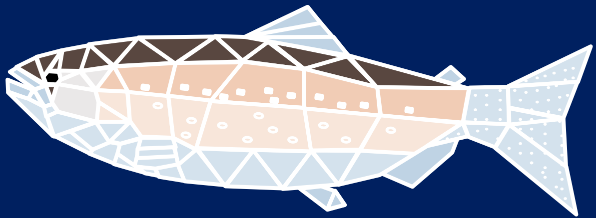
HOW DO HABITAT RESTORATION, FLOW, AND TEMPERATURE AFFECT SALMON AND STEELHEAD POPULATIONS?

CONCLUSIONS FROM AN INDIVIDUAL-BASED MODEL



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Lang Railsback & Associates / Humboldt State University
Arcata California

Why am I here?

- We put many years and dollars into inSALMO

- Many decision processes in California need models that do what inSALMO does
  - River restoration programs
  - Hydropower license applications
  - …

- Don't re-invent the wheel!

inSALMO's purposes

- Model how the number & size of salmon / steelhead smolts varies

inSALMO: Objectives

- Model how the number & size of salmon / steelhead smolts varies with:
  - Flow and temperature regime
  - Physical habitat
    - channel shape
    - spawning gravel distribution
    - cover for feeding, hiding

inSALMO: Objectives

- Model how the number & size of salmon / steelhead smolts varies with:
  - Flow and temperature regime
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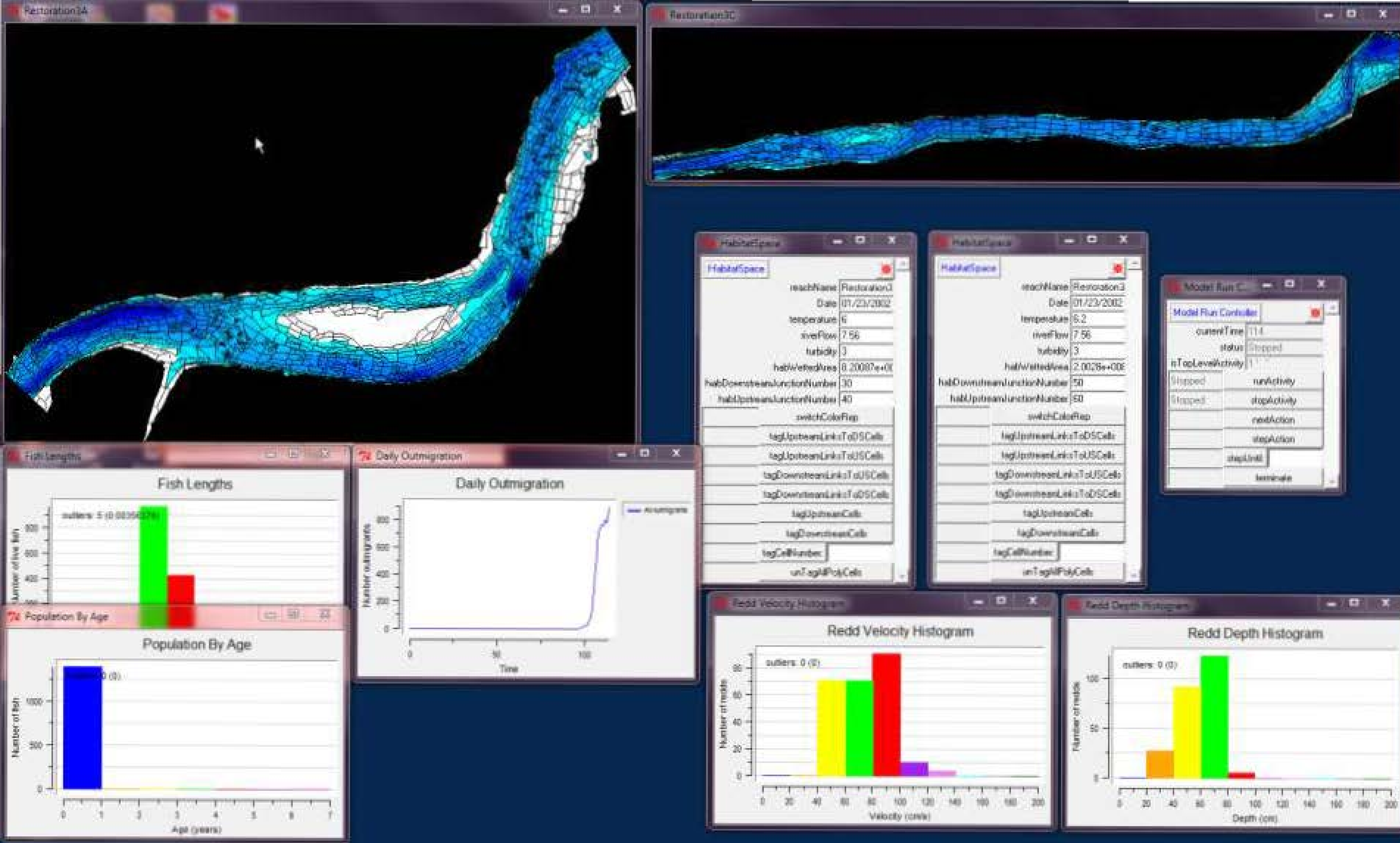
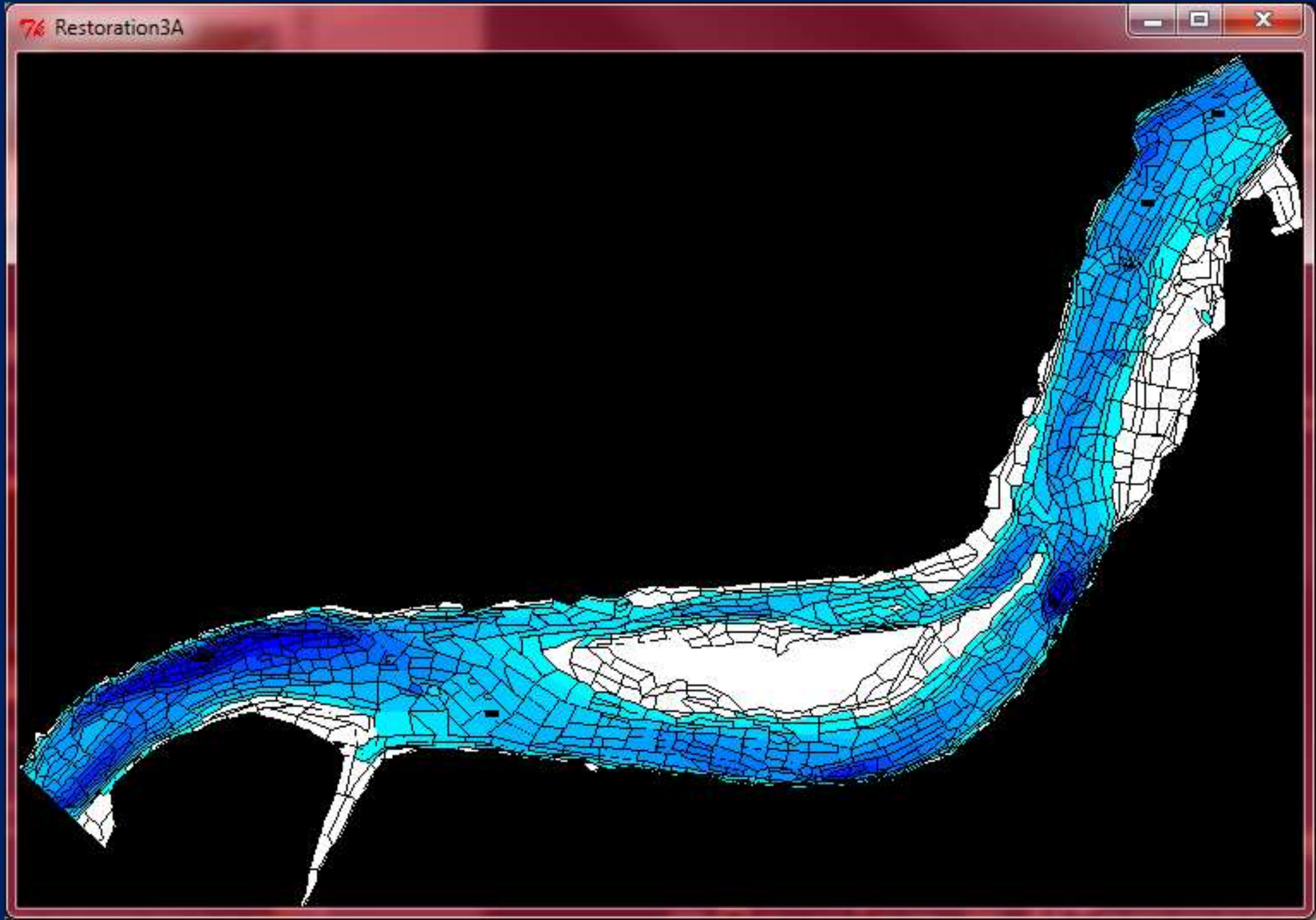
- Considering individual variability and behavior


Restoration3A
Restoration3C
HabitatSpace
reachName
Date
temperature
riverFlow
turbidity
habWettedArea
habDownstreamJunctionNumber
habUpstreamJunctionNumber
switchColorRep
tagUpstreamLinksToDSCells
tagUpstreamLinksToUSCells
tagDownstreamLinksToUSCells
tagDownstreamLinksToDSCells
tagUpstreamCells
tagDownstreamCells
tagCellNumber
unTagAllPolyCells
Model Run Controller
currentTime
status
runActivity
stopActivity
nextAction
stepAction
stepUntil
terminate
Fish Lengths
Daily Outmigration
Time
Population By Age
Number of fish
Age (years)
Redd Velocity Histogram
Velocity (cm/s)
Redd Depth Histogram
Depth (cm)

Habitat

- Each reach reads in daily flow, temperature, turbidity
- Cells update their depth, velocity, food availability from flow



Spawners and redds

- Spawners
  - Create redds in suitable cells
  - Defend redds
- Redds
  - Survive: superimposition, temperature, scour, dewatering
  - Develop = f(Temperature)
  - Hatch into new juveniles

Juveniles

- Select habitat (including downstream migration)
  - *the key adaptive behavior*

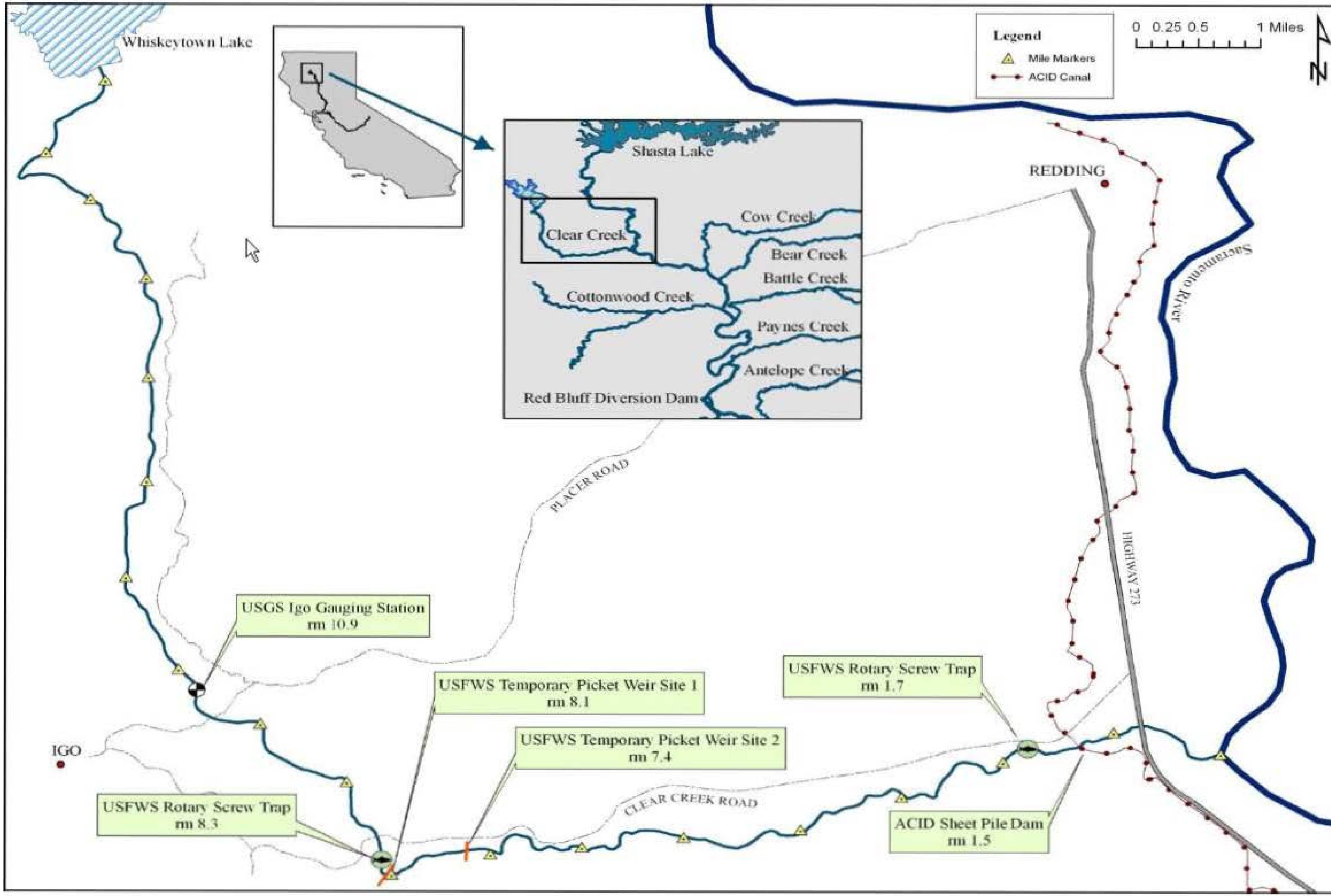
- Survive:
  - predation by fish
  - predation by birds etc.
  - starvation/disease
  - temperature ...

inSALMO and inSTREAM have many measures of credibility

- 15 years of development and use
- Rigorously tested and usable software
- Thorough documentation
- Applications at ~40 sites
- ~13 journal articles
- Validation at individual and population levels
- Funding from ~8 federal and power industry agencies
- Free, open-source, etc.

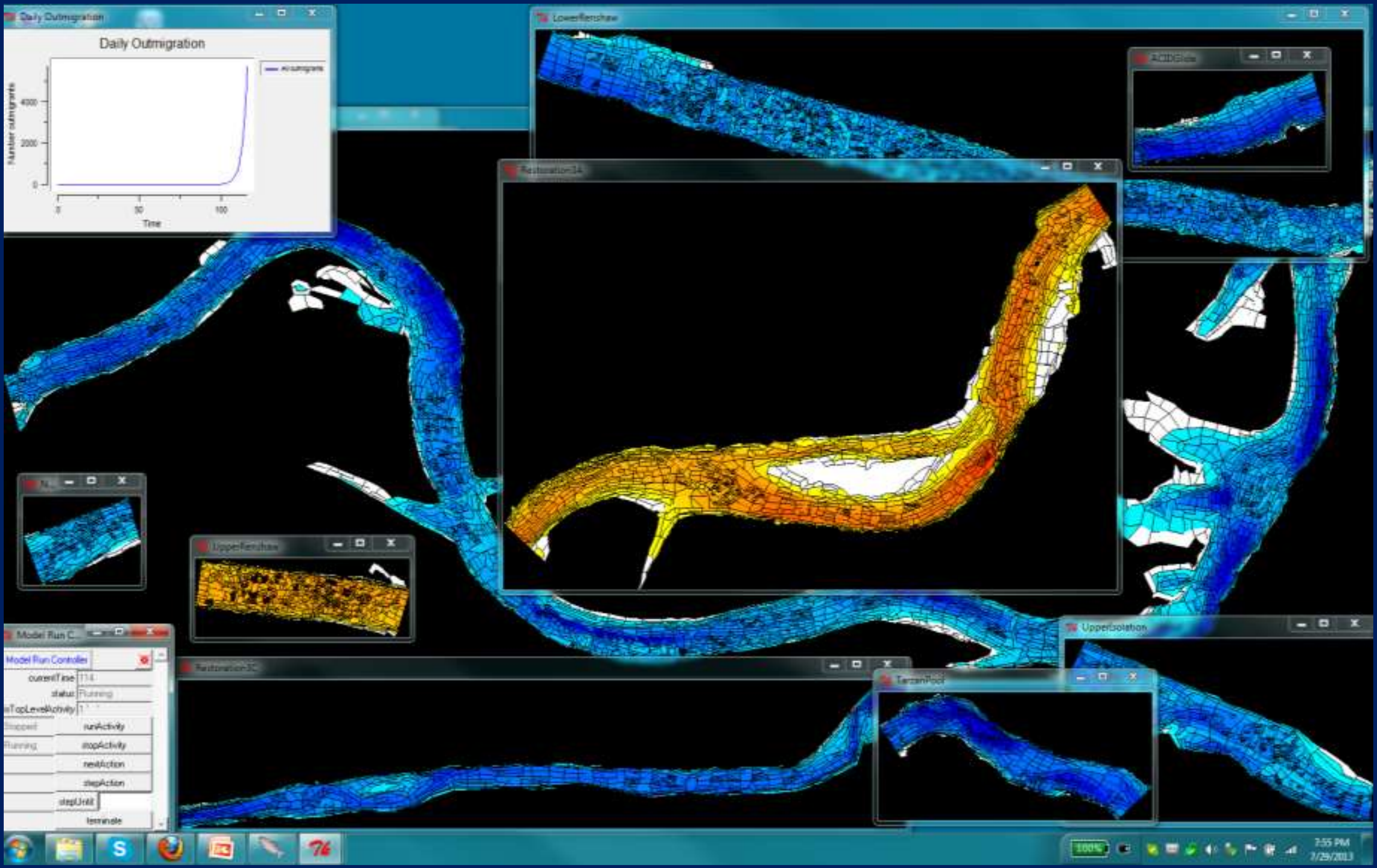
Clear Creek applications: 2010-13

- Develop inSALMO for fall Chinook and steelhead
- Develop input from 17 PHABSIM sites
- Test model results vs. extensive field data
- Simulate and rank management alternatives



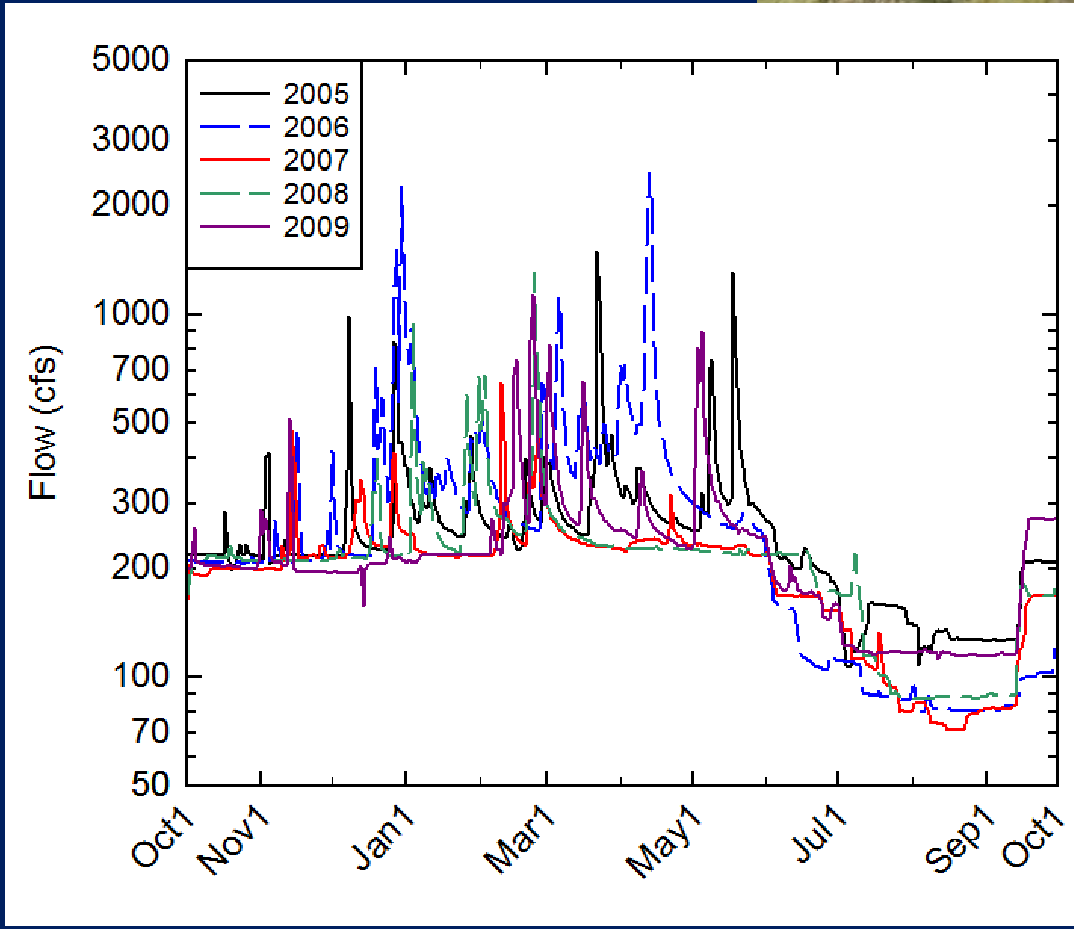
Earley et al. 2011. Juvenile salmonid monitoring in Clear Creek, California, from October 2009 through September 2010. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office.

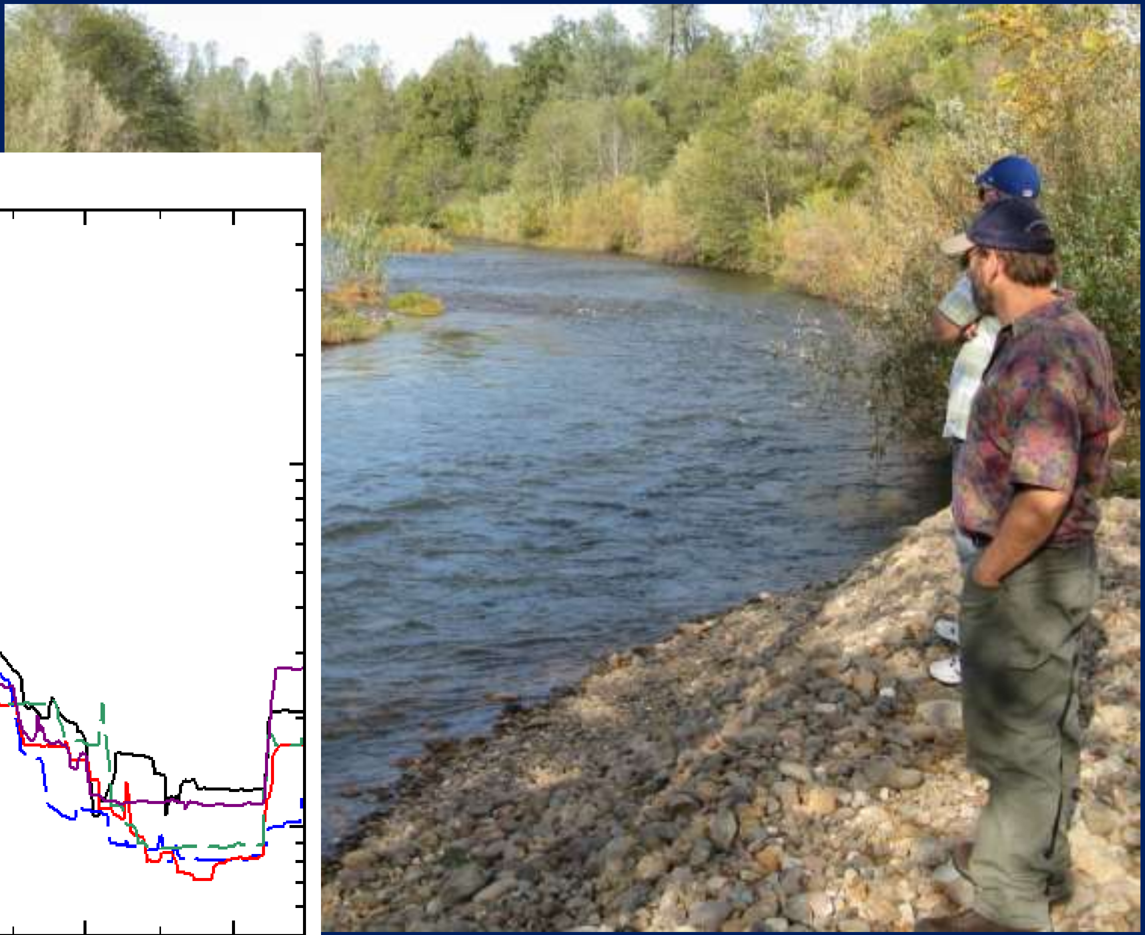
Clear Creek



Daily Outmigration
Time
LowerRenshaw
UpperRenshaw
UpperIsolation
TarzanPool
Model Run Controller
currentTime
status
runActivity
stopActivity
nextAction
stepAction
stepUntil
terminate

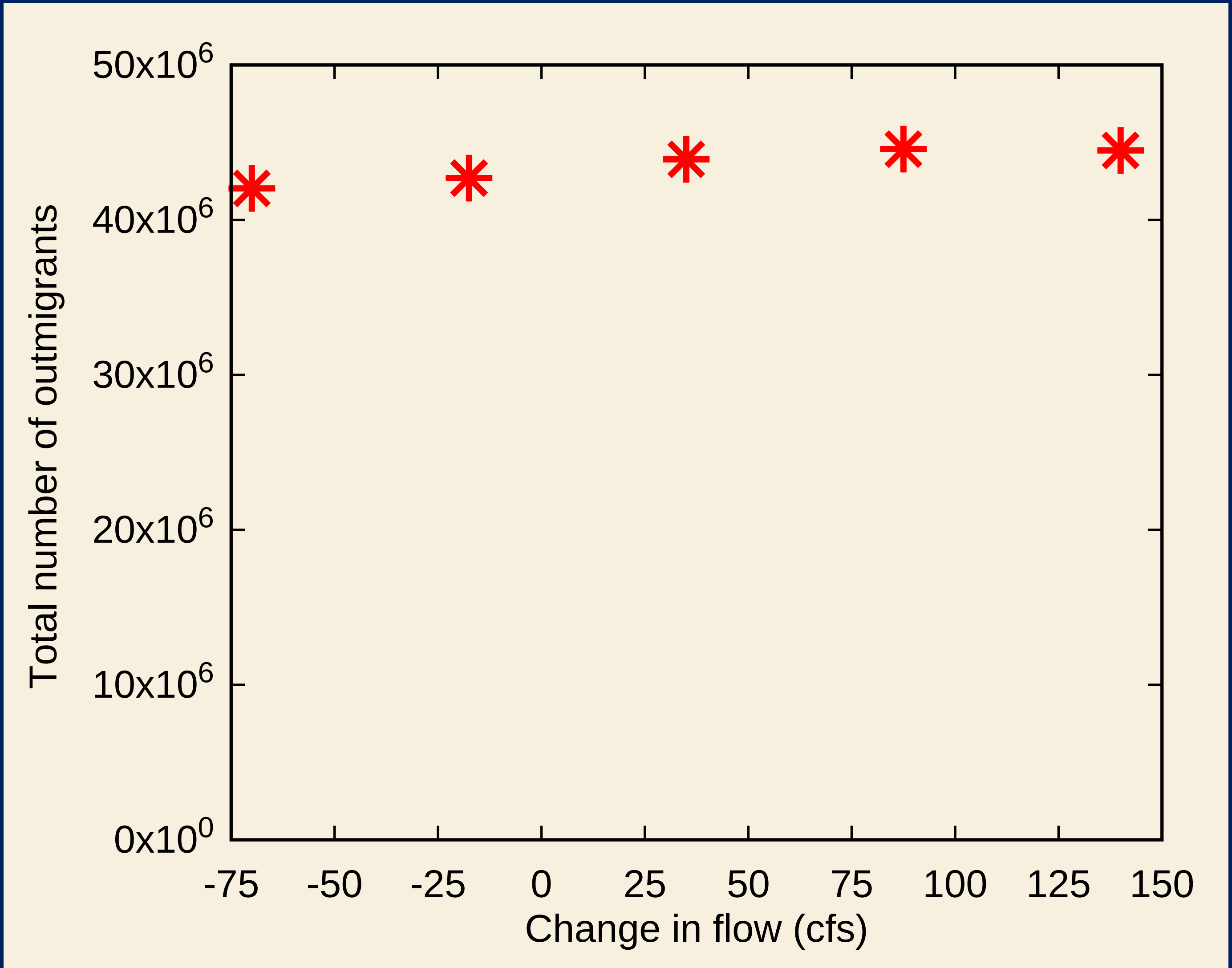
Example analysis: Response of Chinook spawning success to instream flow



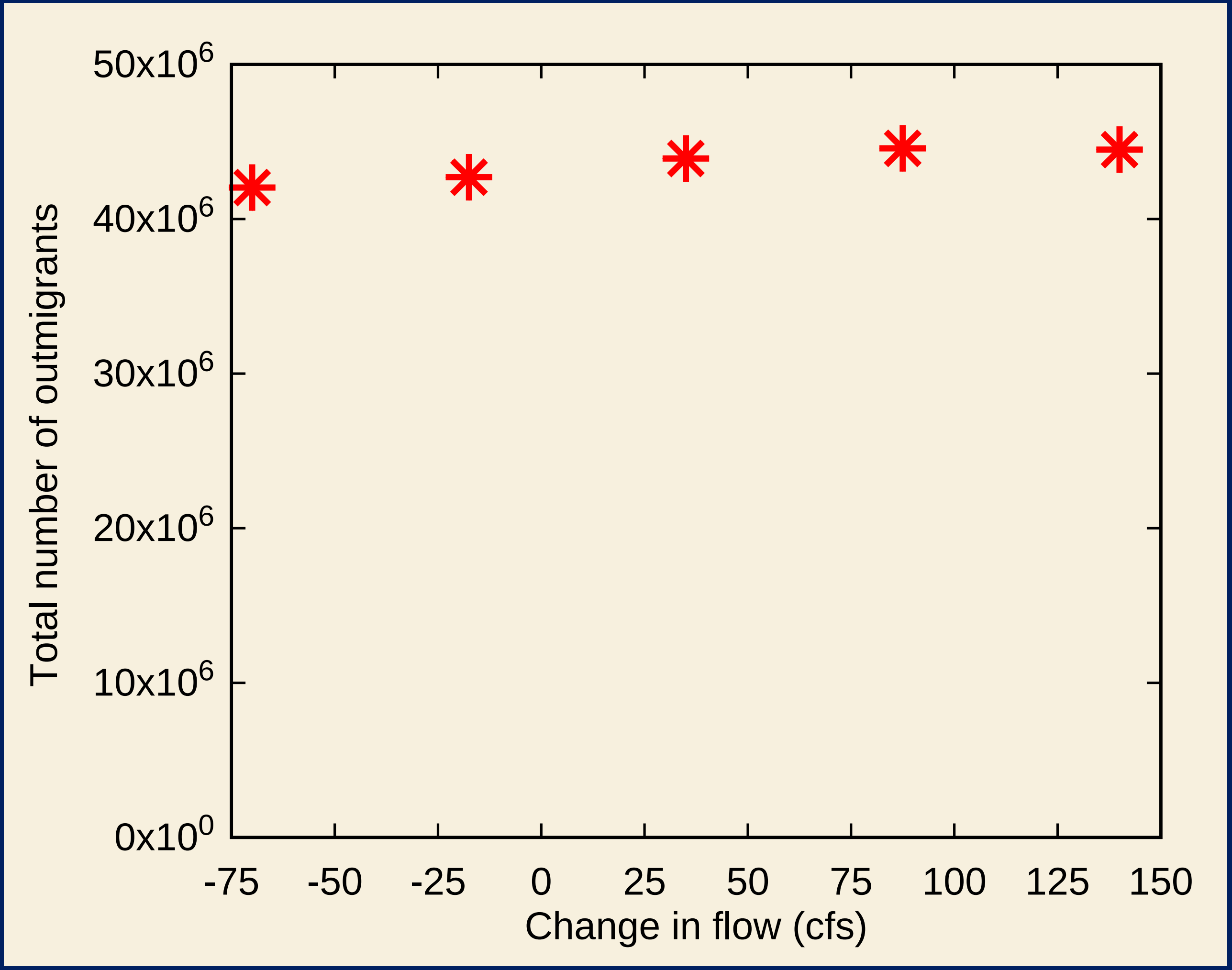


Vary the dam's flow release

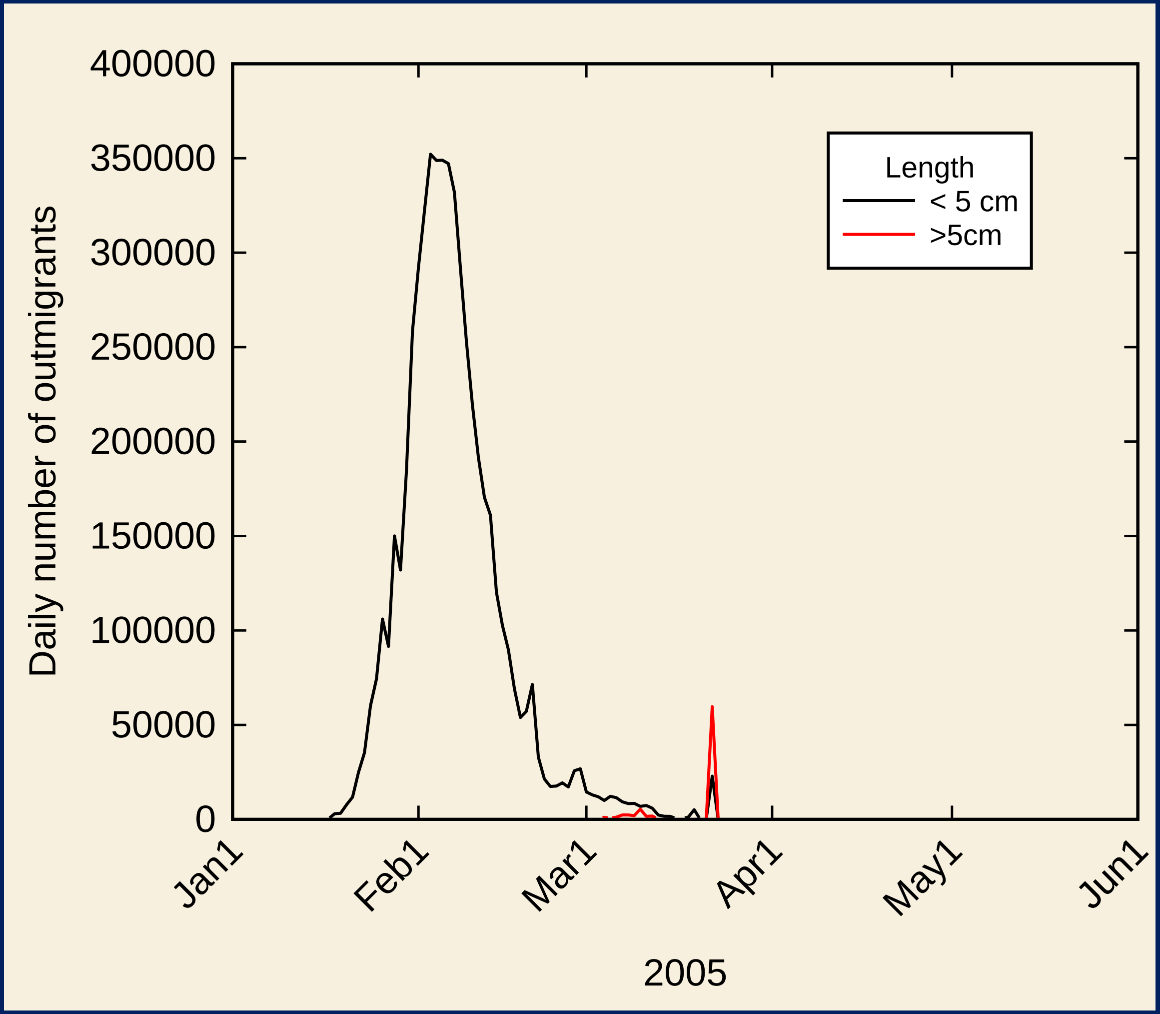
Flow experiment results: Total number of outmigrants



Why does inSALMO predict so little effect of flow on spawning success?

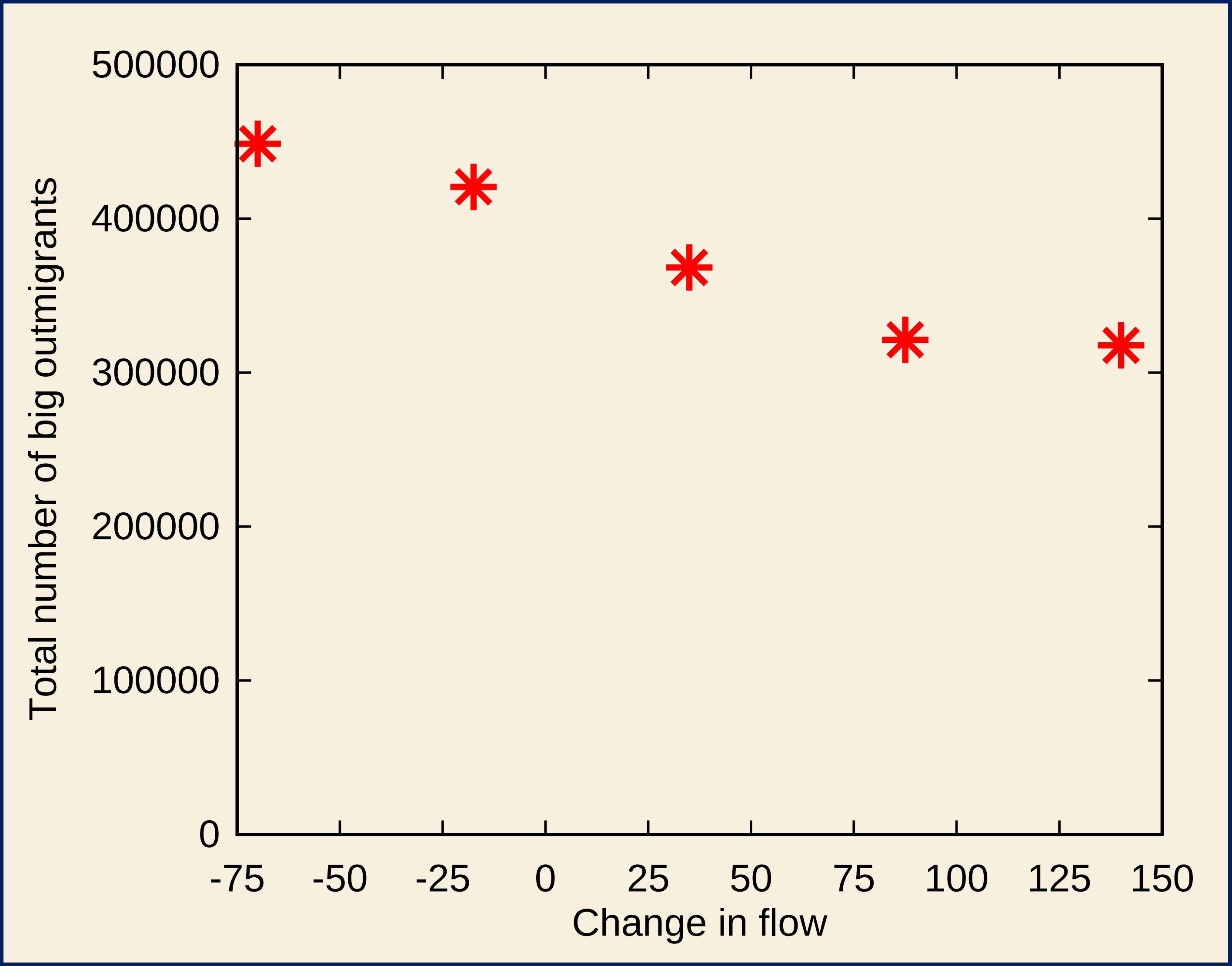


Because the vast majority of fry migrate out immediately after hatching

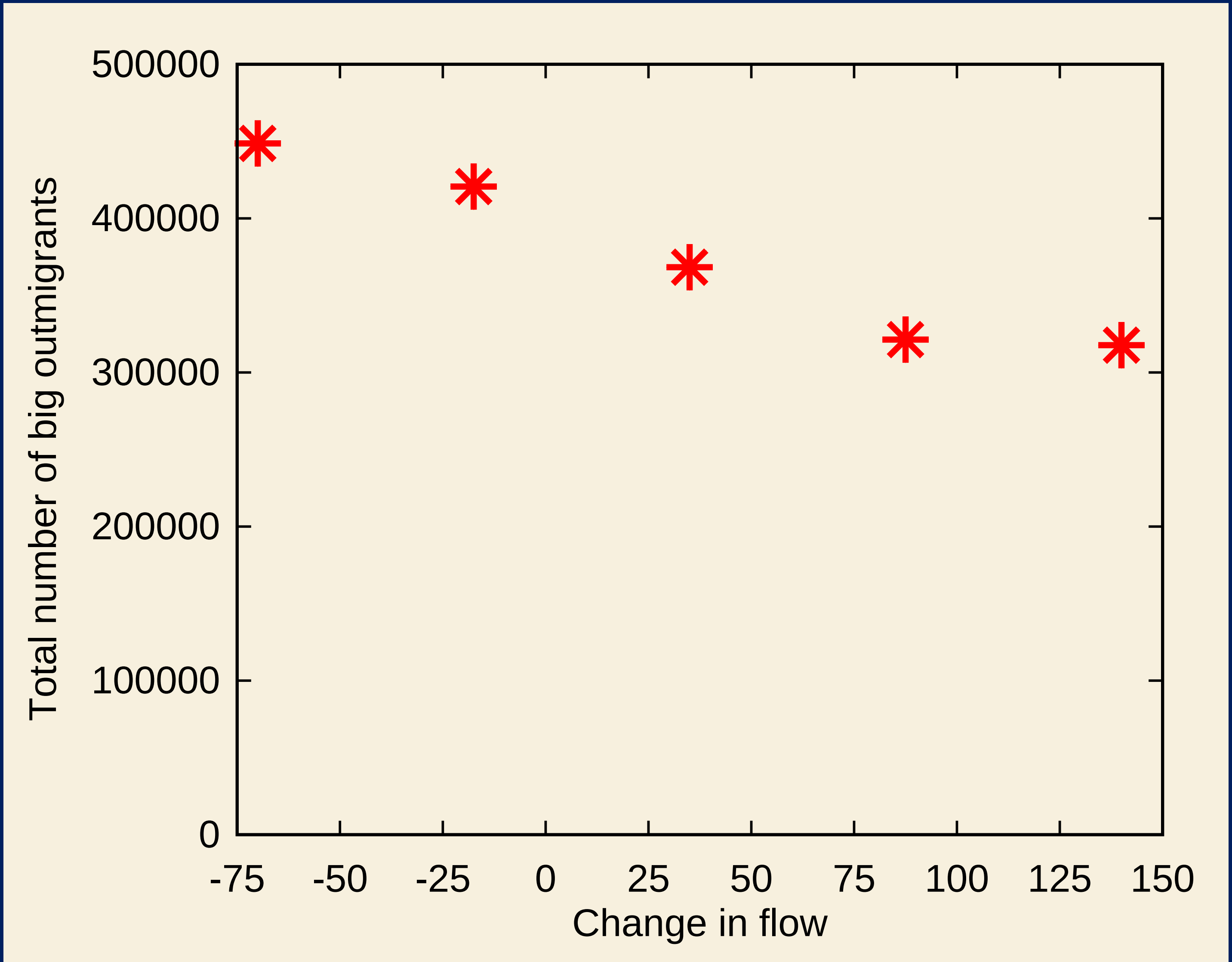


What about the fry that do stay and rear?

Response of >5 cm outmigrants to flow



Why does number of large outmigrants decrease with flow?



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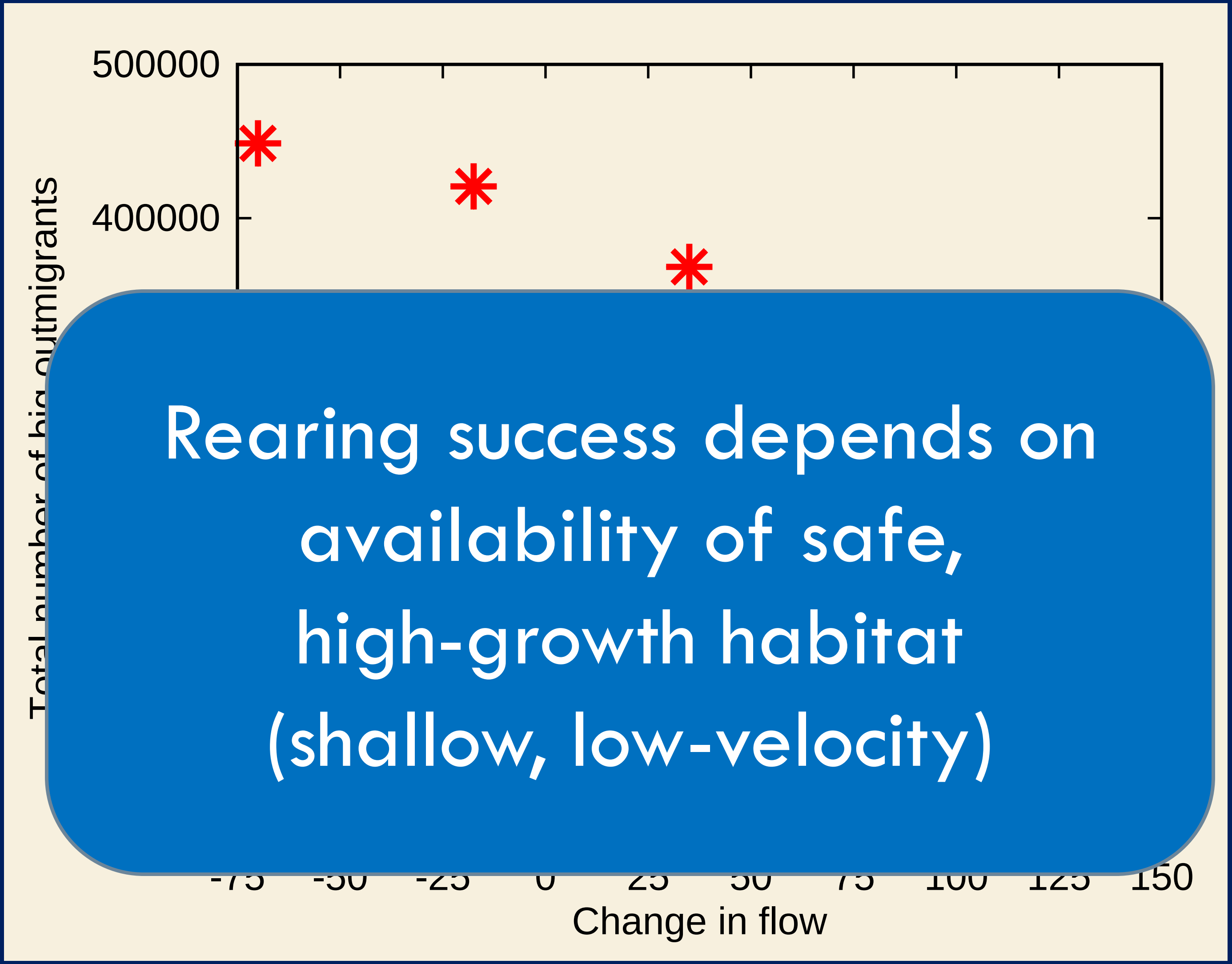


Rearing success depends on availability of safe, high-growth habitat (shallow, low-velocity)

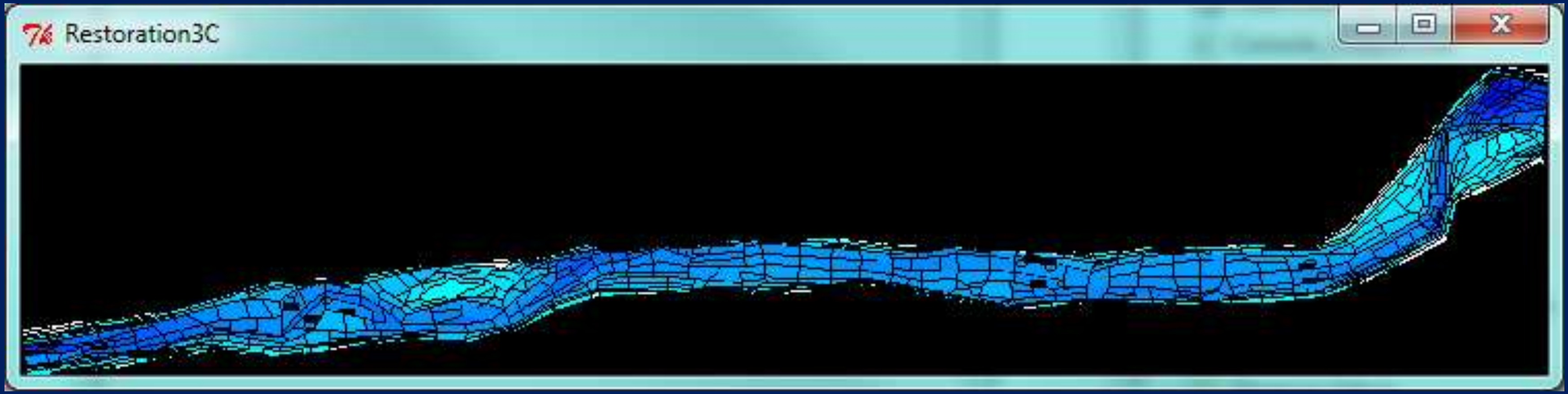
Example application: Would additional habitat restoration be worthwhile?

- Should USFWS invest in re-building *one* of the 12 sites in the lower alluvial segment of Clear Creek?

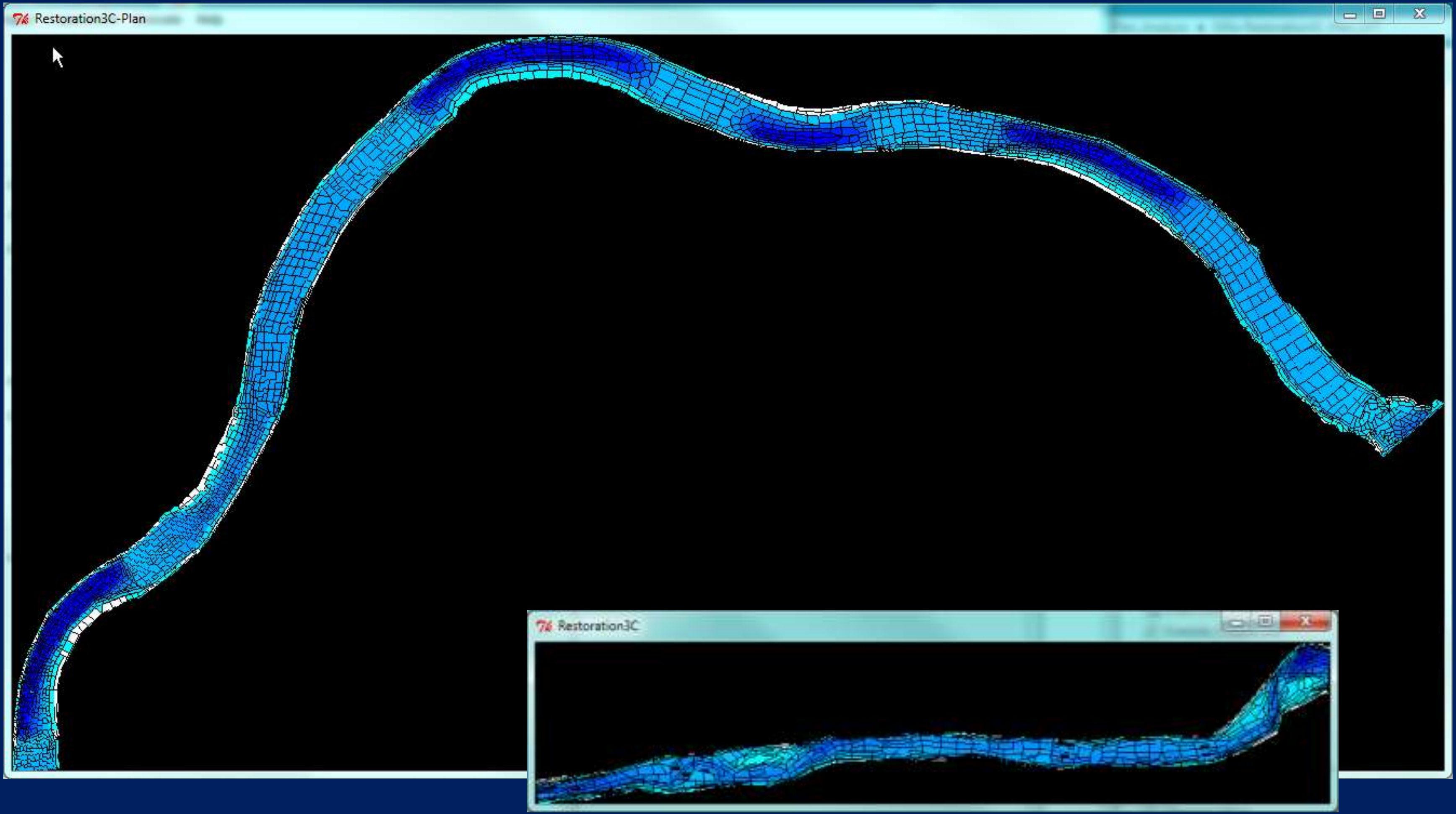
Existing site 3C: incised "ditch" relic of gravel mining

- Modeled from field measurements

  (shaded by depth)

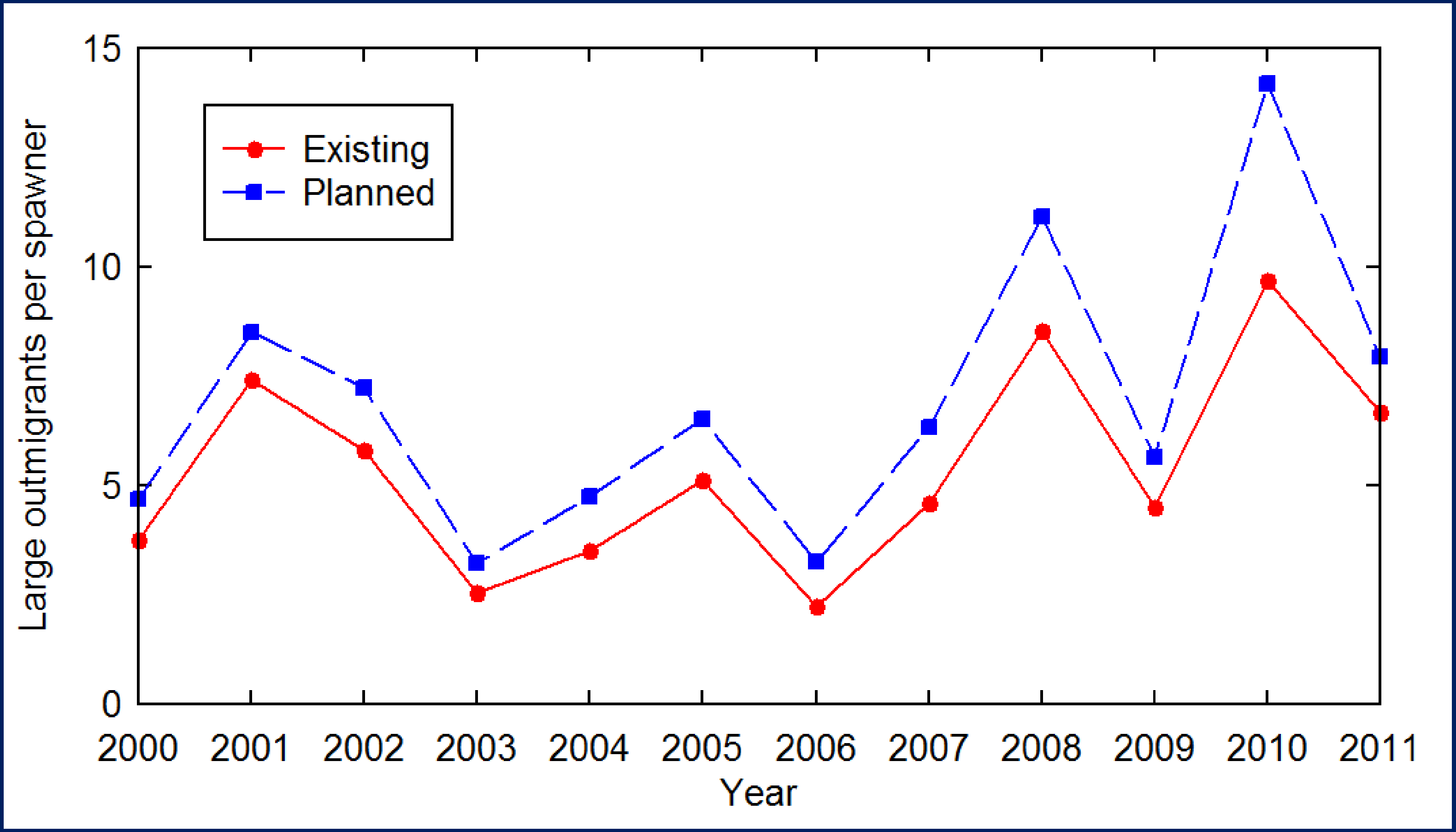


Proposed new 3C channel: Modeled in restoration planning



Current 3C at same scale

Simulation experiment: 12 years with existing, planned site 3C



- *Large* outmigrants per spawner: 30% increase in the 12-site total

Why does inSALMO predict that restoration will produce more large outmigrants?

- The planned restoration provides a large area of shallow, slow habitat where
  - growth is positive
  - piscivory risk is relatively low

- Site 3C is near the downstream end of Clear Creek, so almost all outmigrants pass through it

Example application 3: Does habitat improvement create more steelhead or more resident rainbow trout?

- *Assumption* (Satterthwaite et al.) : low growth, high risk → more anadromy

- What happens when we restore streams to provide *higher* growth and *lower* risk?

Transactions of the American Fisheries Society 138:532–548, 2009

DOI: 10.1577/T08-164.1

Steelhead Life History on California's Central Coast: Insights from a State-Dependent Model

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Does habitat improvement create more steelhead or more residents?

A: *Yes*

NRC Research Press

ARTICLE

Facultative anadromy in salmonids: linking habitat, individual life history decisions, and population-level consequences

Steven F. Railsback, Bret C. Harvey, and Jason L. White

Abstract: Modeling and management of facultative anadromous salmonids is complicated by their ability to select anadromous or resident life histories. Conventional theory for this behavior assumes individuals select the strategy offering highest expected reproductive success but does not predict how population-level consequences such as a stream's smolt production emerge from the anadromy decision and habitat conditions. Our individual-based population model represents juvenile growth, survival, and anadromy decisions as outcomes of habitat and competition. In simulation experiments that varied stream growth and survival conditions, we examined how many simulated juveniles selected anadromy versus residence and how many of those choosing anadromy survived until smolting. Owing to variation in habitat and among individuals, the within-population frequency of anadromy changed gradually with growth and survival conditions instead of switching abruptly. Higher predation risk caused more juveniles to select anadromy, but fewer survived long enough to smolt. Improving growth appears a much safer way to increase smolt production compared with reducing freshwater survival. Smolt production peaked at high growth and moderately high survival, conditions that also produced many residents.

Can. J. Fish. Aquat. Sci. 71: 1270–1278 (2014)

A few examples of unexpected results from inSALMO

Example unexpected results from inSALMO

- It is risky to assume that more flow—or a more natural flow regime—is better when salmon are forced to spawn in mainstems below dams

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- What produces more total outmigrants may not produce more big ones

Example unexpected results from inSALMO

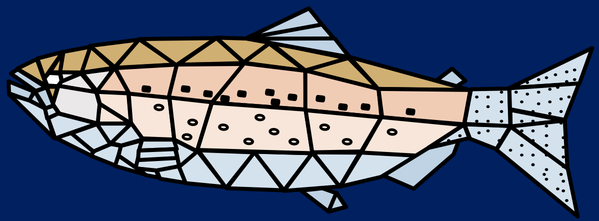
- It is risky to assume that more flow—or a more natural flow regime—is better when salmon are forced to spawn in mainstems below dams
- What produces more total outmigrants may not produce more big ones
- Conditions that produce more steelhead may also produce more residents
  (it's not either-or)

inSALMO

- Many Bay-Delta management decisions require models of how habitat affects salmon & steelhead

- inSALMO was designed exactly for these purposes and has important advantages:
  - Extensive history
  - Testing and validation
  - Usability and documentation
  - Publication
  - Agency involvement

inSALMO



- inSALMO takes serious time and effort to use...

- but far less than building new models!!

inSALMO

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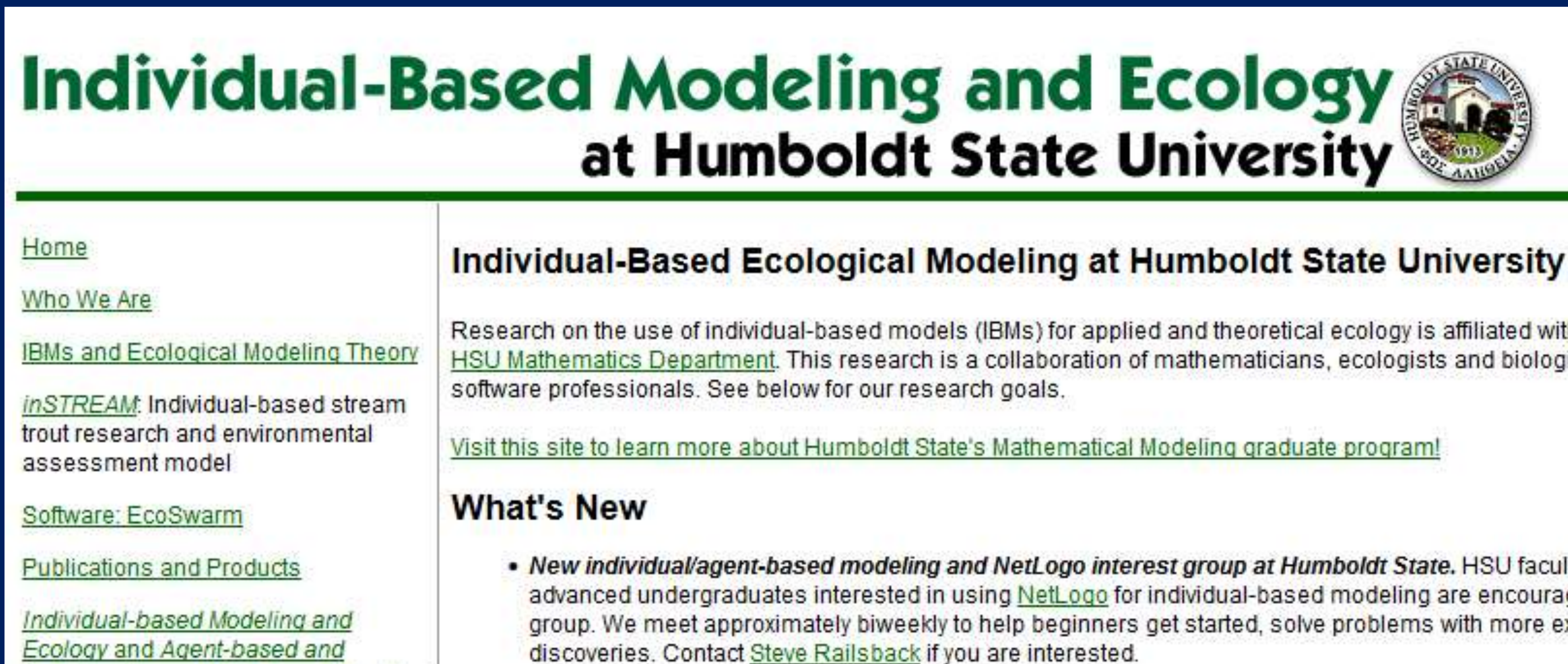
www.humboldt.edu/ecomodel


Individual-Based Modeling and Ecology
at Humboldt State University

Home

Who We Are

IBMs and Ecological Modeling Theory

inSTREAM: Individual-based stream trout research and environmental assessment model

Software: EcoSwarm

Publications and Products

Individual-based Modeling and Ecology and Agent-based and

Individual-Based Ecological Modeling at Humboldt State University

Research on the use of individual-based models (IBMs) for applied and theoretical ecology is affiliated with HSU Mathematics Department. This research is a collaboration of mathematicians, ecologists and biologis software professionals. See below for our research goals.

Visit this site to learn more about Humboldt State's Mathematical Modeling graduate program!

What's New

- ***New individual/agent-based modeling and NetLogo interest group at Humboldt State.*** HSU faculty advanced undergraduates interested in using NetLogo for individual-based modeling are encourag group. We meet approximately biweekly to help beginners get started, solve problems with more exp discoveries. Contact Steve Railsback if you are interested.

- Steve@LangRailsback.com