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

CONCLUSIONS FROM AN INDIVIDUAL-BASED MODEL

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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

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- Considering individual variability and behavior
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
Clear Creek
Example analysis: Response of Chinook spawning success to instream flow

Vary the dam’s flow release
Flow experiment results:
Total number of outmigrants

![Graph showing the relationship between change in flow (cfs) and total number of outmigrants.](image)
Why does inSALMO predict so little effect of flow on spawning success?

![Graph showing the relationship between change in flow (cfs) and total number of outmigrants. The x-axis represents change in flow (cfs) ranging from -75 to 150, and the y-axis represents total number of outmigrants ranging from 0 to 50x10^6. The graph shows a lack of correlation between flow and outmigrant numbers.]
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

![Graph showing the relationship between change in flow and total number of big outmigrants. The x-axis represents the change in flow, and the y-axis represents the total number of big outmigrants. There are red markers indicating the data points.](image-url)
Why does number of large outmigrants decrease with flow?
Why does number of large outmigrants decrease with flow?

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 $\rightarrow$ more anadromy

- What happens when we restore streams to provide higher growth and lower risk?
Does habitat improvement create more steelhead or more residents?

A: Yes

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.

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
Example unexpected results from inSALMO

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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!!
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Individual-Based Modeling and Ecology at Humboldt State University

Research on the use of individual-based models (IBMs) for applied and theoretical ecology is affiliated with the HSU Mathematics Department. This research is a collaboration of mathematicians, ecologists and biologists and 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 and advanced undergraduates interested in using NetLogo for individual-based modeling are encouraged to join the group. We meet approximately biweekly to help beginners get started, solve problems with more experience, and share discoveries. Contact Steve Railsback if you are interested.

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