# Ecological models for assessing hydropeaking and habitat restoration scenarios

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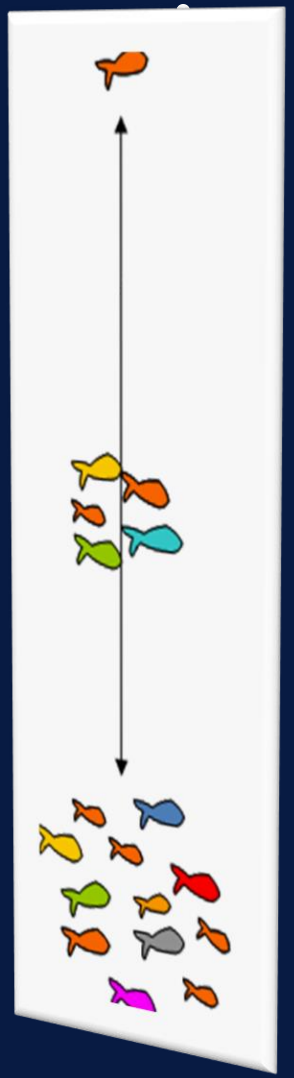
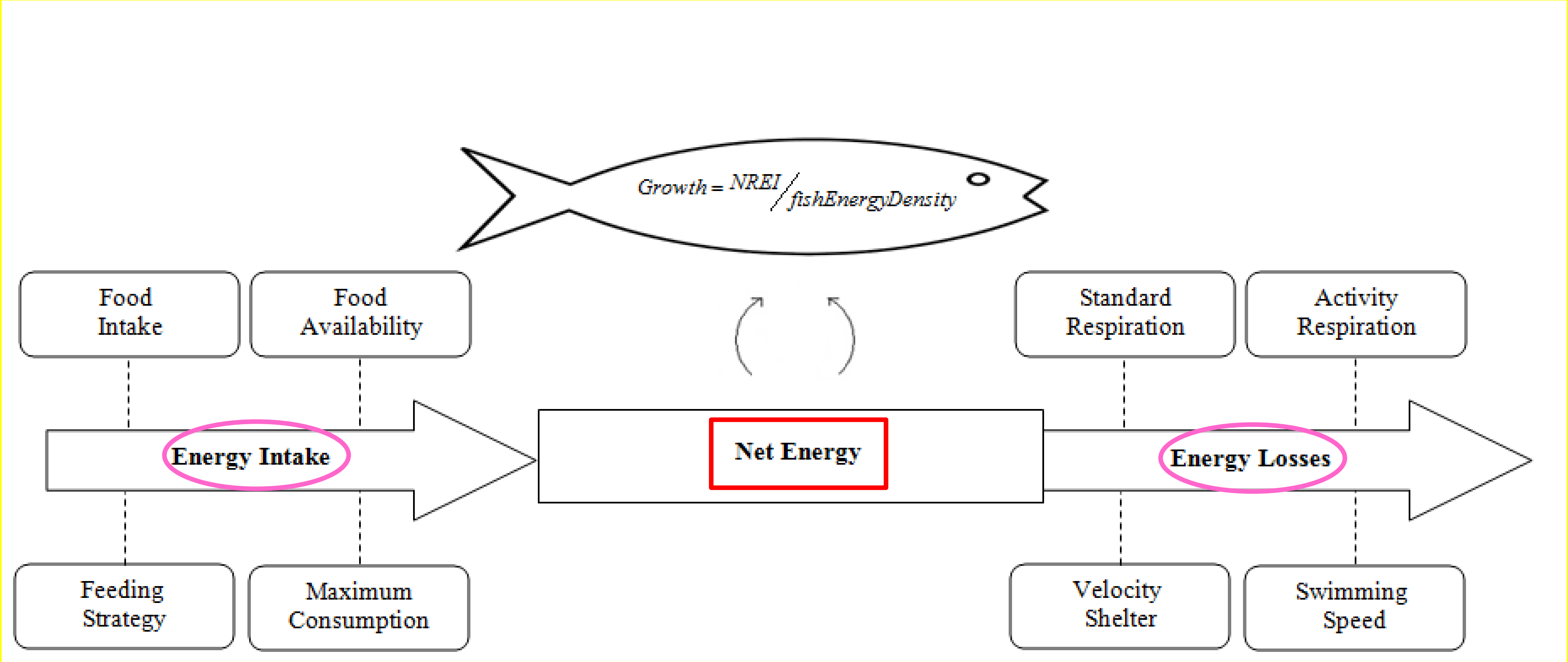
# Outline

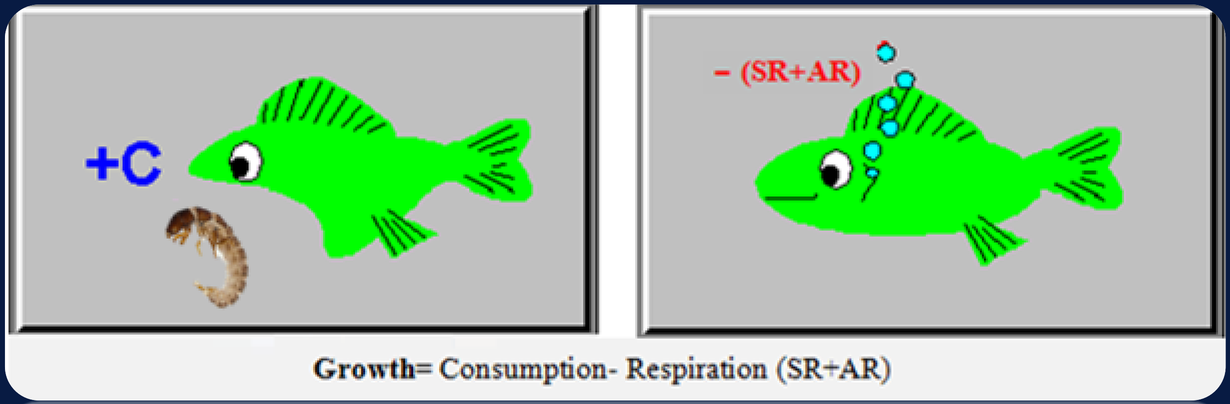
- Individual-based model (IBMs) purposes and design goals
  - InSTREAM and InSALMO
- History of model developments
- Example applications
- Future research

# Stream fish IBMs

- Fish population responses *emerge* from models of individual behavior, growth, survival, reproduction
  - We can model the population if we capture the essential characteristics of individuals & habitat.
  - Valuable for planning management scenarios.
  - Prioritize management decisions and biodiversity conservation actions.

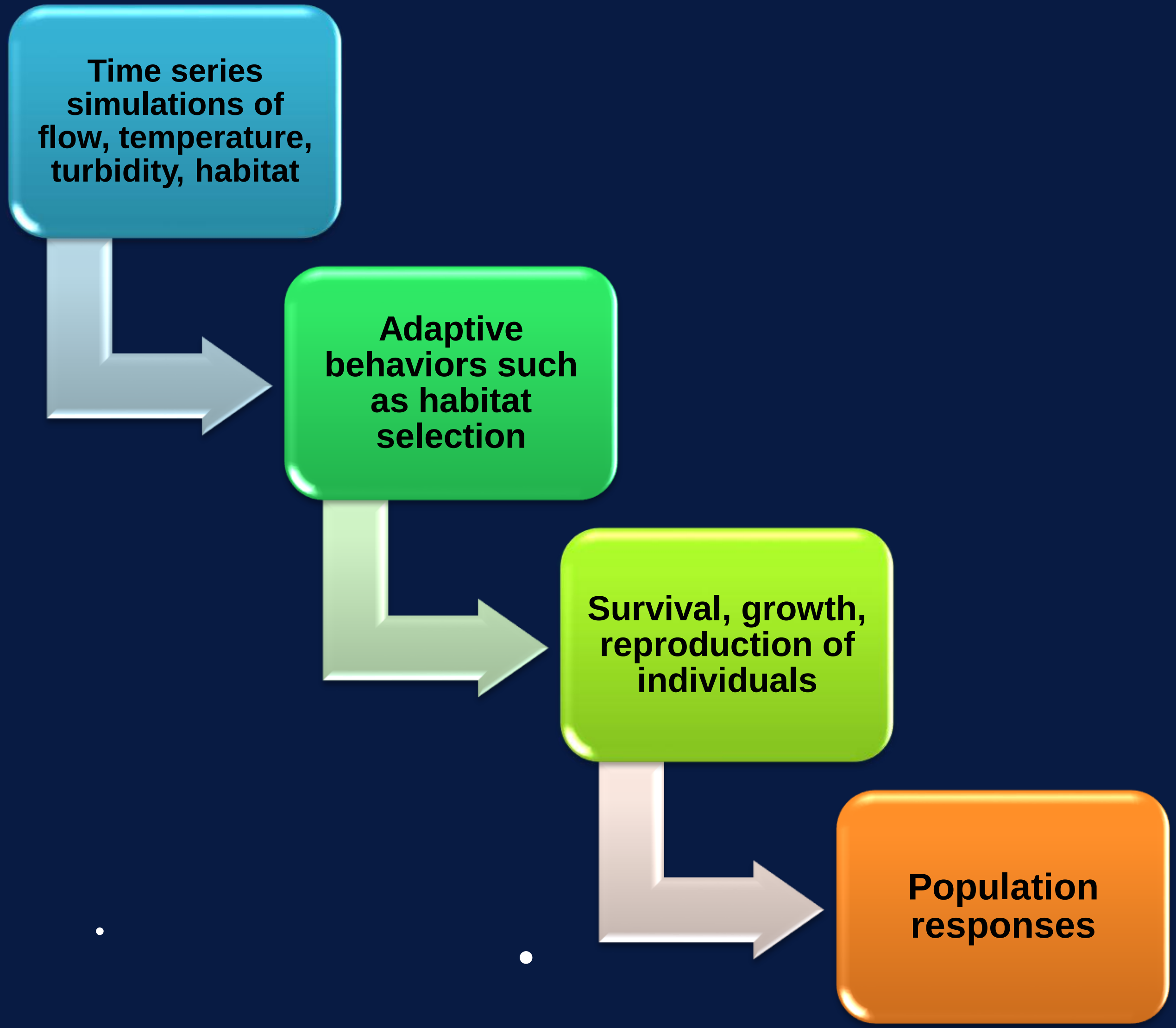




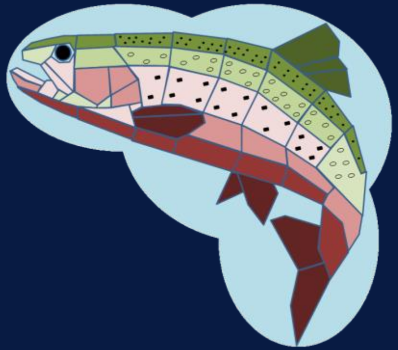

Conceptual model of fish growth based on bioenergetics approach

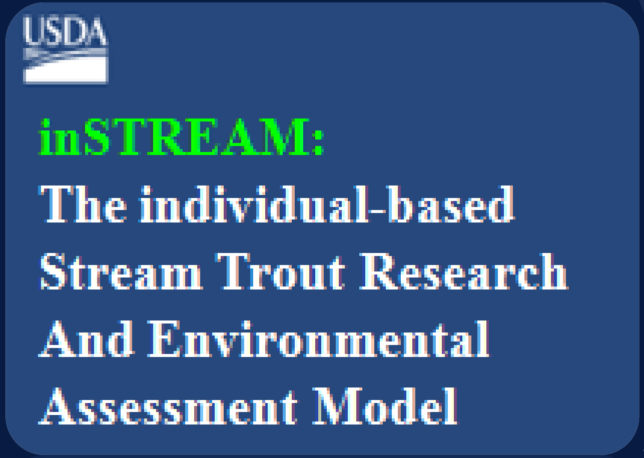
# Stream fish IBMs

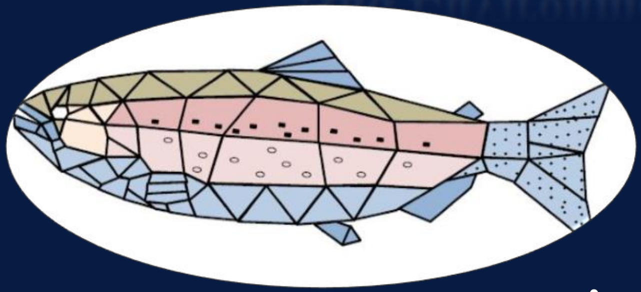


# InSTREAM and InSALMO

## individual-based models designed as river management tools





- Dr. Steve Railsback
Dr. Bret Harvey

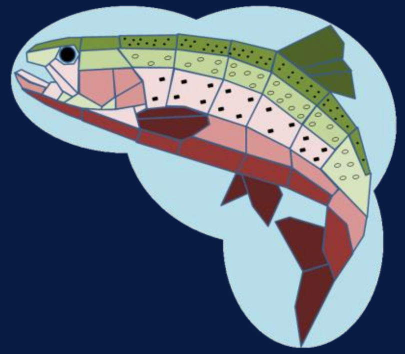
# Purposes of InSTREAM and InSALMO

- Instream flow assessment:
  - *How do alternative flow and temperature regimes affect salmonid populations?*

- Evaluation and design of habitat restoration projects:
  - *What are the relative benefits of alternative restoration measures or channel designs?*

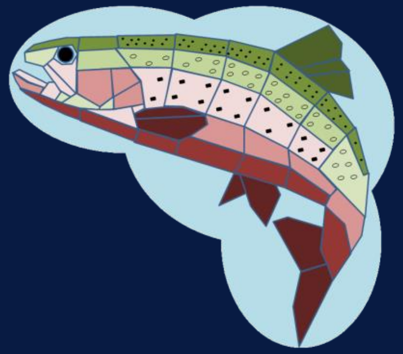
- Evaluation of watershed management, especially via turbidity

- Testing ecological theory in a virtual ecosystem



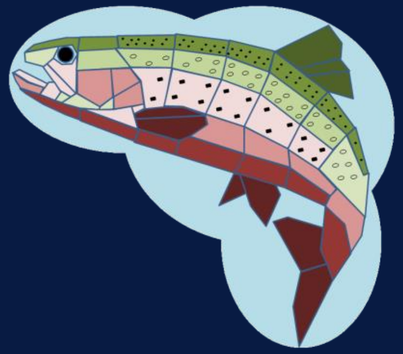
# InSTREAM vs. InSALMO

- InSTREAM: Simulates long-term dynamics of resident trout populations
- InSALMO: Simulates freshwater life stages of salmon
  - *Adult arrival and holding*
  - *Spawning*
  - *Egg incubation*
  - *Juvenile rearing and outmigration*



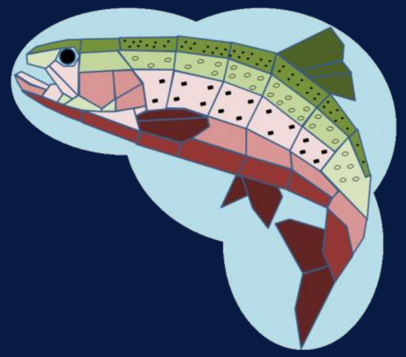
# Design goals

- Overcome fundamental limitations of habitat suitability models by:
    - *Representing time and effects of habitat variation over time*
    - *Representing the interacting effects of flow, temperature, competition, etc.*
    - *Producing outputs that have clear management meaning and are testable*



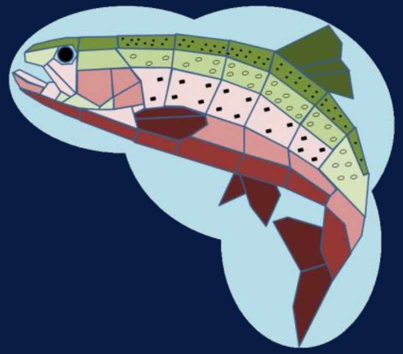
# Design goals

- Put more biology in instream flow assessment
  - *We know a lot about salmonids, so let's make it easy to use more of that knowledge in management decisions*

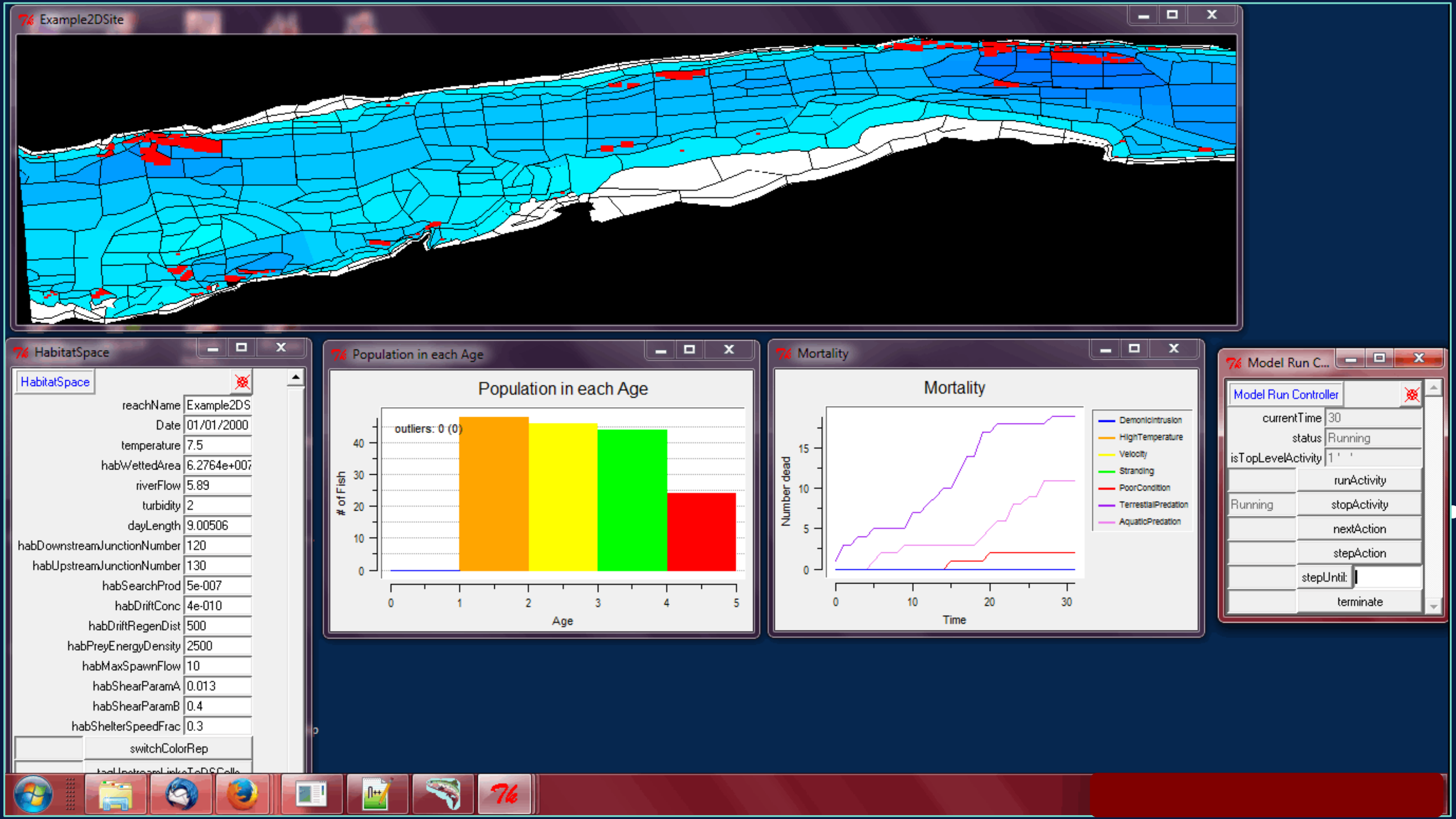


# Design goals

- Make assessments more rigorous, transparent, and reproducible:
    - *Document more of our assumptions in words and computer code*
    - *Make it easy to test assumptions and replace them when we need to*
    - *The models are complex but we don’t have to struggle to determine what their results mean*



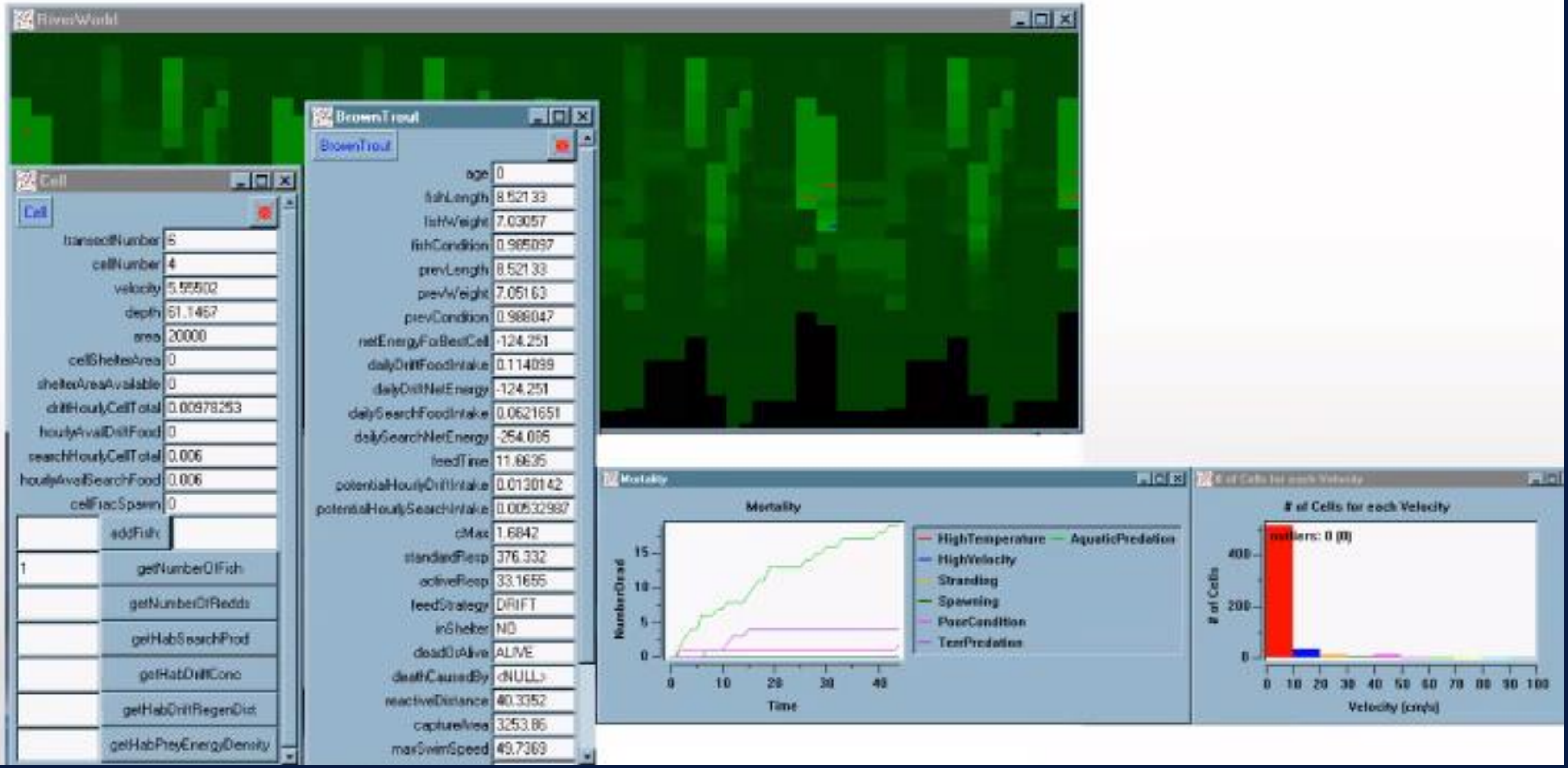
- Hydraulic model to simulate the reach
- Habitat cells (depth, velocity and habitat variables)
- Key individual behaviors
  - ✓ Habitat and activity (feeding or hiding) selection
  - ✓ Feeding and growth
  - ✓ Moratlity
  - ✓ spawning




**A movie of a model run**

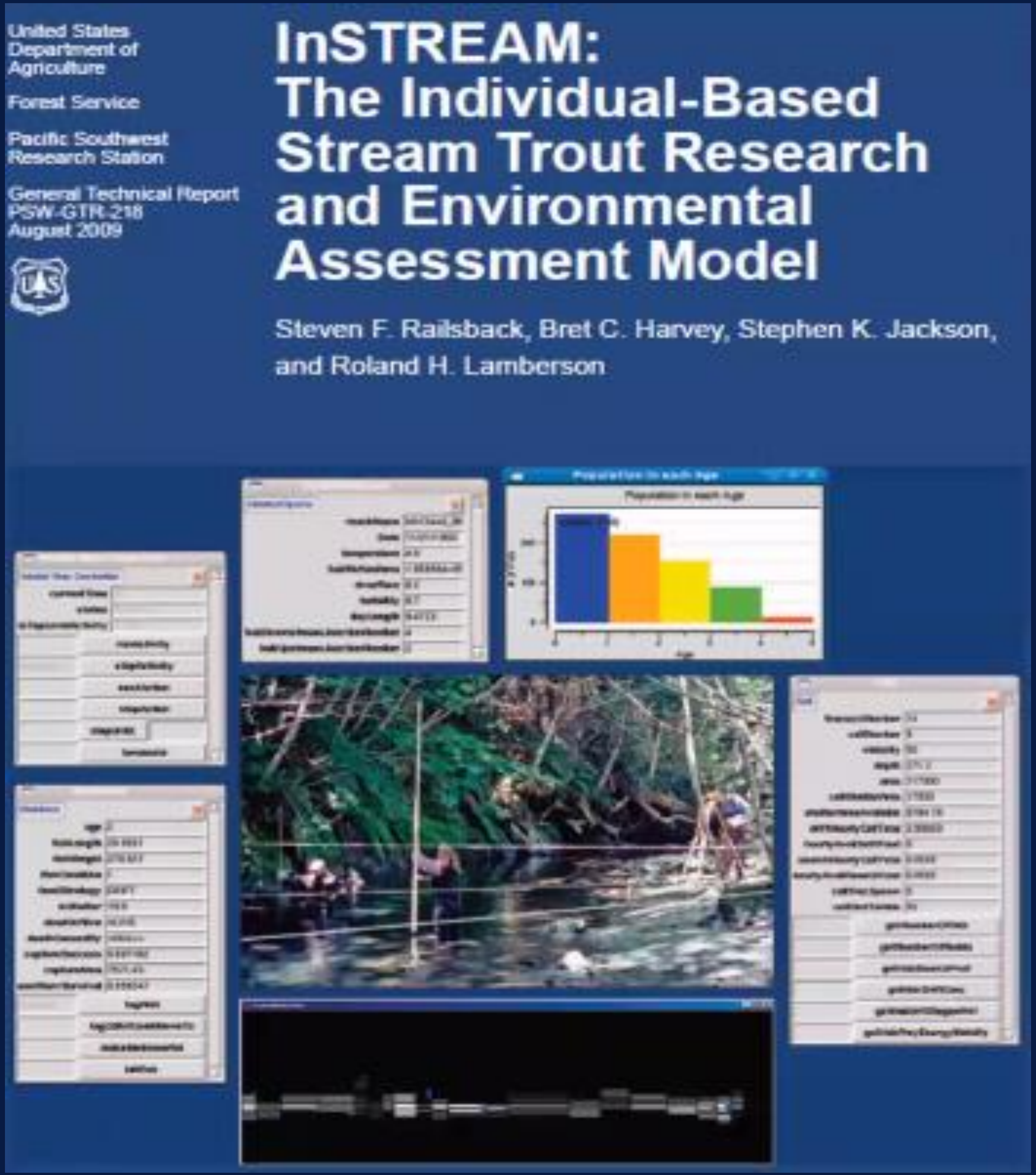
# Some history

inSTREAM version 1
1999



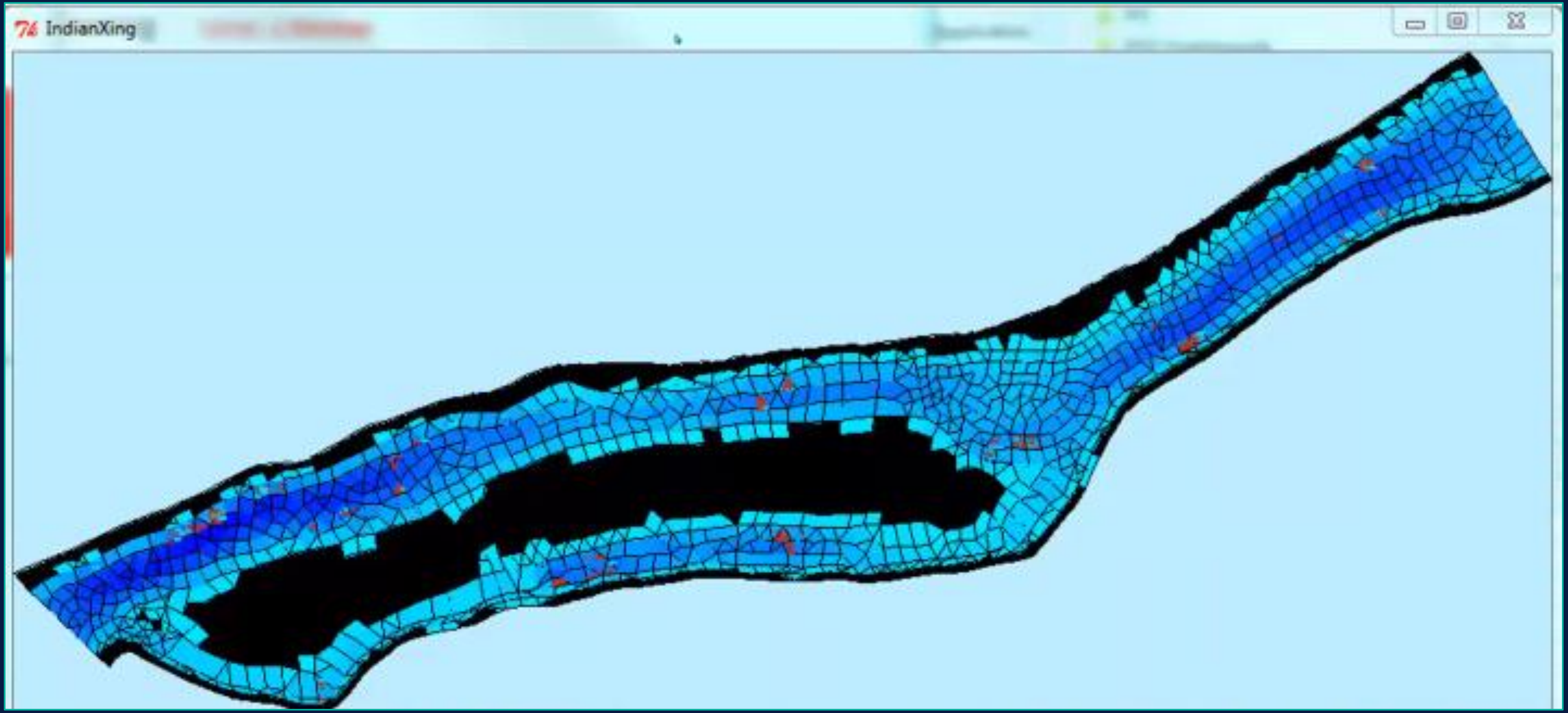
# inSTREAM 4 (2009)

- First public release with complete user guidance



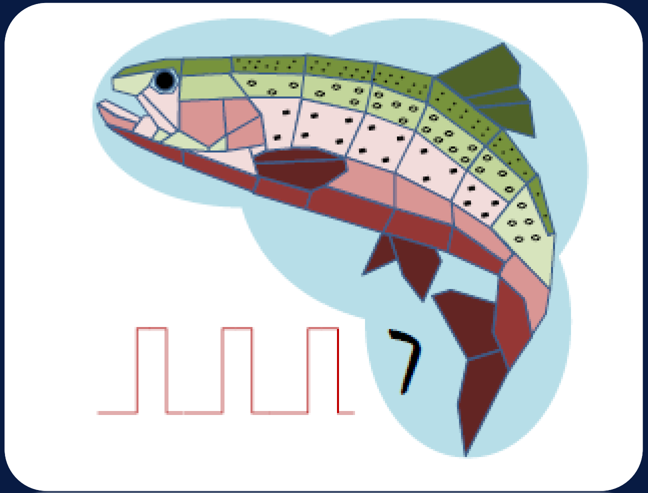
# inSTREAM 5.0

## Two-dimensional habitat (2013)



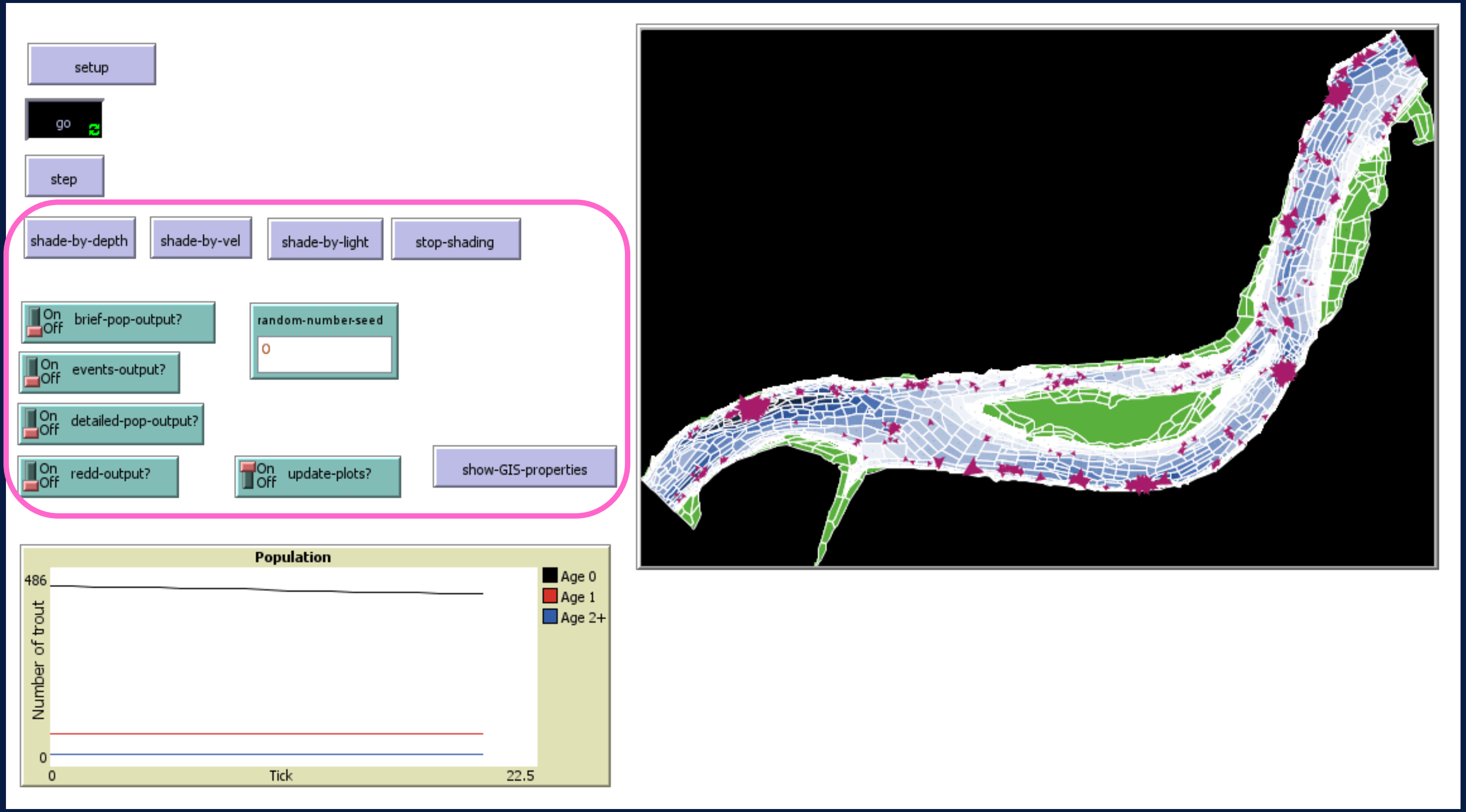
# **InSTREAM 7 (2020):** the most recent of a family of individual-based salmonid models

- Explicit representation of the daily light cycle (night, dawn, day, and dusk) and how light affects feeding, predation risk, and behavior
- Complete update of all components
- New software in a widely used, well-supported platform (NetLogo)
- A version for hydropower peaking



# InSTREAM 7 (2020)

- Cell geometry and habitat variables imported from GIS.
- Cell depth and velocity imported from any hydraulic model.
- Interface controls
    - ✓ let users pause and restart a simulation
    - ✓ turn output files on and off
    - ✓ select which cell variable (depth, velocity, light intensity) to display

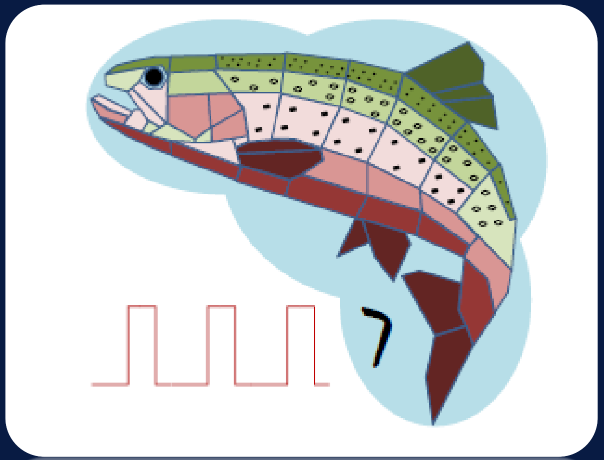



https://ecomodel.humboldt.edu/instream-7

# InSTREAM 7-SD

- to model how individual trout respond to substantial changes in flow at any time during a day, and the resulting effects on population measures such as abundance and growth.

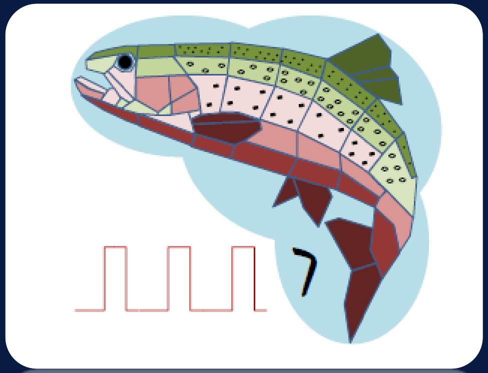
- a new reach-scale parameter ***reach-flow-change-for-time-step***



# InSTREAM 7-SD

## Key model inputs:

- Habitat cell geometry and characteristics
- 2-D hydraulic model output data for water depth and velocity
- Time series of flow, temperature and turbidity
- Ecological data
- Site- and species- specific parameters

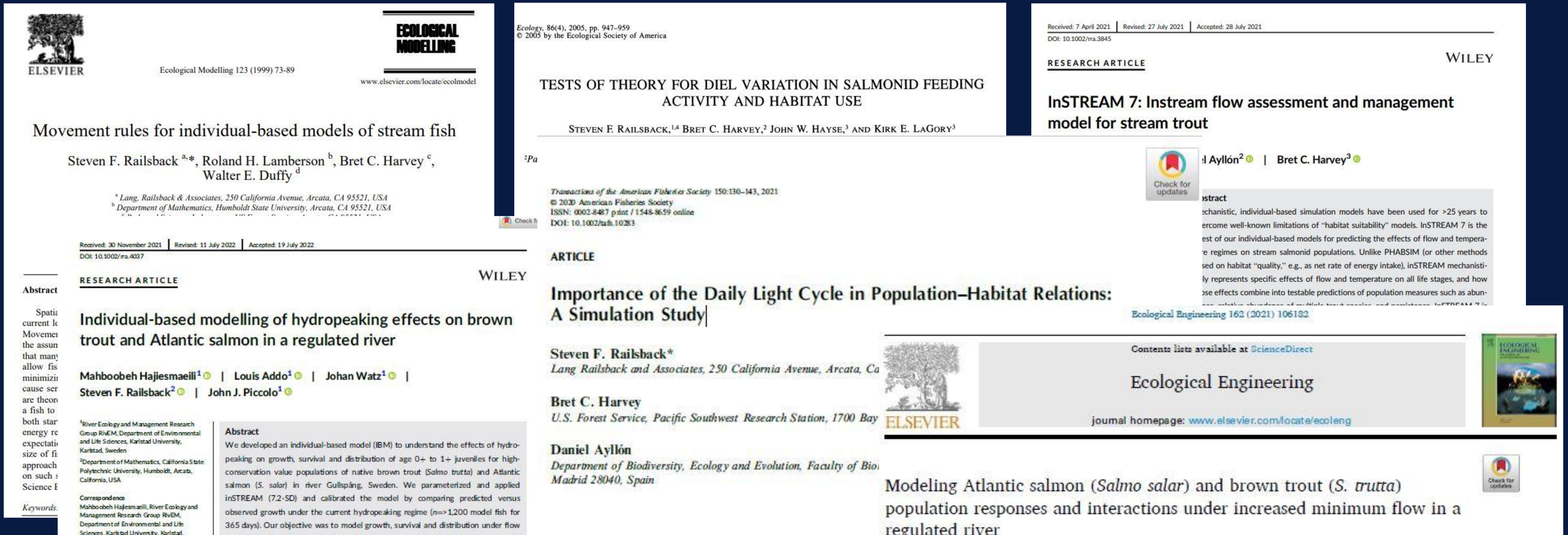


## Outputs:

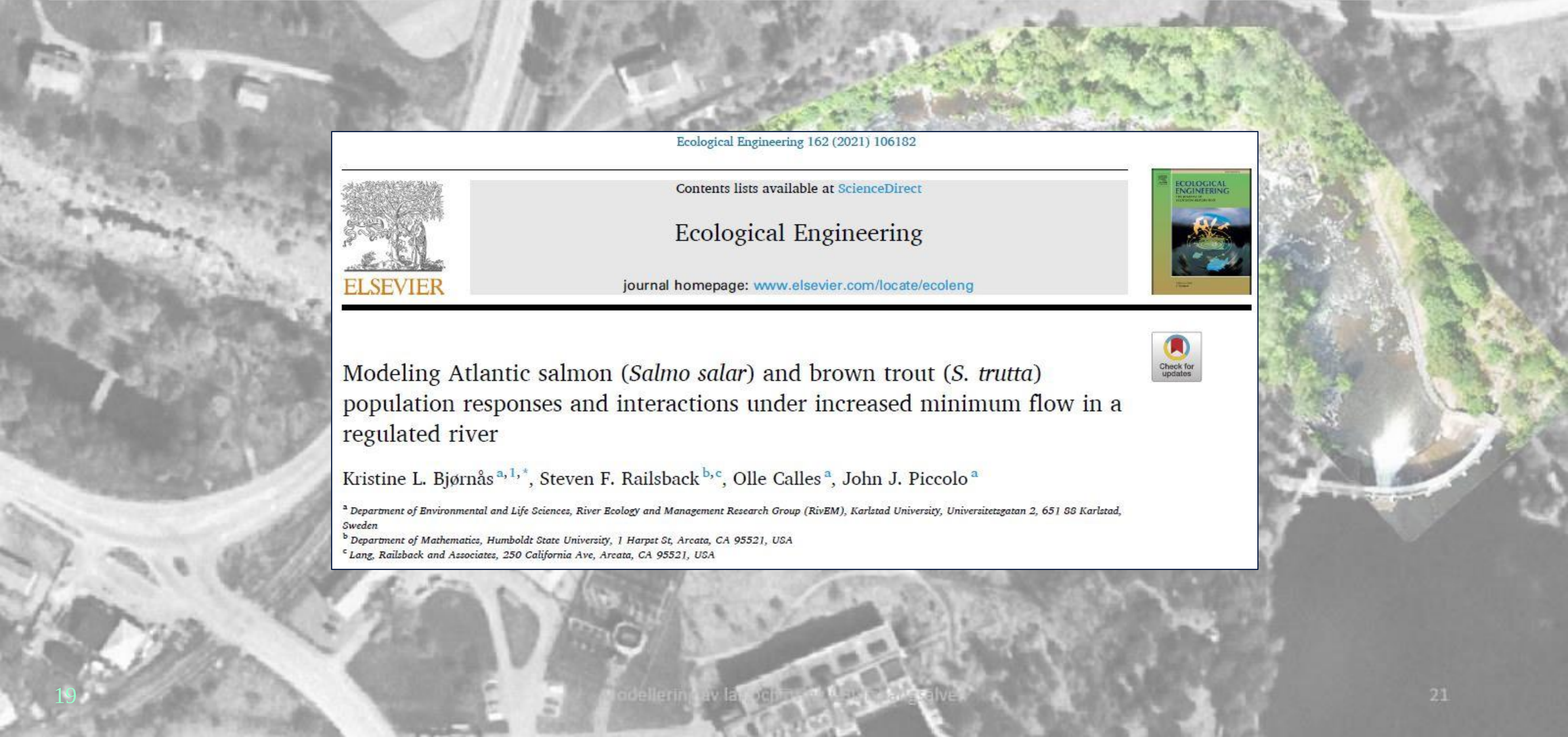
- Population outputs:
- Growth
- Survival
- Behavior
- Fish distributions at any given time step

# In summary

- 9 major versions in > 20 years
- Applications at ~50 sites (in US, Iran, Spain, Sweden)
- ~30 open-literature publications that describe, test, and apply the models



# Example applications at KAU:
## *Instream flow assessment*



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Modeling Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) population responses and interactions under increased minimum flow in a regulated river

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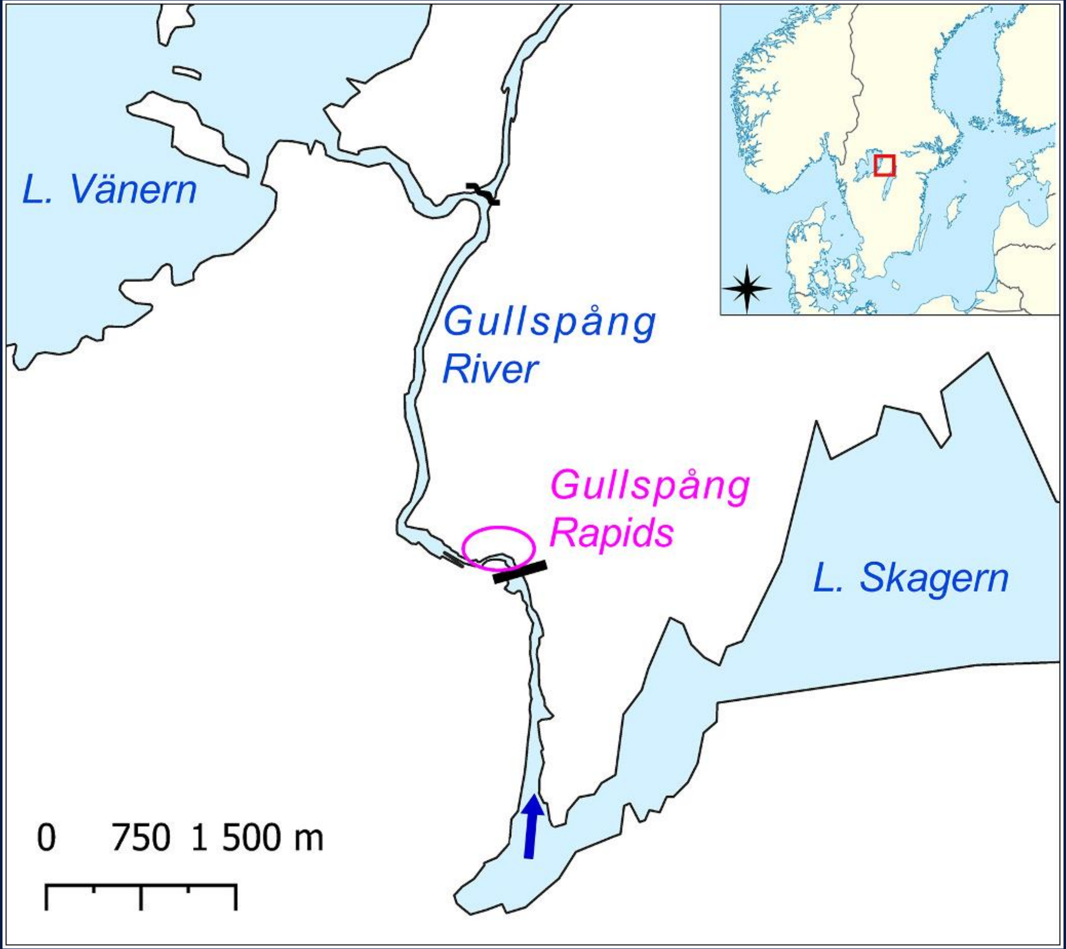
[a] Department of Environmental and Life Sciences, River Ecology and Management Research Group (RivEM), Karlstad University, Universitetsgatan 2, 651 88 Karlstad, Sweden
[b] Department of Mathematics, Humboldt State University, 1 Harpst St, Arcata, CA 95521, USA
[c] Lang, Railsback and Associates, 250 California Ave, Arcata, CA 95521, USA

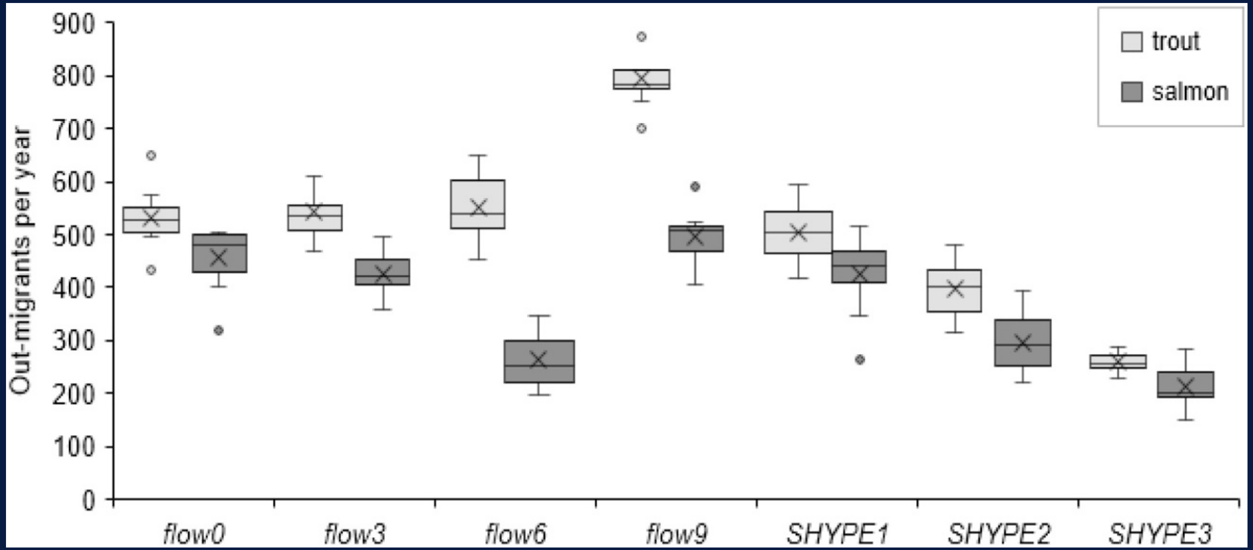
# Example applications at KAU:
## InSTREAM version 6.1

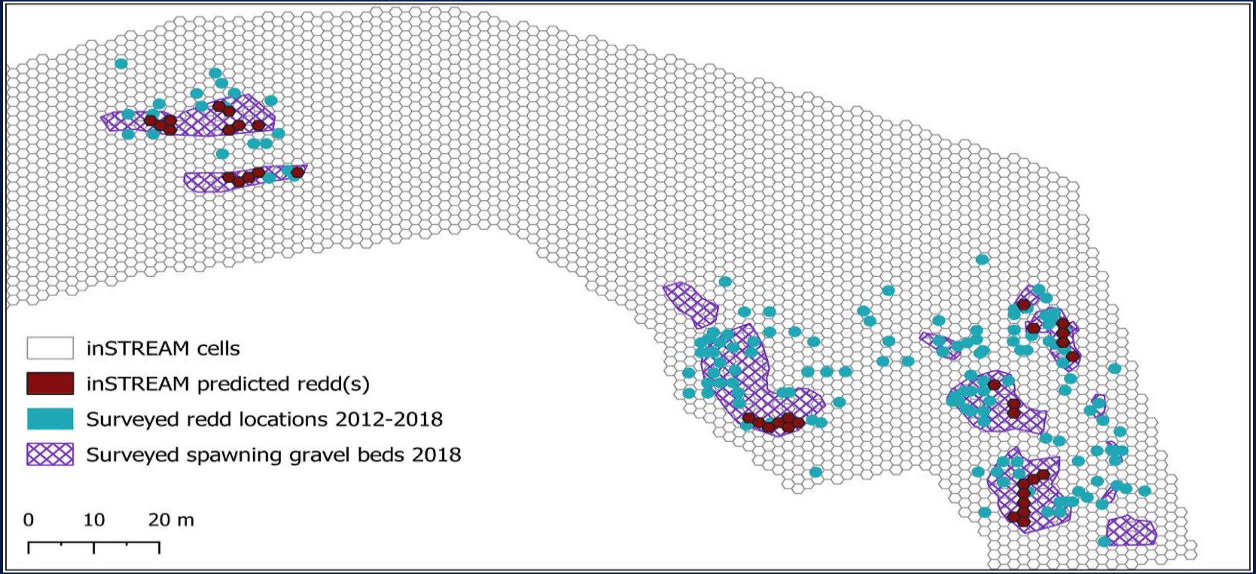
- Aim:
  - Assessing the effects of alternative min flow regimes on recruitment of lake-migrating Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in the Gullspång River, Sweden.




The regulated Gullspång River, S Sweden, connects Lake Skagern with Lake Vanern.

- In general, little effect of increasing minimum flow.
- Higher flow seems to benefit trout over salmon.
- Increased availability of velocity shelters, increased production of both salmon and trout.
- Flow restoration based on simplistic flow scenarios will have limited effect, unless complemented by an increase of instream structural complexity.



# Example applications at KAU:
## *Assessing hydropeaking effects*

Check for updates

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RESEARCH ARTICLE

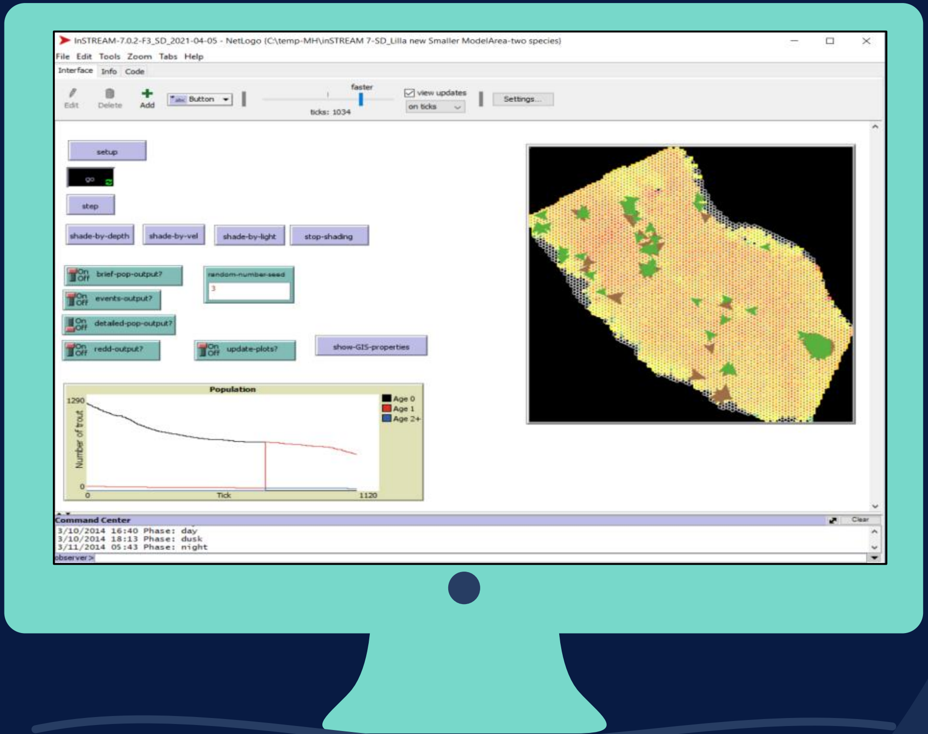
WILEY

### Individual-based modelling of hydropeaking effects on brown trout and Atlantic salmon in a regulated river

Mahboobeh Hajiesmaeili[1] | Louis Addo[1] | Johan Watz[1] | Steven F. Railsback[2] | John J. Piccolo[1]

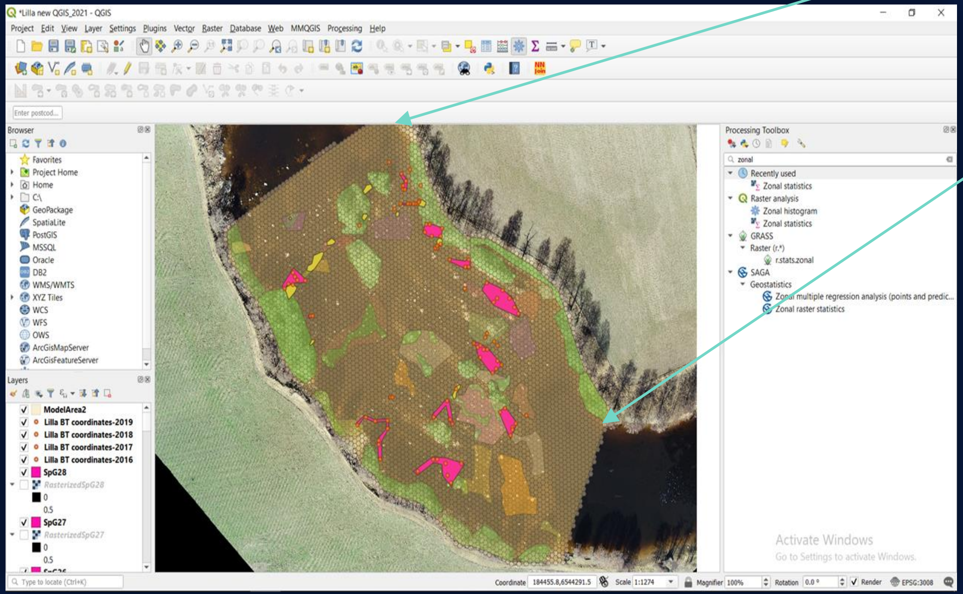
# The first application of inSTREAM 7.2-SD

- To assess effects of peaking flows on populations of brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*)
- Objectives:
  - To assess the growth, survival and distribution of age 0+ to 1+ trout and salmon under various hydropeaking and steady-flow scenarios, as well as under a natural flow regime.

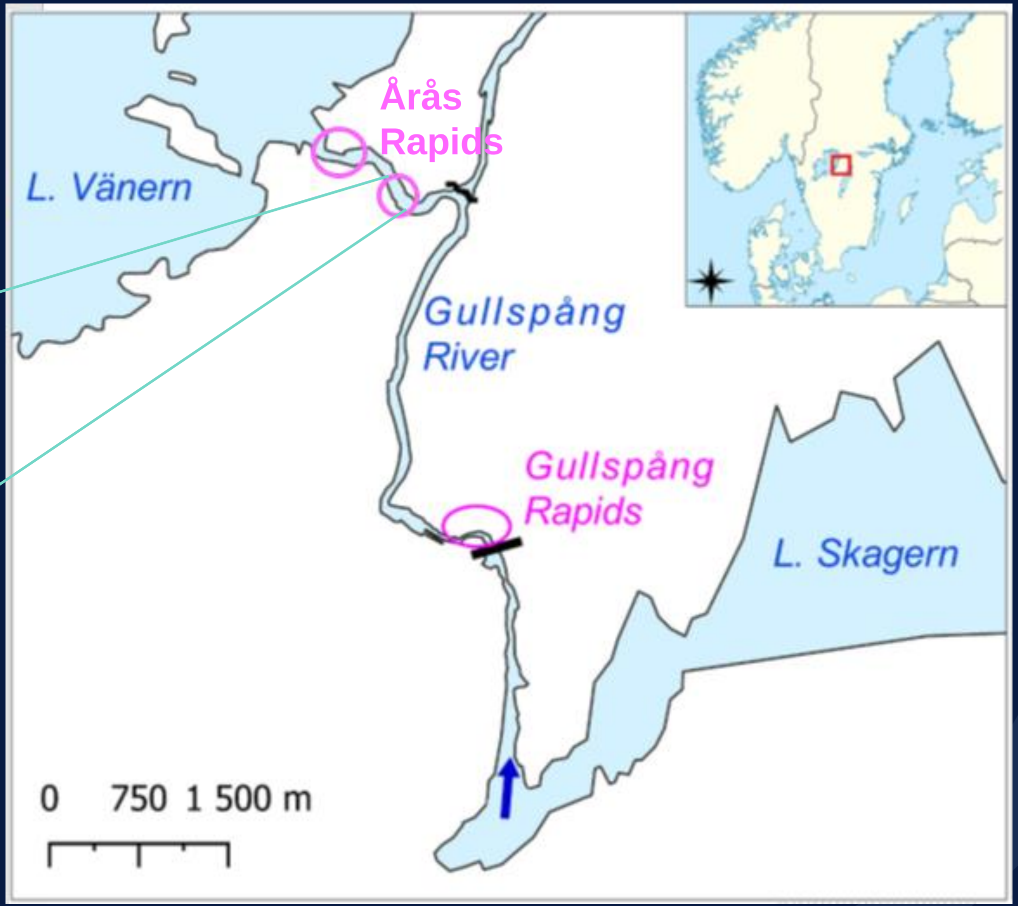


# Study site

QGIS



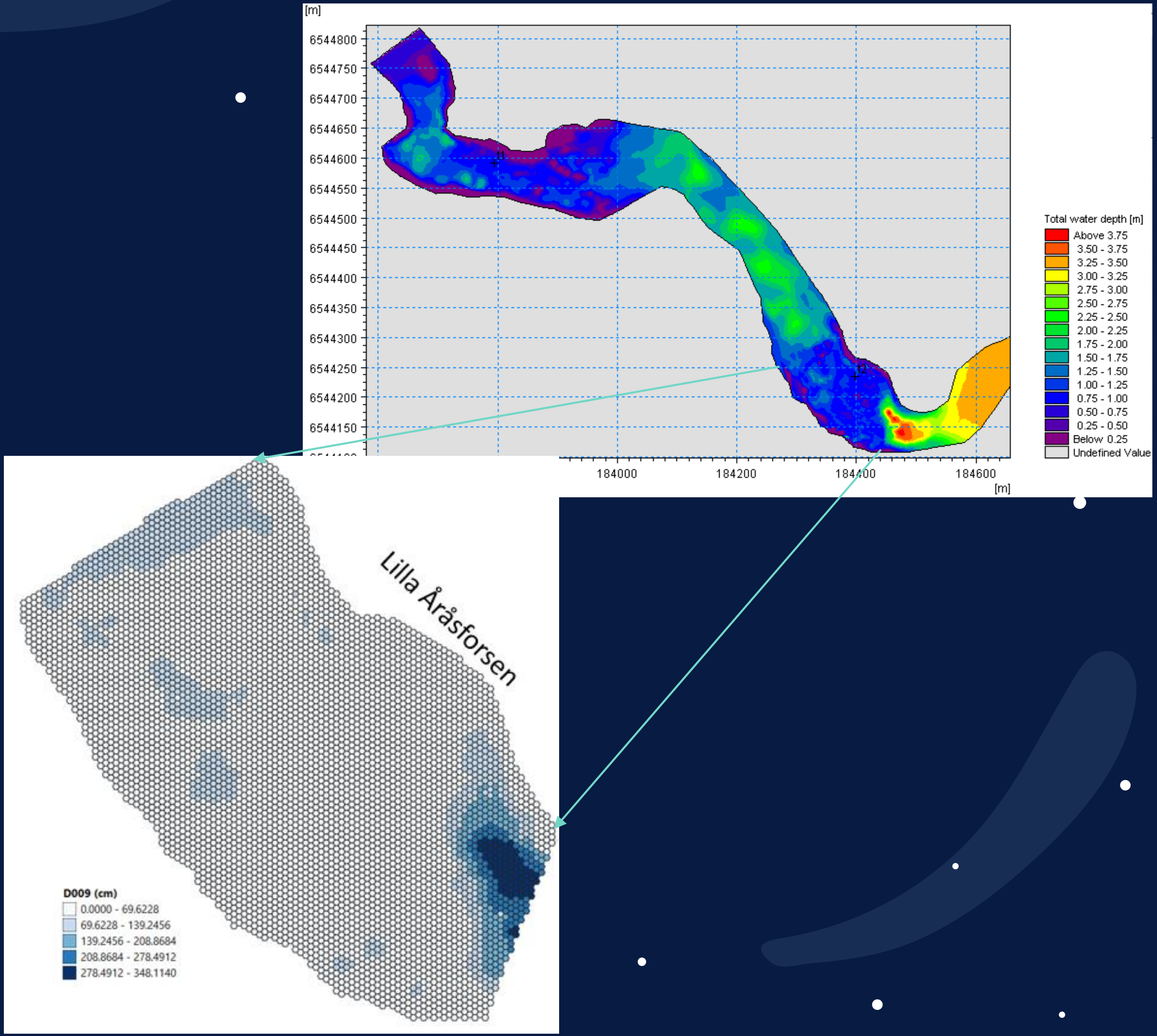
## Gullspång River (Lilla Åråsforsen)



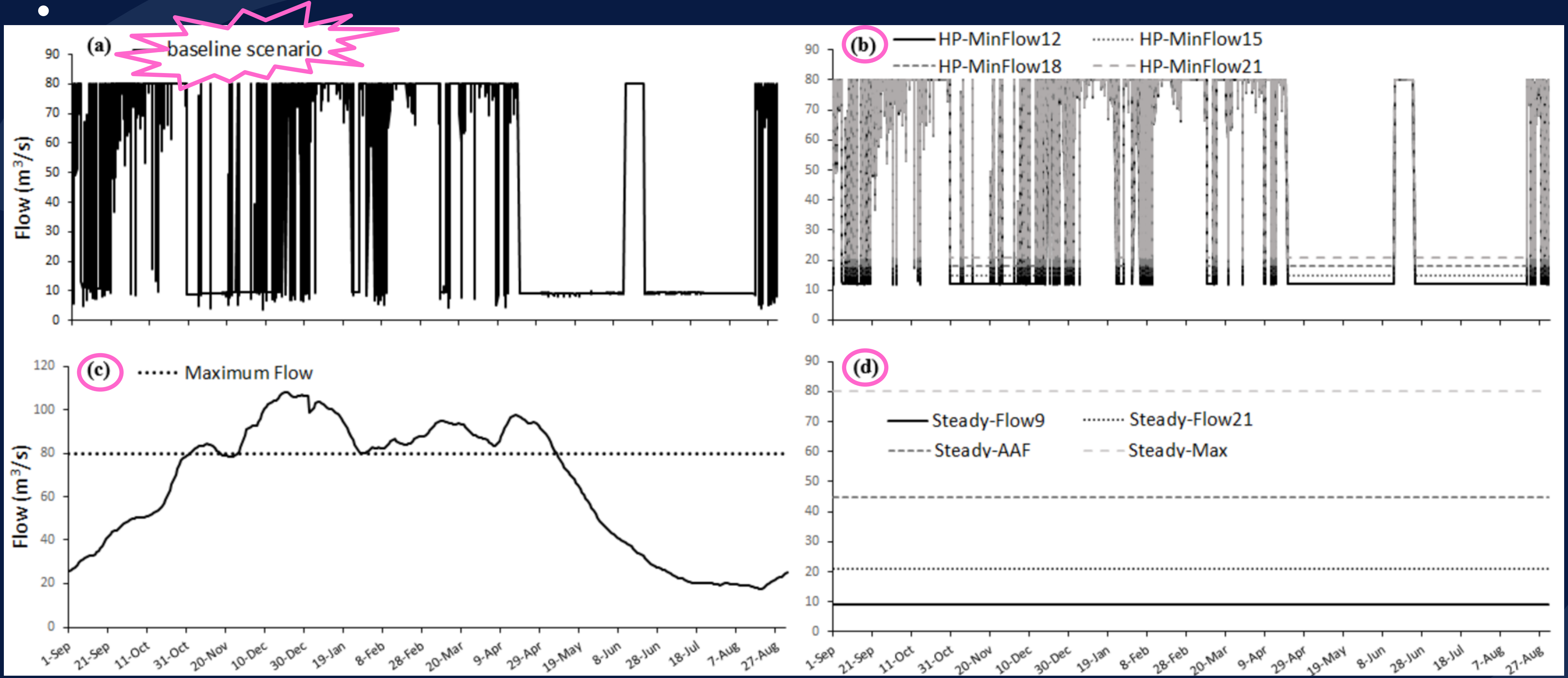

Circled areas are the main spawning and rearing habitats,
A= Gullspångsforsen, B= Lilla and C= Stora Åråsforsen

# Hydraulic input

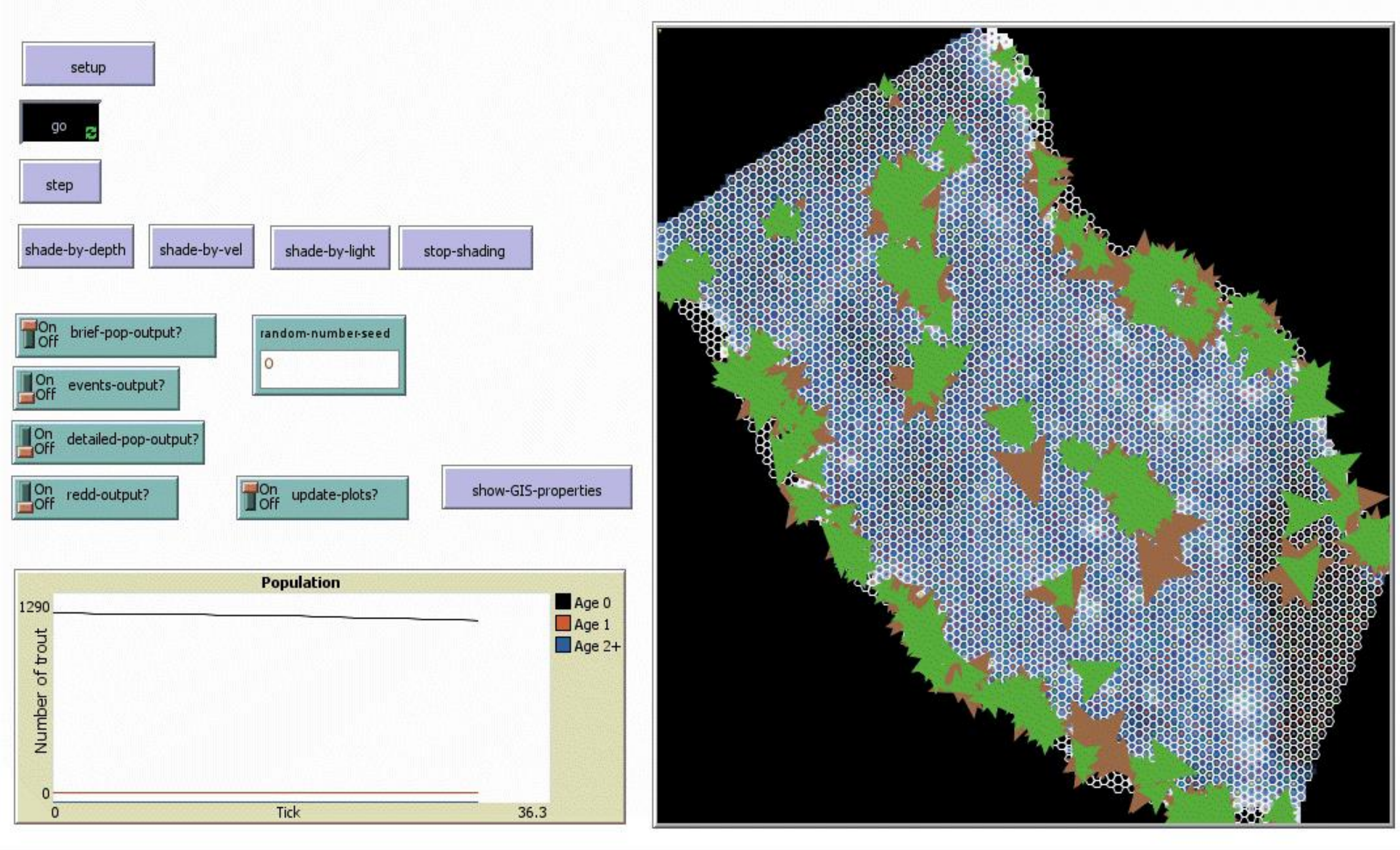
Hydraulic input in the form of cell depths and velocities at a wide range of flows:
2-D hydrodynamic modelling of LÅ using MIKE 21 (DHI Sweden).



# Flow scenarios



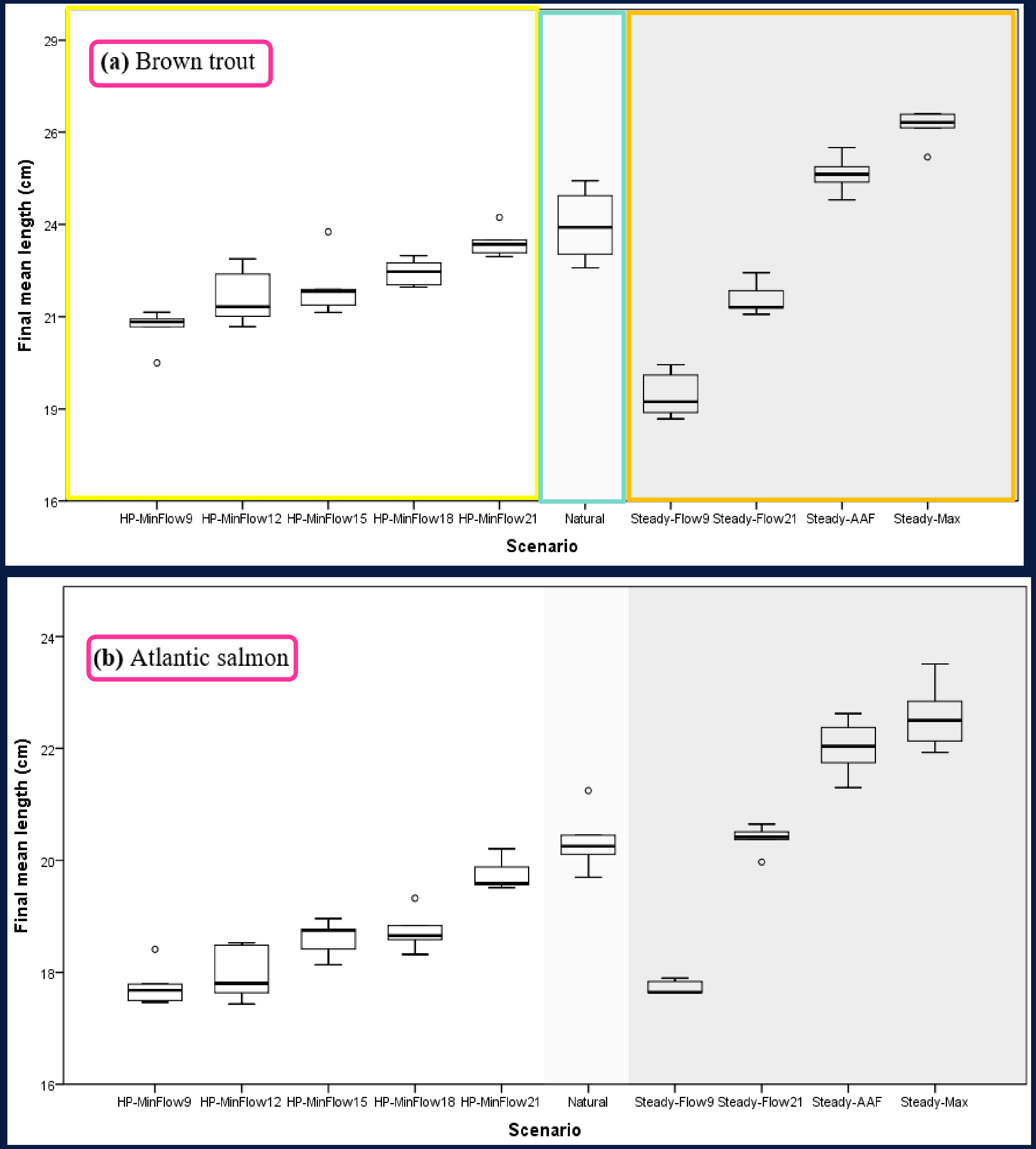
# InSTREAM simulation experiments




*inSTREAM 7.2-SD model runs for LÅ*

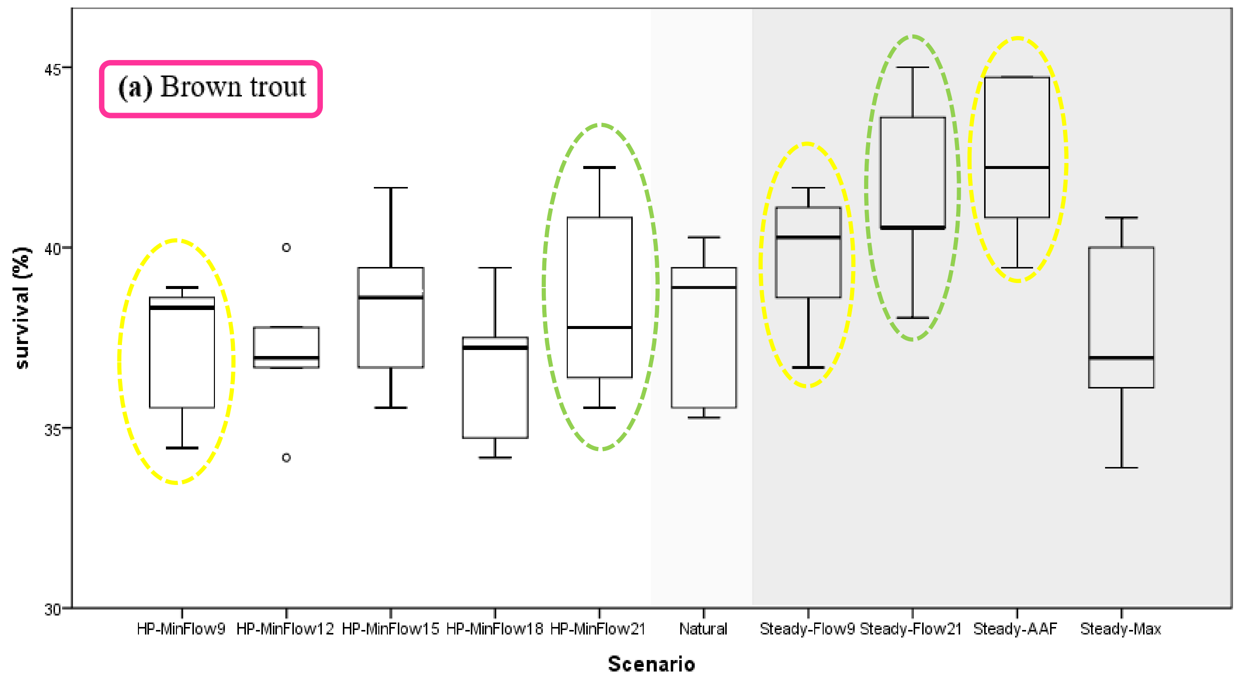
# Effects of different flow scenarios on brown trout and Atlantic salmon final predicted mean length

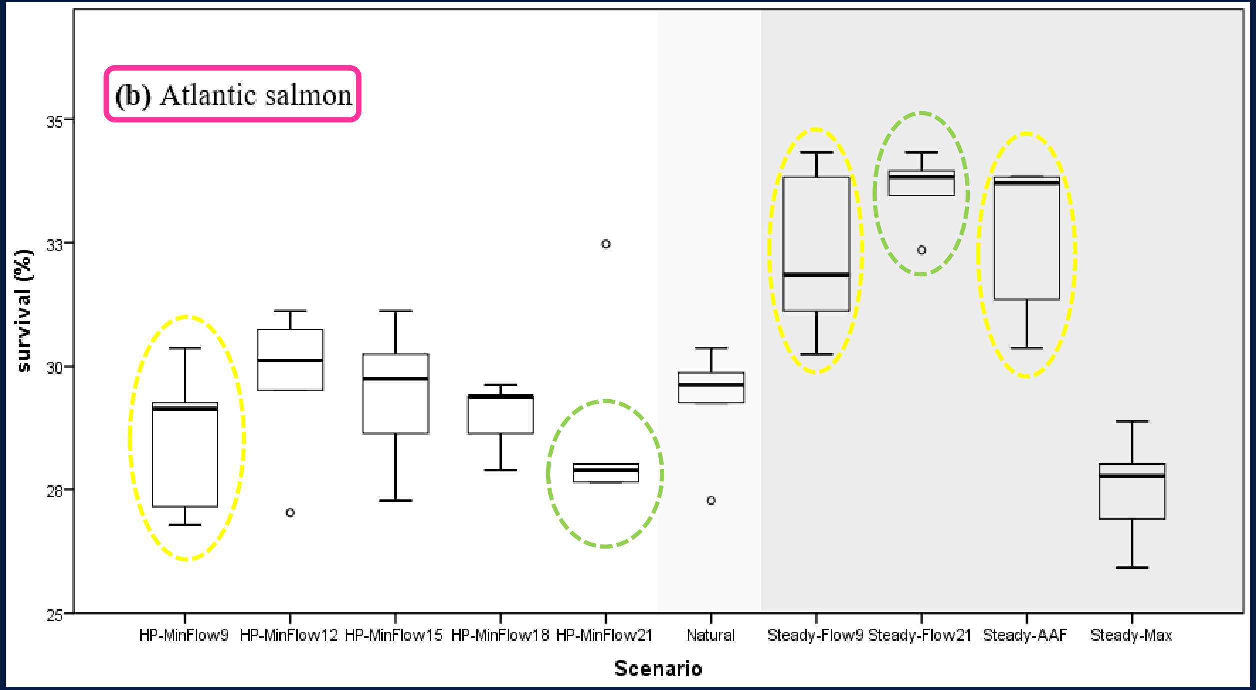
- Hydropeaking generally resulted in modest (10%) negative effects on growth of both species



# Survival

- Negative effects on survival of both species.
- Survival was more affected than was growth; smaller fish were more affected than larger fish.



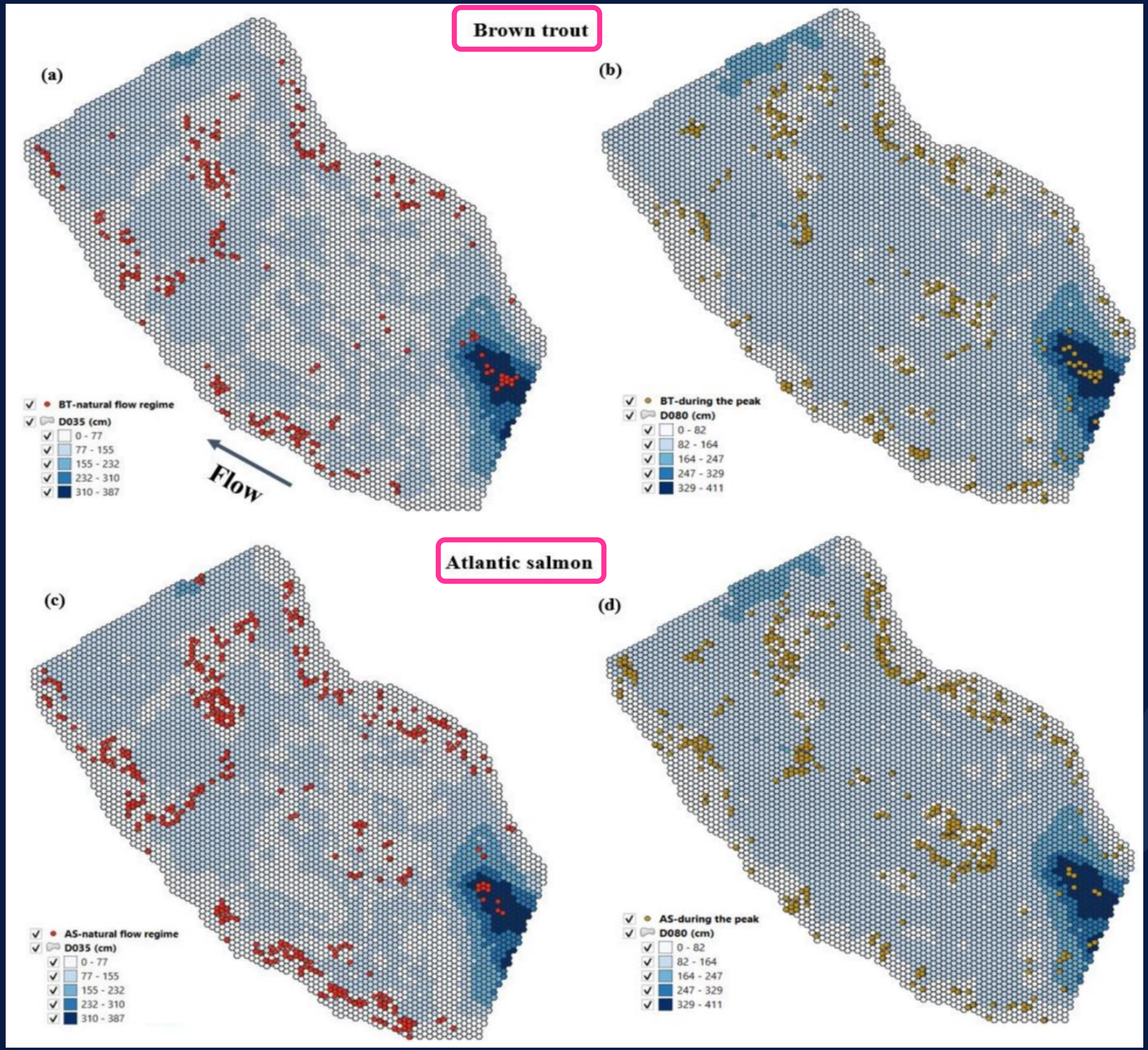
# Fish distribution

- Individuals packed more tightly and moved more during the peak at the baseline hydropeaking scenario, compared to the natural flow regime.

- Although salmon were more abundant than trout, there were more trout in deeper water.

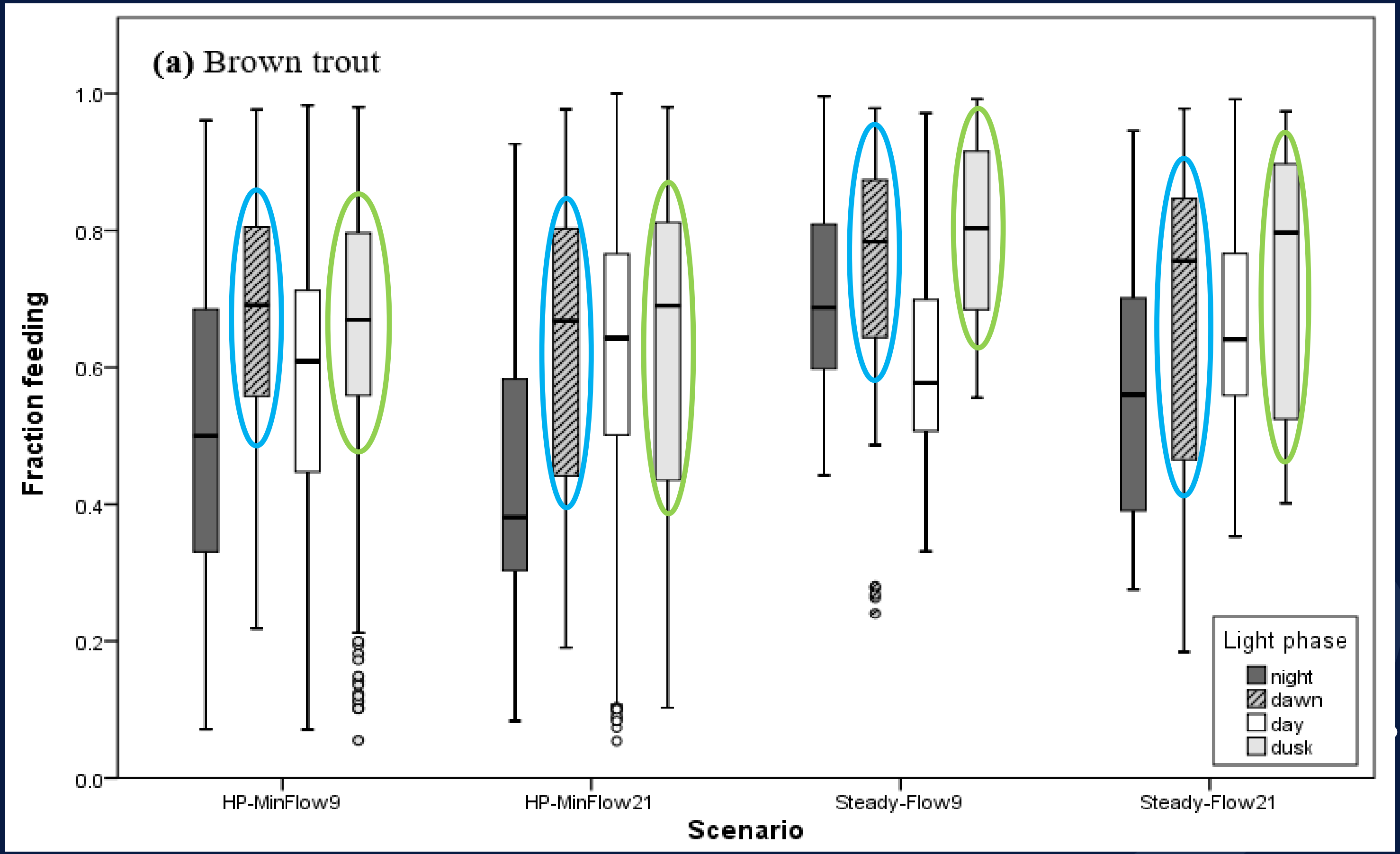
Natural flow

Hydropeaking



# Daily light cycle: feeding behavior

- Patterns of diel habitat selection and activity (feeding vs. hiding) can change in response to how we manage flows.
- Most individuals fed during dawn and dusk, when feeding was more efficient than at night and safer than during the day.
- Crepuscular periods are not represented in other habitat models.



# Example applications at KAU:

## *Comparison between a correlative and an IBM model*

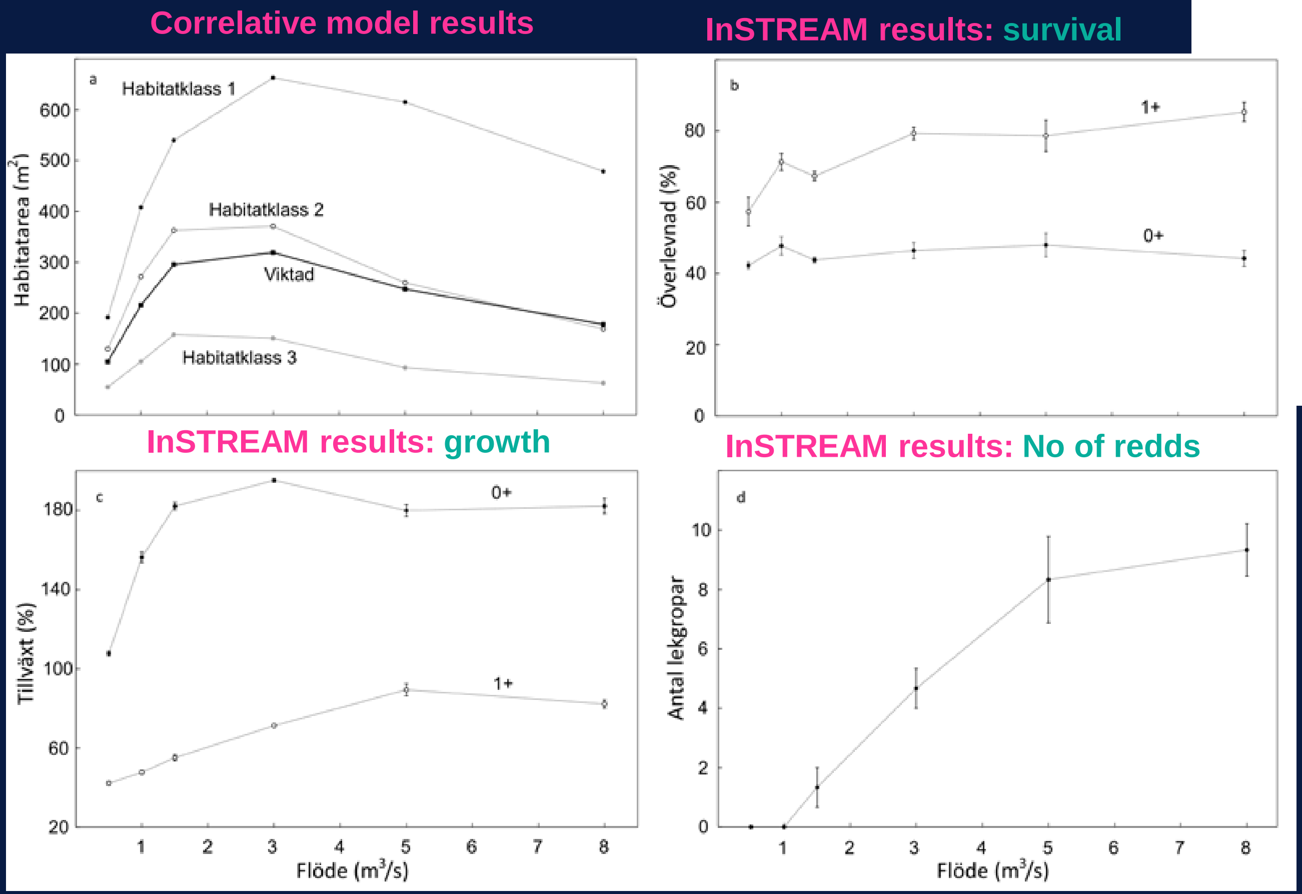
VATTEN – Journal of Water Management and Research 78: 2. 2022

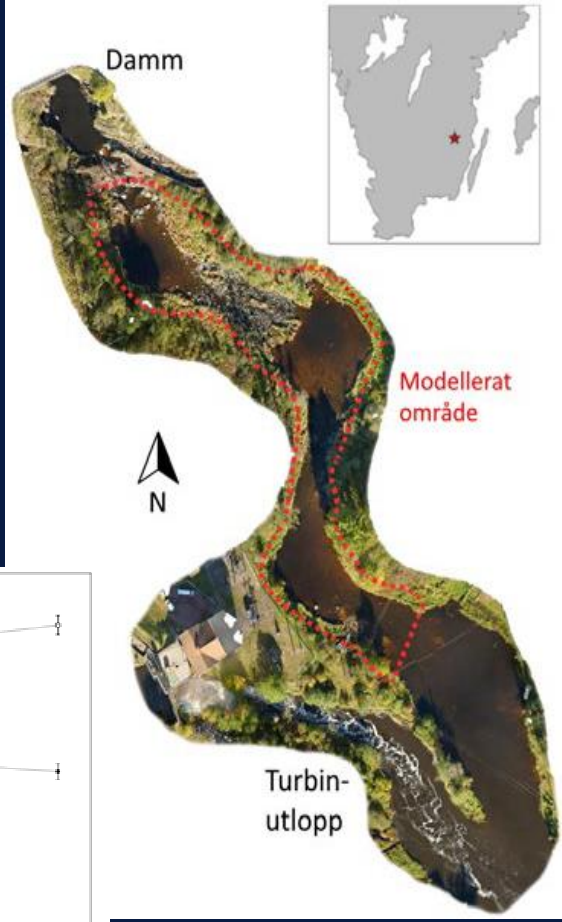
**HUR MYCKET VATTEN BEHÖVER HAVSÖRINGEN? EN JÄMFÖRELSE AV EN KORRELATIV OCH EN INDIVIDBASERAD MODELL FÖR ATT FÖRUTSÄGA EFFEKTER AV FLÖDEN PÅ STRÖMLEVANDE FISKAR**

HOW MUCH WATER DO SEA TROUT NEED? A COMPARISON BETWEEN A CORRELATIVE AND AN INDIVIDUAL-BASED MODEL TO PREDICT EFFECTS OF FLOW ON STREAM FISH POPULATIONS

*Johan Watz[1,*], Mahboobeh Hajiesmaeili[1], Louis Addo[1], Olle Calles[1], Ola Nordblom[2], Johan Tielman[3], John J. Piccolo[1]*

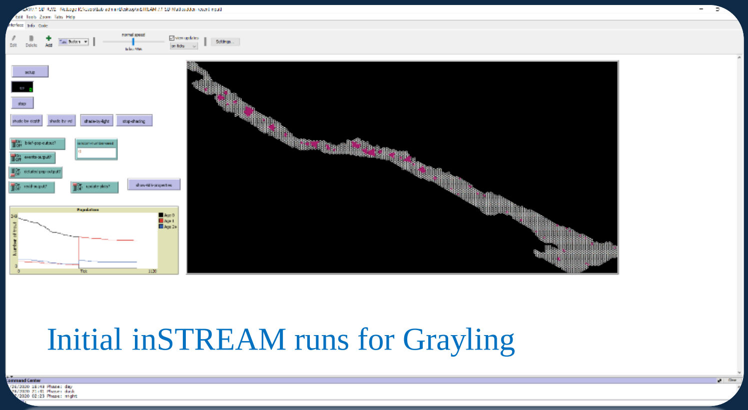
- Correlative models can be useful for predicating flow effects on the youngest year classes, but may underestimate flow requirements for larger fish.
- IBMs provide mechanistic explanations for observed phenomena and can be used with dynamic flows.



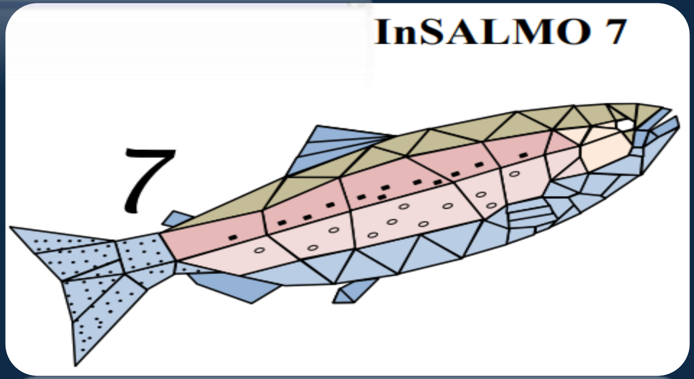



# *Future resesarch*

- Lower Gullspångsälven
  - InSALMO 7.3-SD (Lilla Å)
  - InSTREAM 7-SD (Stora Å)
- Dalälven
  - InSALMO 7.3-SD (Kungsådran)
- Grayling IBM (Luleälven)

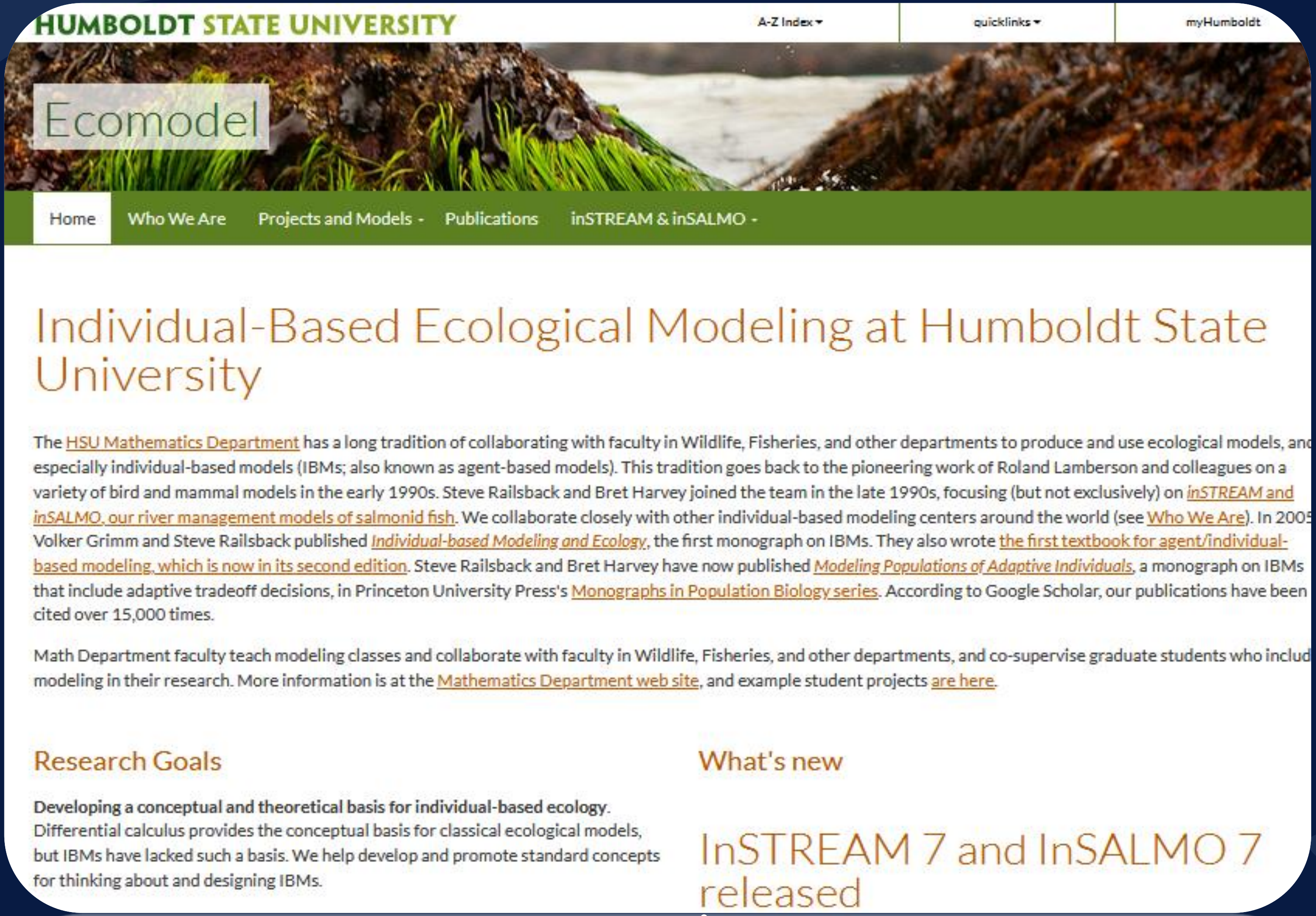


Initial inSTREAM runs for Grayling




# More information:

www.humboldt.edu/ecomodel



# Thank you

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