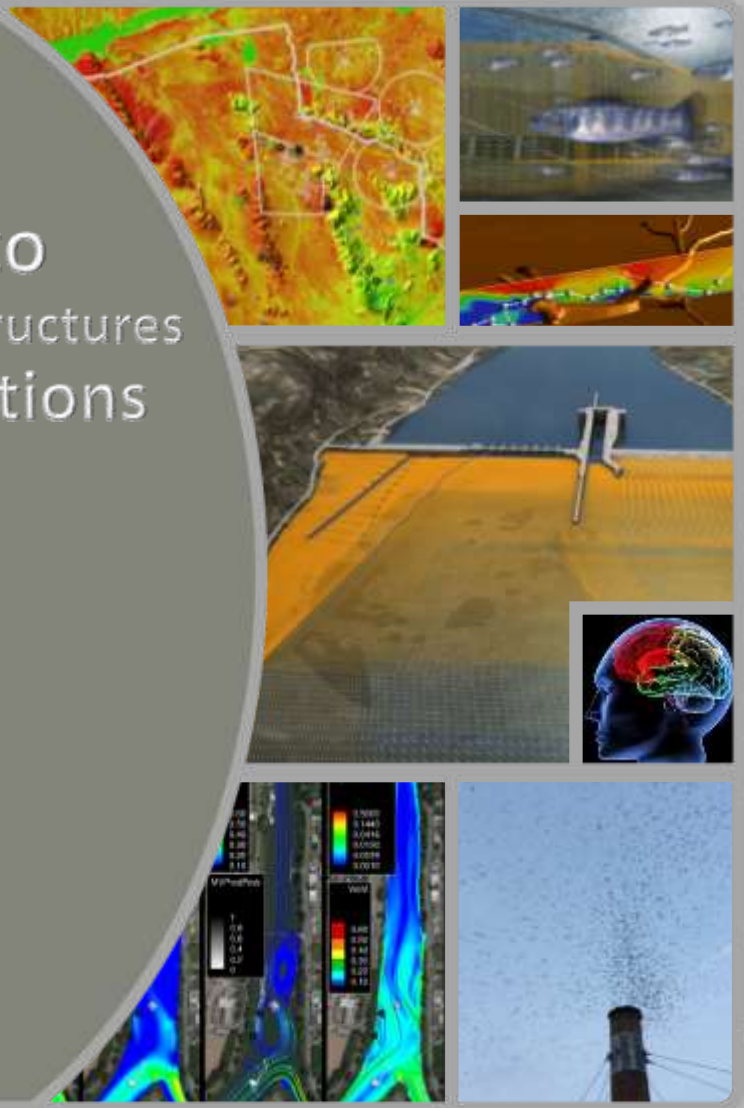
Predicting near-future juvenile salmon response to water management and engineered structures across diverse tidal river conditions



R. Andrew Goodwin, PhD, PE

U.S. Army Engineer R&D Center

Portland, Oregon

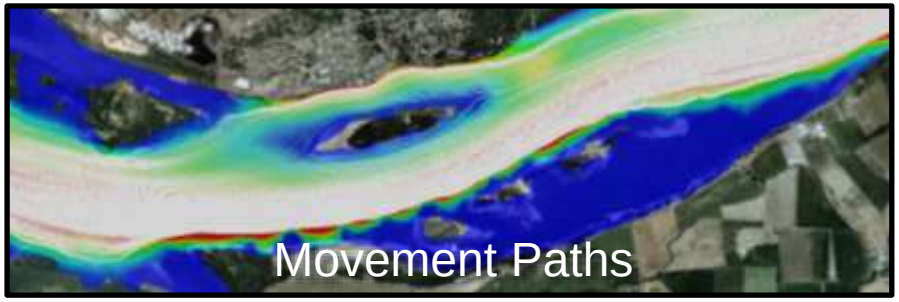
Collaborators & Contributors

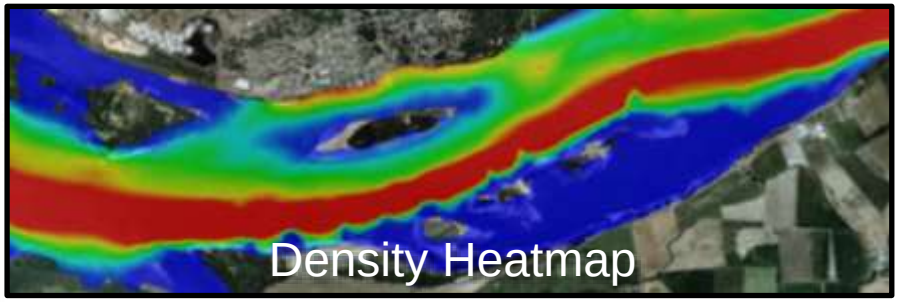
Many, many, …

18 May 2023

ELAM model: Peer-reviewed Fish Prediction

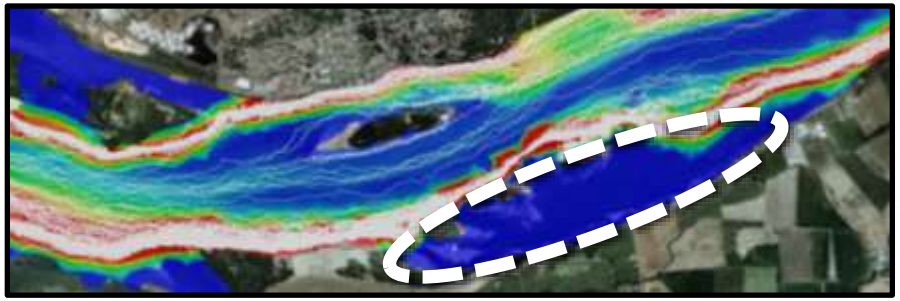
Water Flow Particles



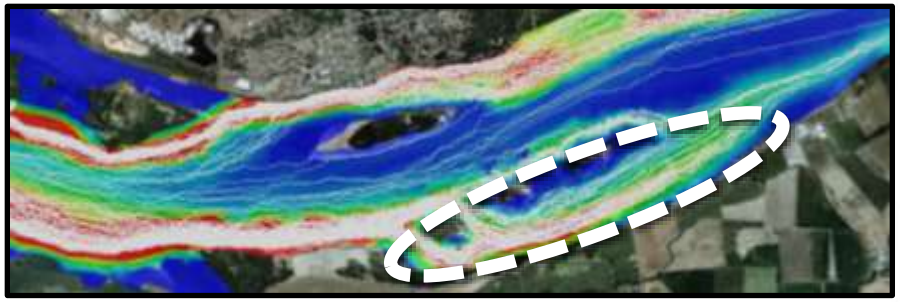


Species Movement Forecast

w/out engineered modification



w/engineered modification

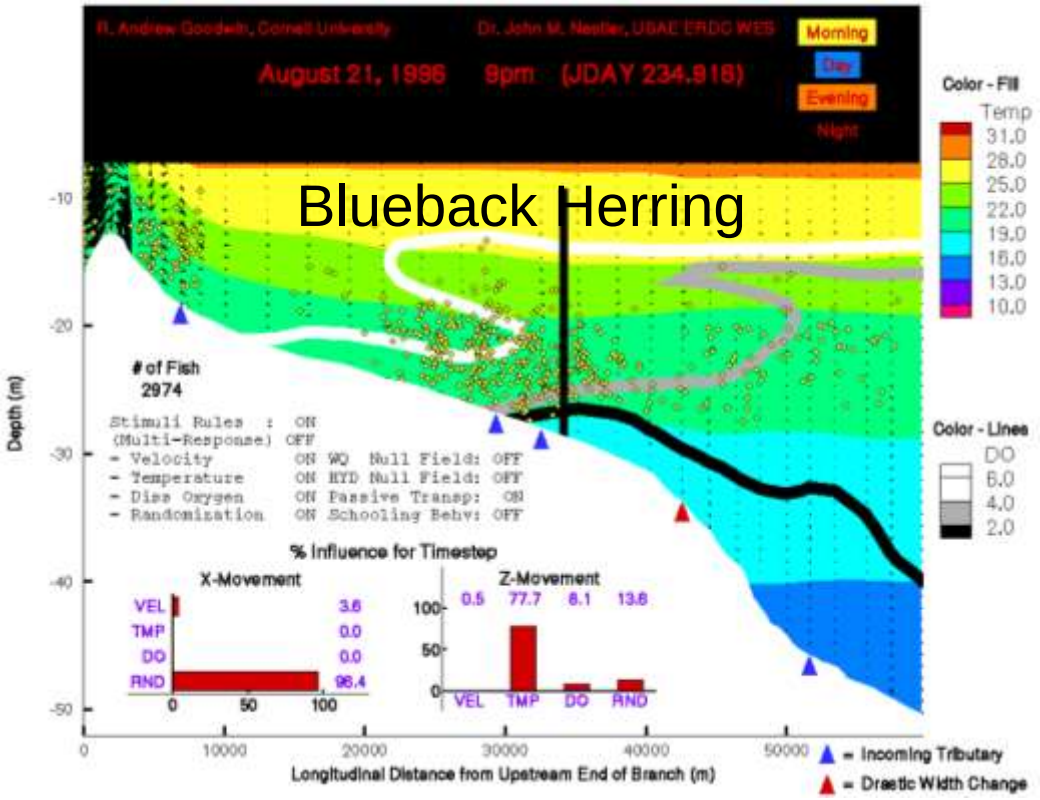


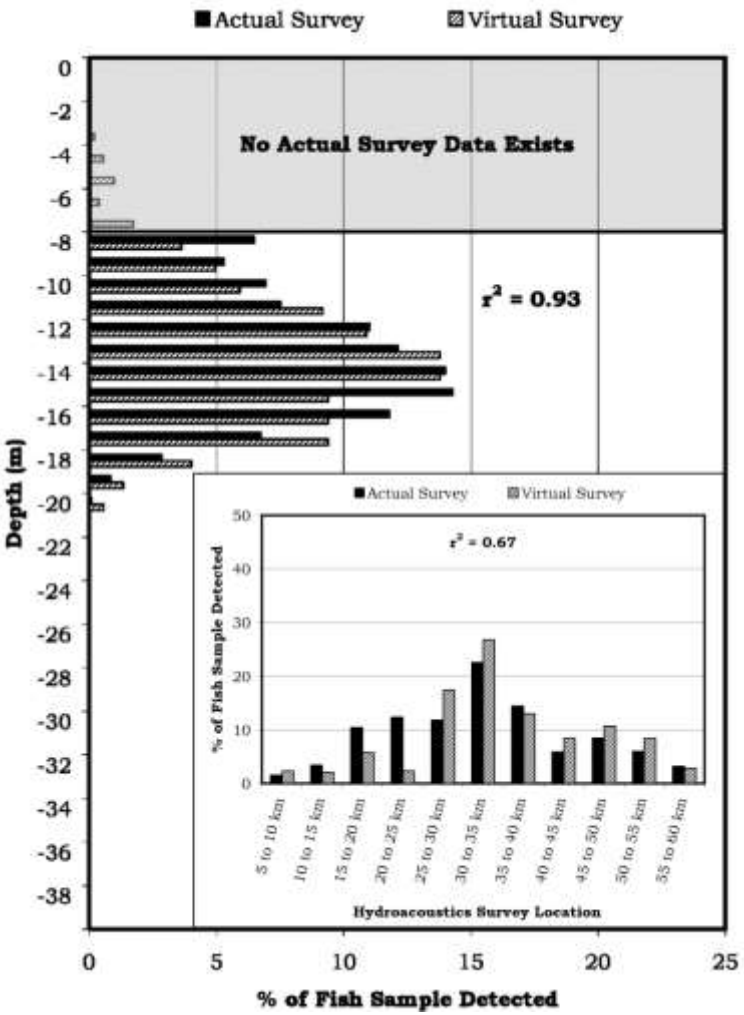
Habitat Selection / Species Distribution

~25 years ago

- Temperature
- Dissolved oxygen
- 2-D hydrodynamics

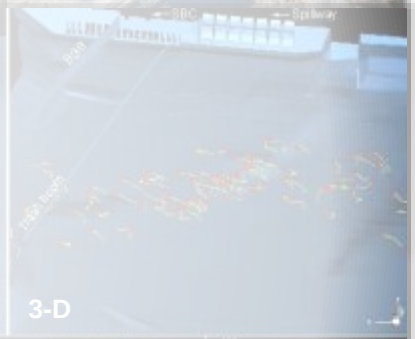
CE-QUAL-W2





25 Years: Out-of-Sample Fish 3-D Movement Prediction

Hydraulic + Individual- (Agent-) based Modeling w/cognition for engineering design (Years 2003-10)



Year 2000

SIMULATING MO
AQUATIC ECOSY

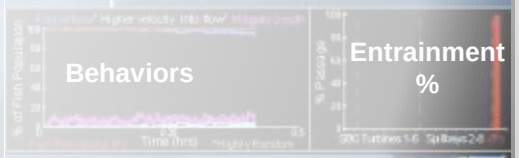
PNAS Proceedings of the National Academy of Sciences of the United States of America

Year 2014

Fish navigation of large dams emerges from their modulation of flow field experience

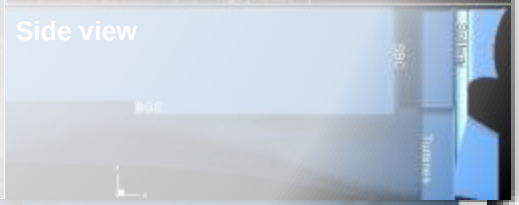
R. Andrew Goodwin[a,1], Marcela Politano[b], Justin W. Garvin[c], John M. Nestler[d], Duncan Hay[e], James J. Anderson[f], Larry J. Weber[b], Eric Dimperio[a], David L. Smith[d], and Mark Timko[g]

view



CGI

Side view



Cornell
Li

Ecological Modelling
Volume 192, Issues 1–2, 15 February 2006, Pages 197–223

Forecasting 3-D fish movement behavior using a Eulerian–Lagrangian–agent method (ELAM)

R. Andrew Goodwin, John M. Nestler, James J. Anderson, Larry J. Weber, Daniel P. Loucks

Year 2004

Tidal Sacramento River at Georgiana Slough

Tidal Sacramento River at Georgiana Slough

Year 2023 (in press)

frontiers in Ecology and Evolution

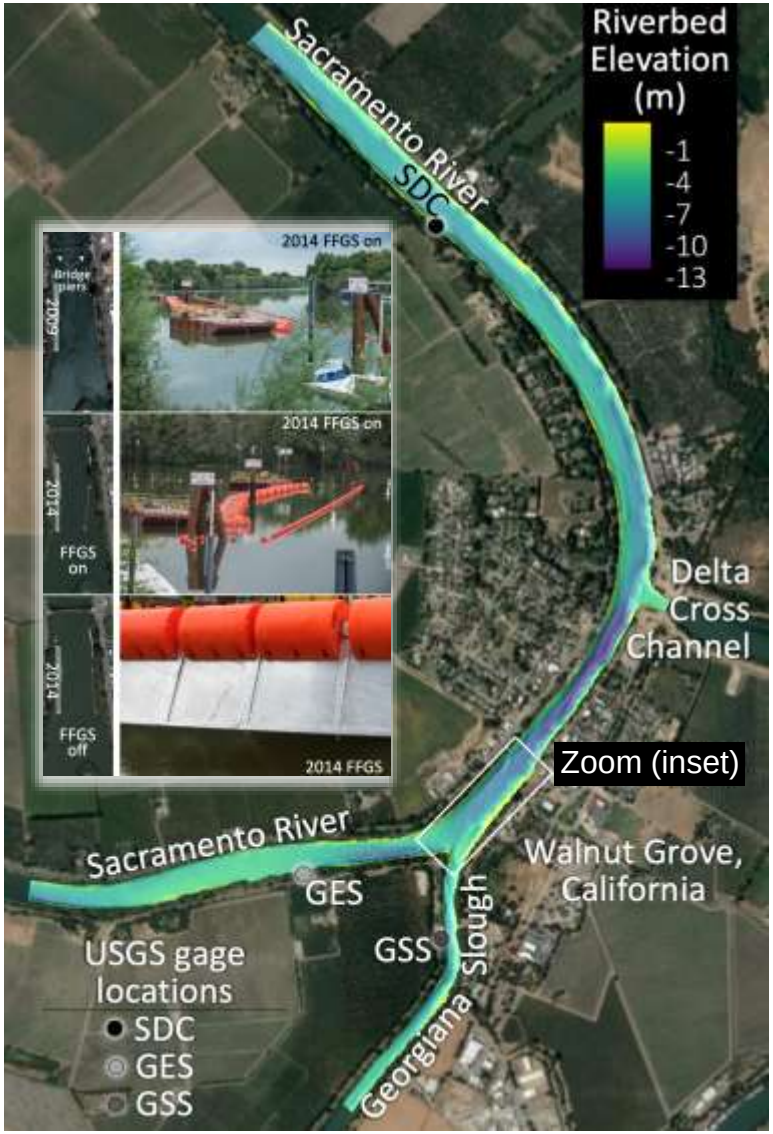
Research Topic
Cognitive Movement Ecology

Behavioral and Evolutionary Ecology

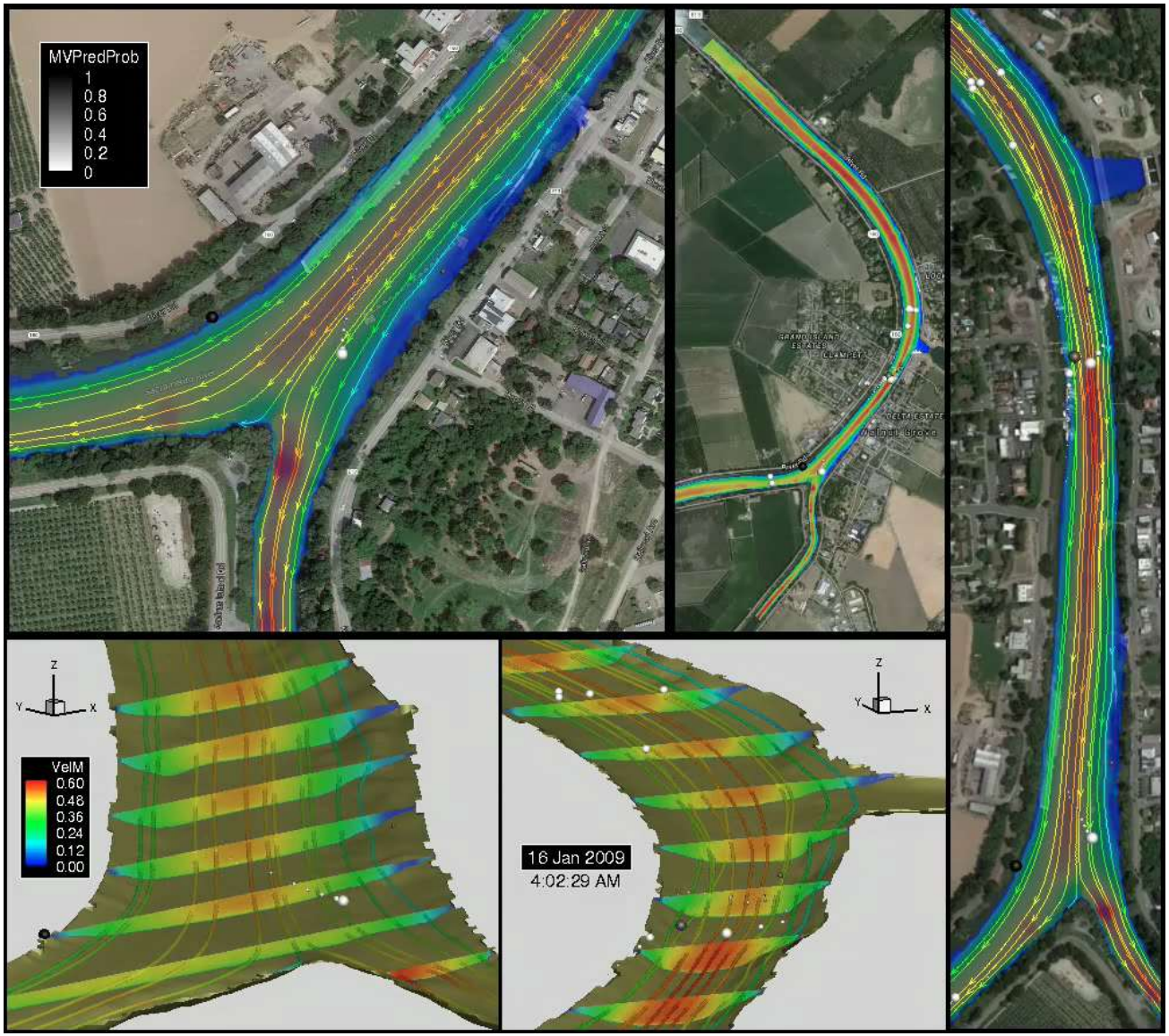
Predicting near-term, out-of-sample fish passage, guidance, and movement across diverse river environments by cognitively relating momentary behavioral decisions to multiscale memories of past hydrodynamic experiences

R. Andrew Goodwin[1,*], Yong G. Lai[2], David E. Taflin[3], David L. Smith[4], Jacob McQuirk[5], Robert Trang[5], and Ryan Reeves[5]

- Updated cognitive-based algorithms for predicting fish movement, guidance, and entrainment
- Simplest formulation of many evaluated
- Behaviors emerge from animal's recent past experience (environmental context)
- Selective tidal stream transport a superset of the behaviors at large hydropower dams – potential for unified prediction model



Tidal Sacramento River at Georgiana Slough

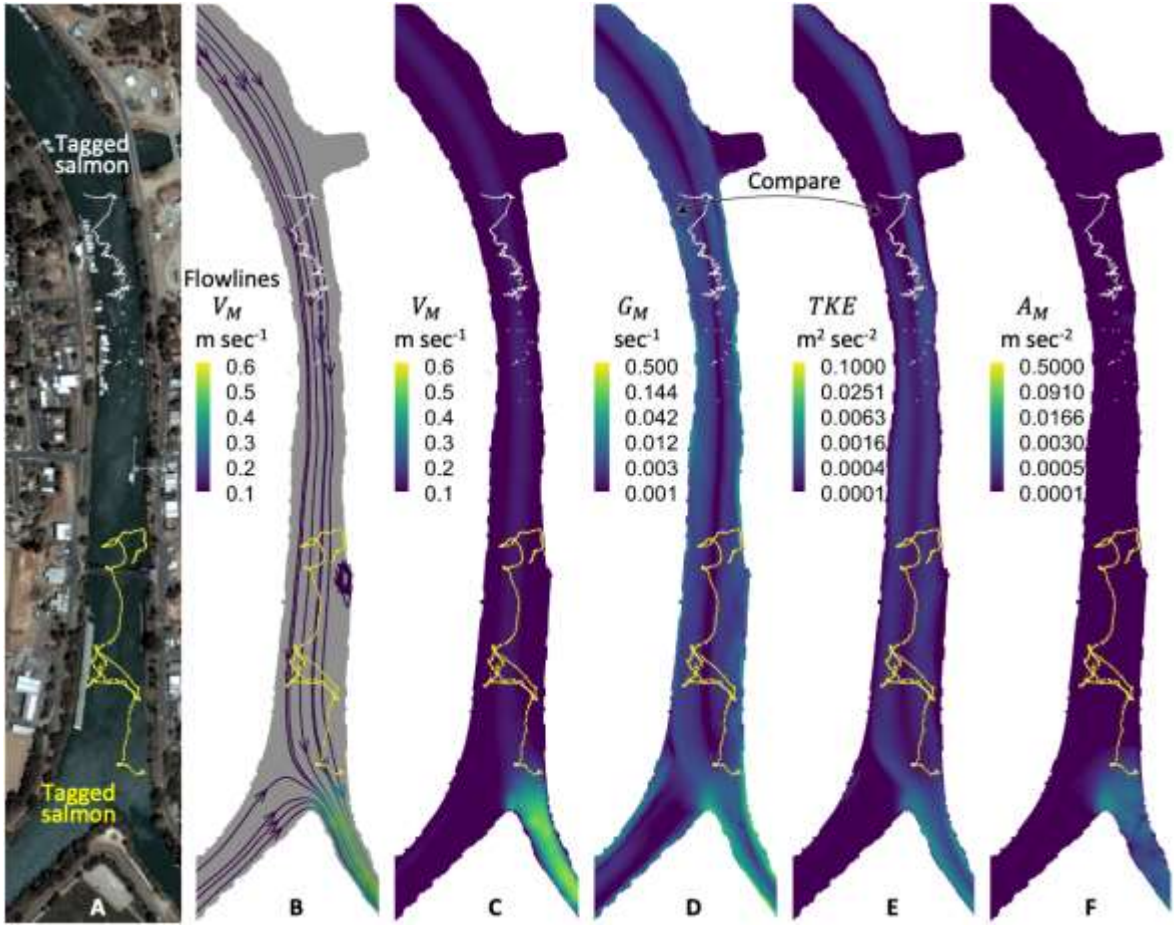


U2RANS CFD – Yong Lai, USBR // Acoustic-tag Telemetry – USGS

Fish Behavior is Complex – Different Movement Modes

Heatmaps of tagged salmon movement modes observed during simulation windows

Hydrodynamic Behavioral Stimuli

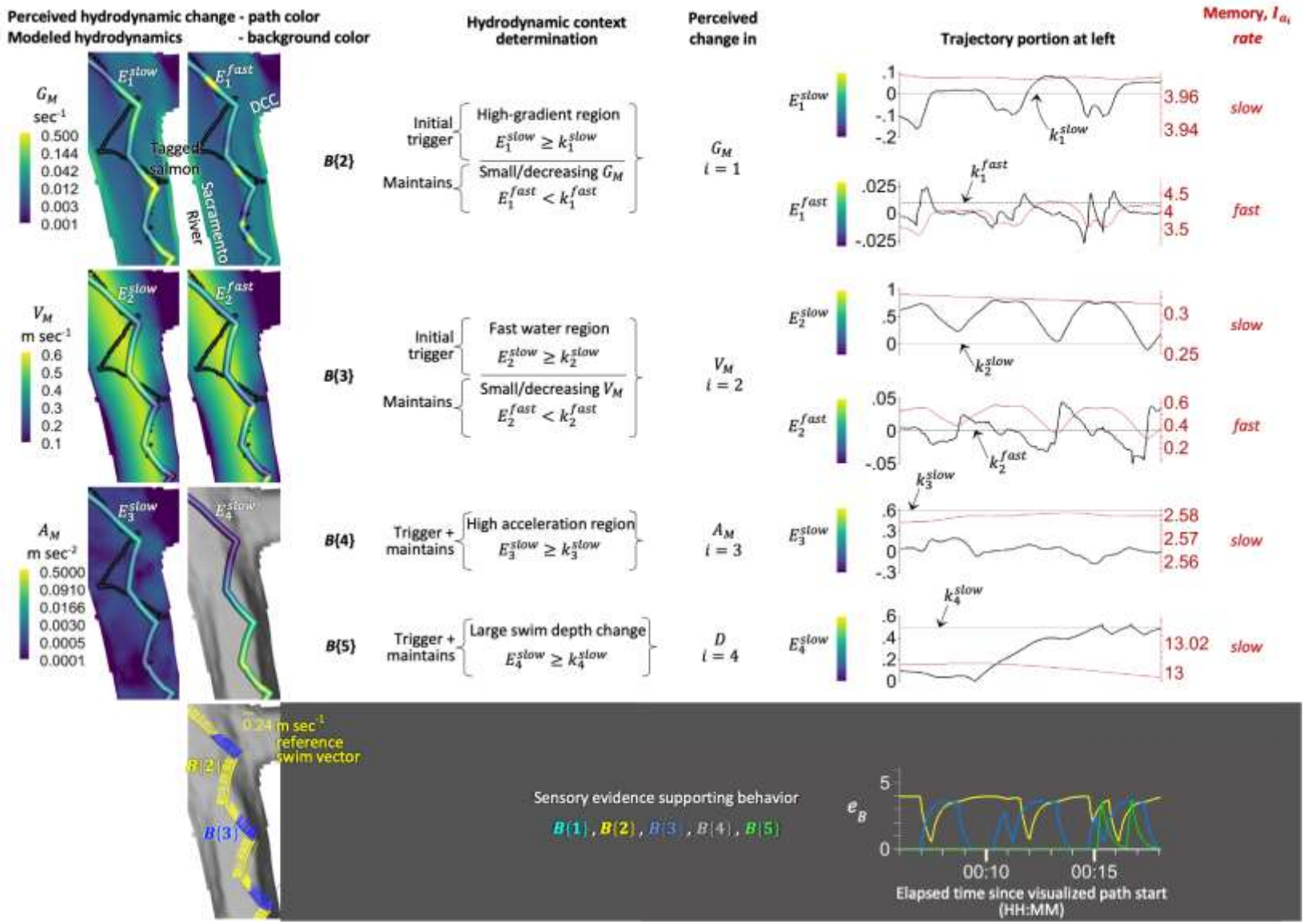


Engineering design relevance	Orientation Alignment Attraction Repulsion Modulation	Trigger Accumulated sensory evidence, e_g, indicates
Guide salmon with bulk water flow	**Flowline alignment** swim with flow	Absence of other triggers
Guide salmon away from bulk water flow	**Velocity (V_M) attraction** swim toward fastest water	Small or decreasing perceived change in spatial gradient of water speed G_M ($\downarrow E_1^{fast}$) in large G_M ($\uparrow E_1^{slow}$)
	Gradient (G_M) attraction swim toward largest spatial gradient in water speed	Small or decreasing perceived change in water speed V_M ($\downarrow E_2^{fast}$) in fast water ($\uparrow E_2^{slow}$)
Repulse salmon	**Acceleration (A_M) repulsion** swim against flowline, away from large A_M	Large perceived change in water acceleration/deceleration A_M ($\uparrow E_3^{slow}$)
In deep environments Guide salmon away from bulk water flow	**Pressure (depth, D) modulation** swim toward habituated/acclimatized depth	Large perceived change in swim bladder pressure or depth D ($\uparrow E_4^{slow}$)

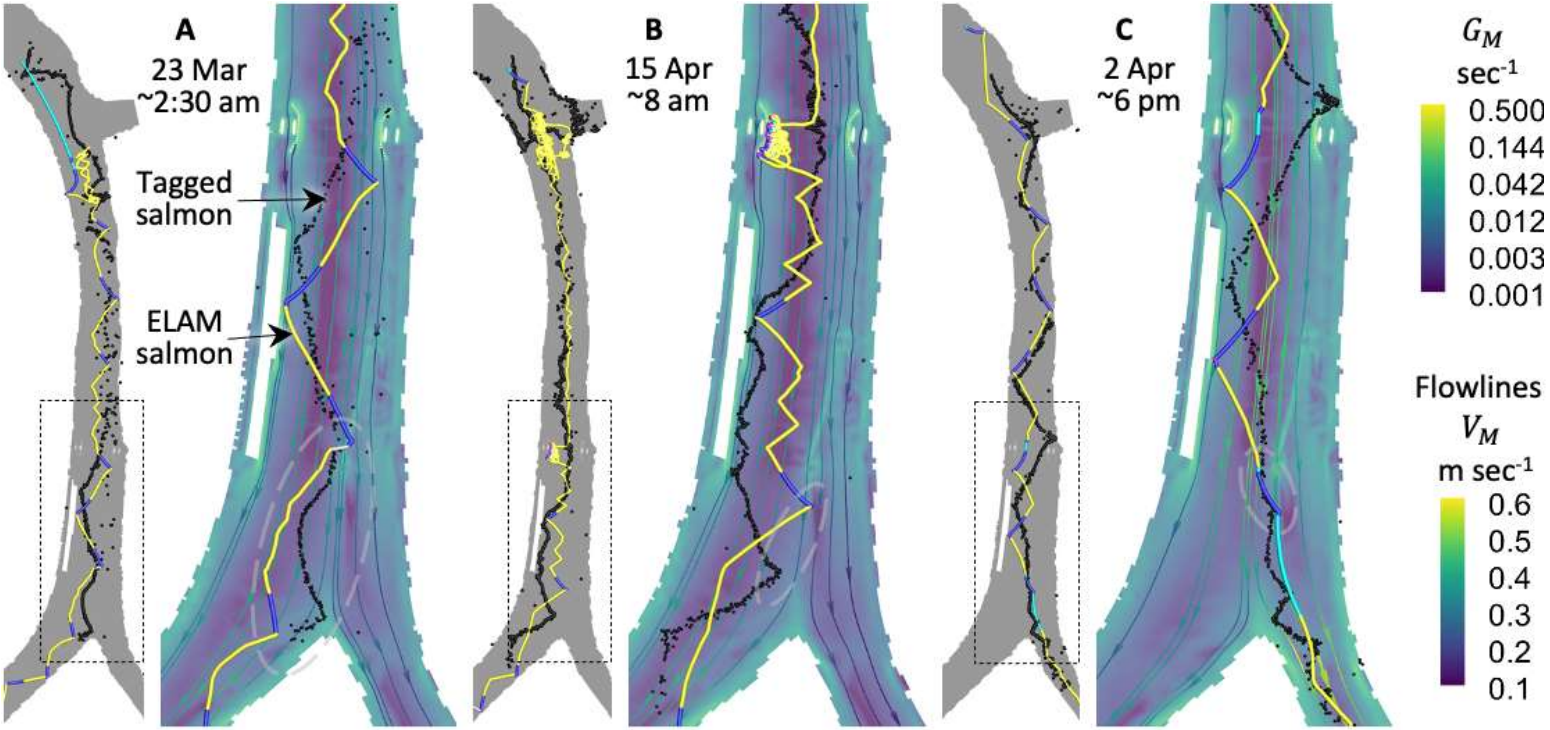
N/A = not applicable.

$\downarrow$ = small or decreasing values; $\uparrow$ = large values.

Perceptual Decision-Making (Cognition)

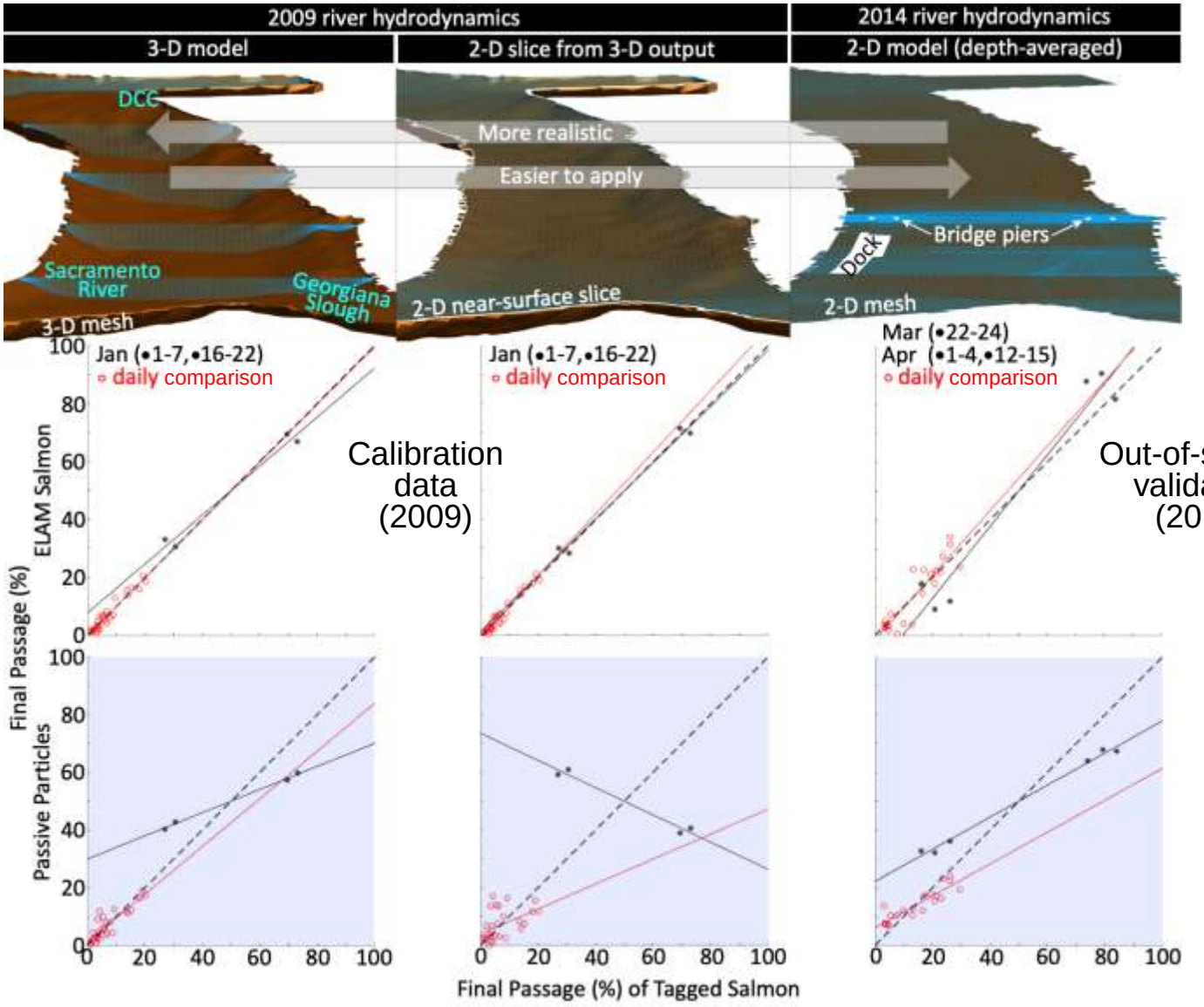


Out-of-Sample Movement Prediction



$B\{1\}$: flowline alignment	$B\{2\}$: velocity (V_M) attraction	$B\{3\}$: gradient (G_M) attraction	$B\{4\}$: acceleration (A_M) repulsion

Predicting Out-of-Sample Guidance/Entrainment



Modeled Fish Behavior "On"

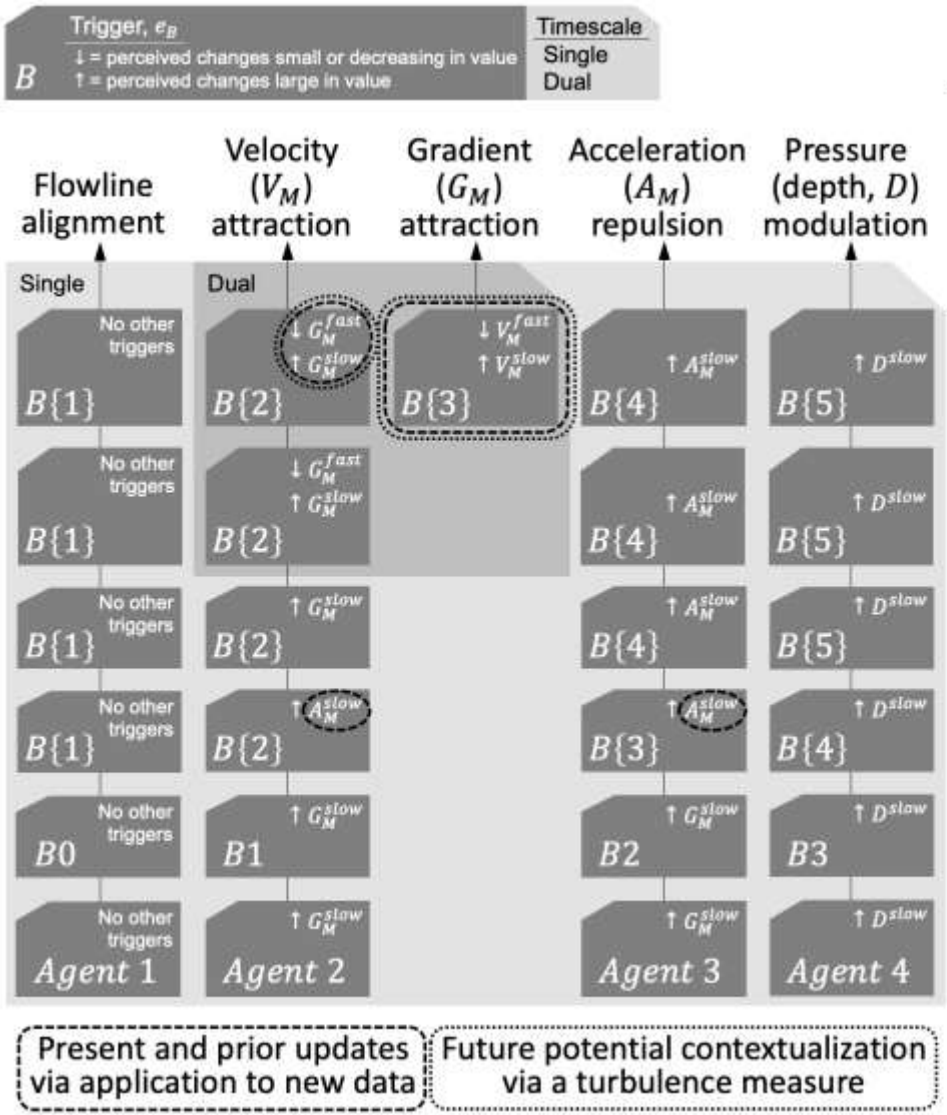
Behavior "Off"

Passive particles

Calibration data (2009)

Out-of-sample validation (2014)

What $65+ Million of Telemetry & CFD is Saying



Behavioral repertoire insight grows with dataset diversity

Tidal river	Hydropower dam
Selective tidal stream transport	Fish passage

25 days Varying flow

Hypothesis to evaluate Varying flow

Hypothesis to evaluate Steady flow

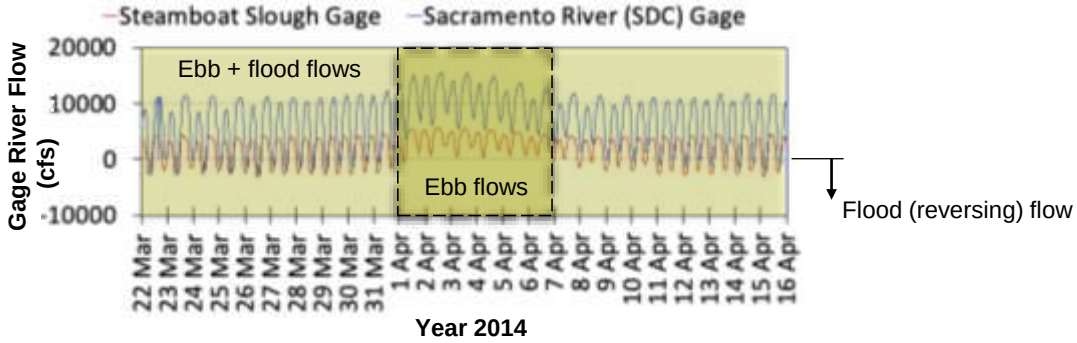
47 data sets[3] Steady flow

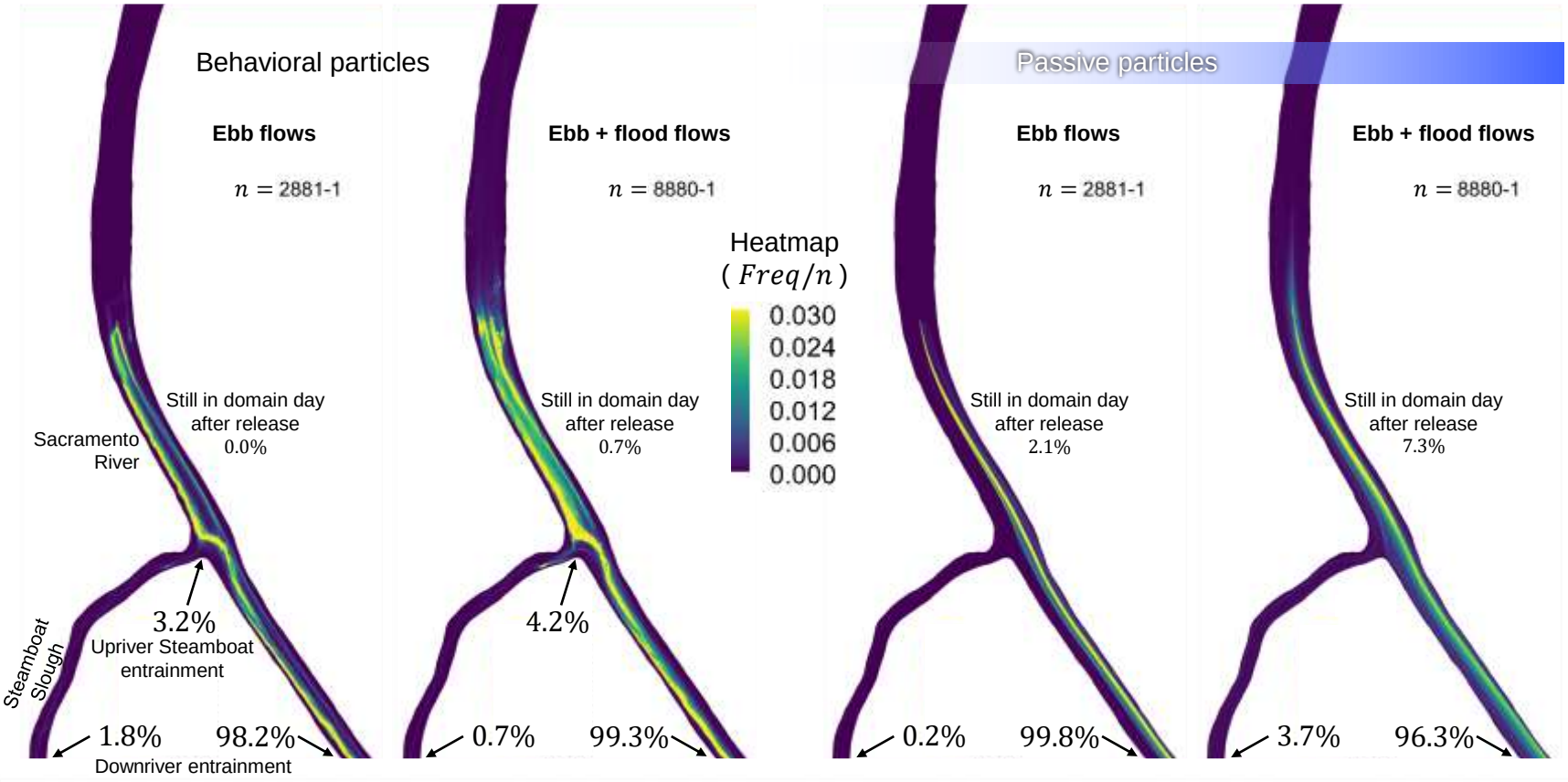
20 data sets[2] Steady flow

11 data sets[1] Steady flow

Predicting Out-of-Sample Guidance/Entrainment

Base case

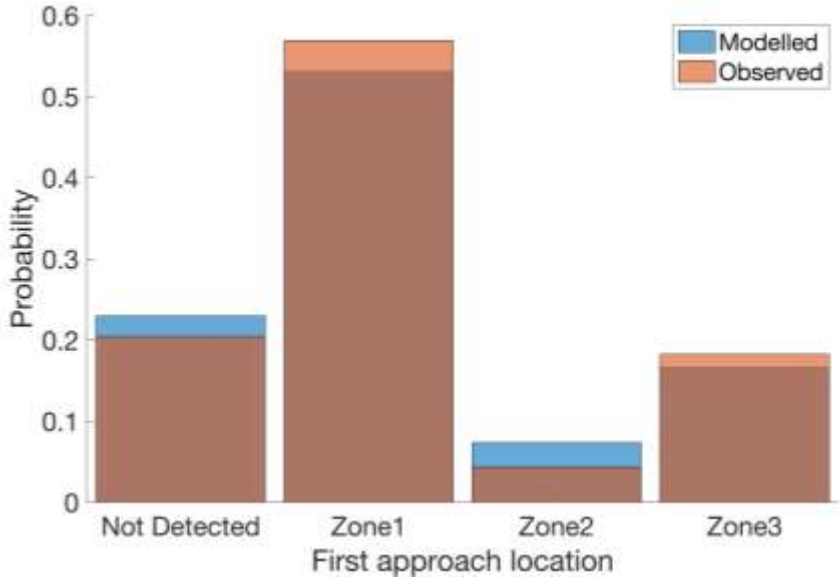


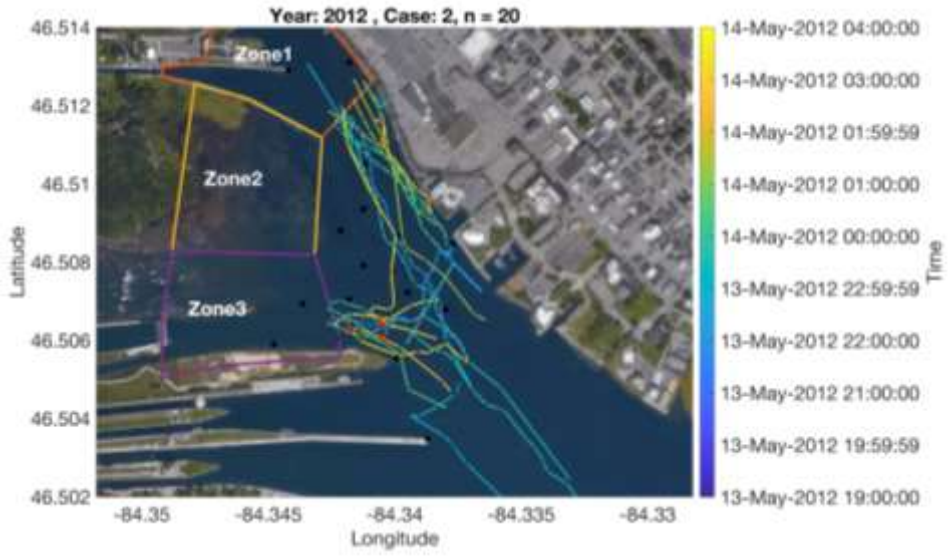


Predicting Upstream-migrating Invasive Lamprey
Laurentian Great Lakes

Fish orientation

- V_M-dependent
- Conditional on lower G_M while experiencing above a certain threshold

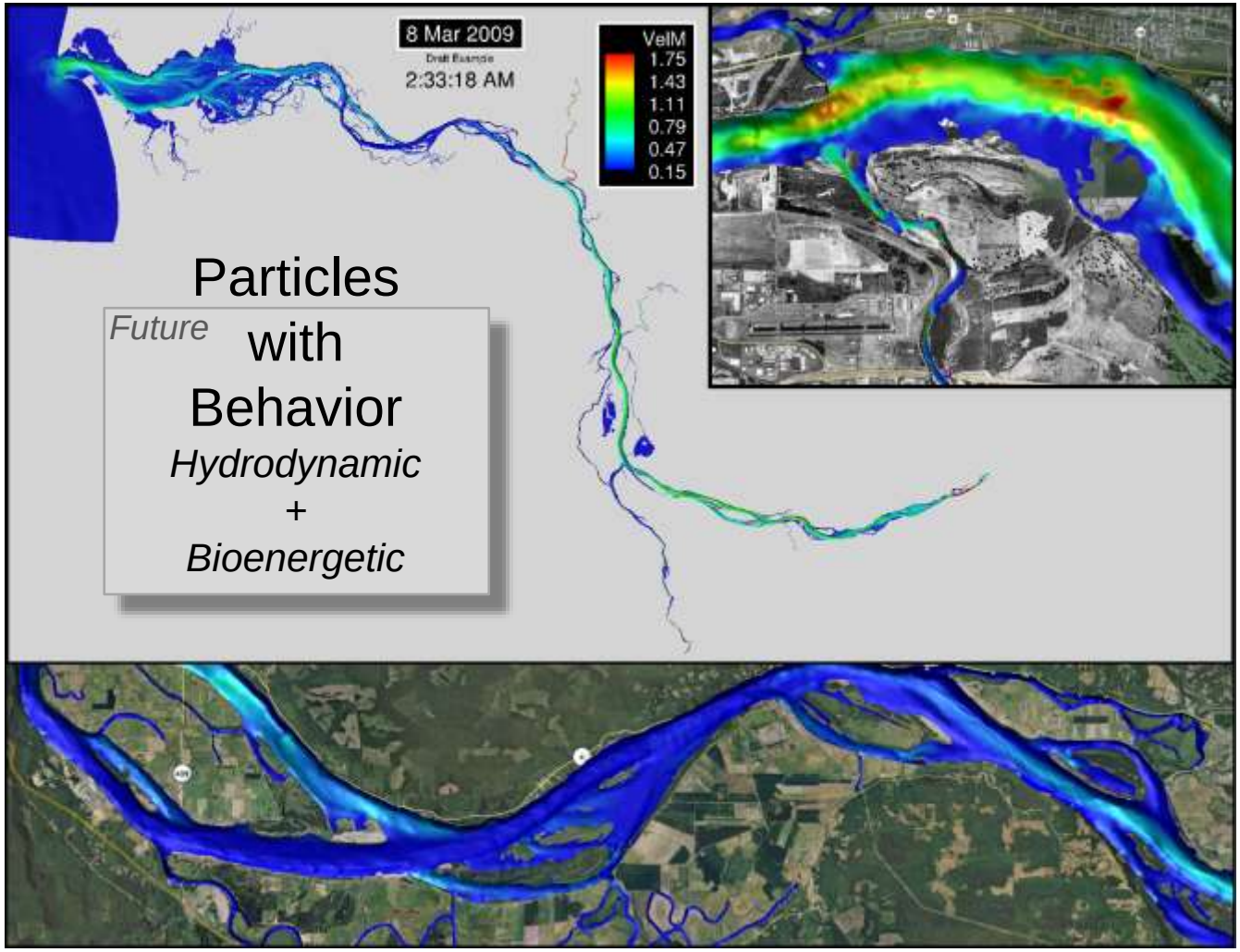




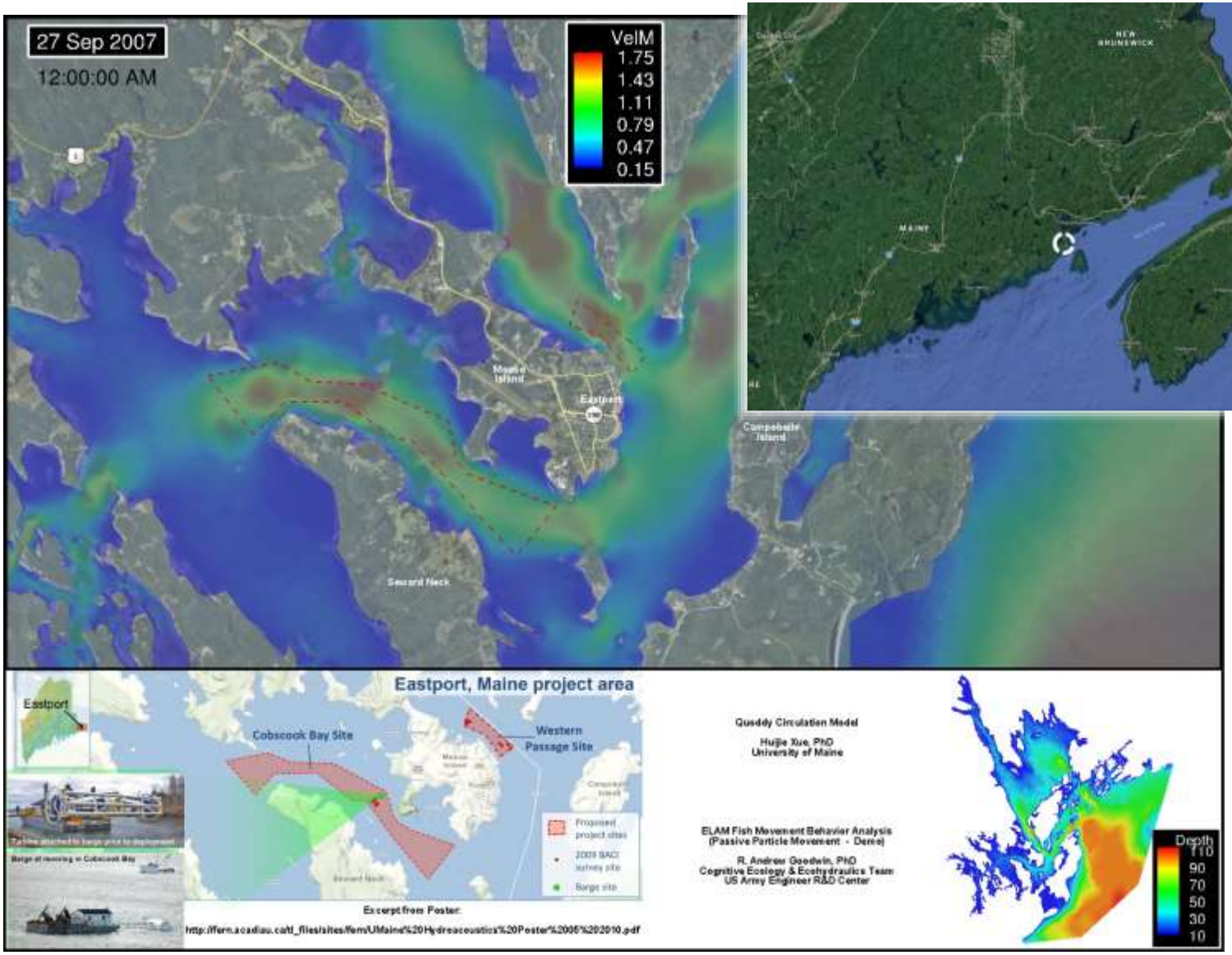
James Kerr
University of Guelph

River / Estuary Restoration

(Project & Reach Scales)



Tidal Estuary Renewable Energy



ELAM Theory-Informed Machine Learning

Real-time Fish Trajectory Prediction

Boardman River, Michigan
Great Lakes Fishery Commission

Bi-directional, selective fish passage