Sustaining hydropower production and salmonid populations: Ecological models for assessing hydropeaking and habitat restoration scenarios

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Ecological modeling with IBM (Individual-Based Mode

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MSc. Hydropower Development, Norway (2016)
BSc (hon) Agricultural Engineering, Ghana (2012)

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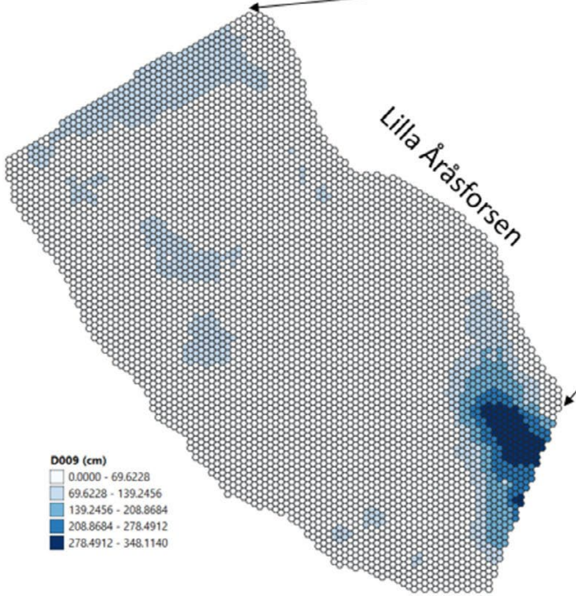
River Ecology and Management - RivEM

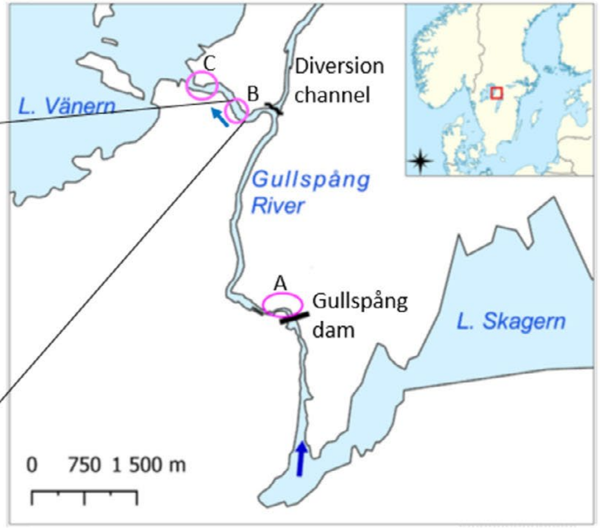
Hydropeaking and Fish

- Density of drifting invertebrates
- Stranding
- Spawning conditions e.g. redds dewatering
- Behaviour
- Growth
- Reproduction
- Mortality

→ Population development & community structure (long-term)

Lilla Åråsforsen





9m

Hydropeaking Regulation : 20 August to 19 April (9 to 230 m^3/s)

Lilla Åråsforsen : 9 to 80 m^3/s

Mitigation measures against hydropeaking effects

- Operational Measures ✓
  - ➢ Flow modification from the hydropower plant

→ Limiting max turbine Q, ramping rates,minimum flow modification, etc

- Constructional Measures ✗
  - ➢ Hydraulic structures

→ Additional channel, artificial reefs in reservoirs, canals for securing sailing depths, building of multi-level outlet structures in reservoirs

- Compensation and maintenance meaures
  - ➢ in-stream renovation works ✗
  - ➢ Maintenance measures

→ River widening, gravel and sediment placement, planting of trees, installing weirs, etc

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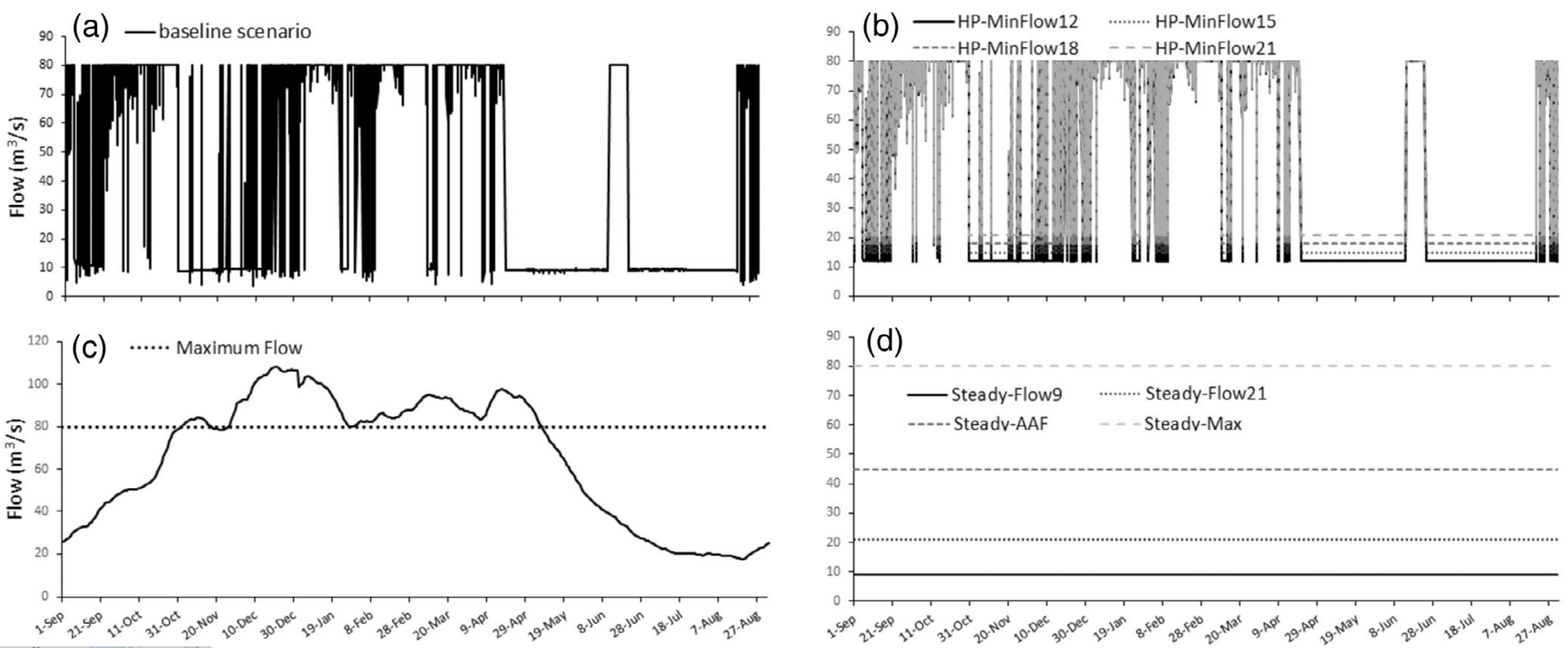
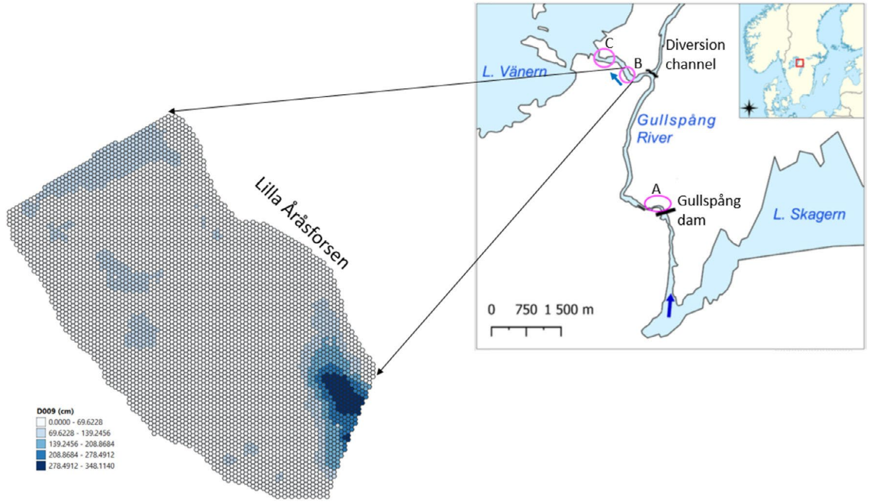
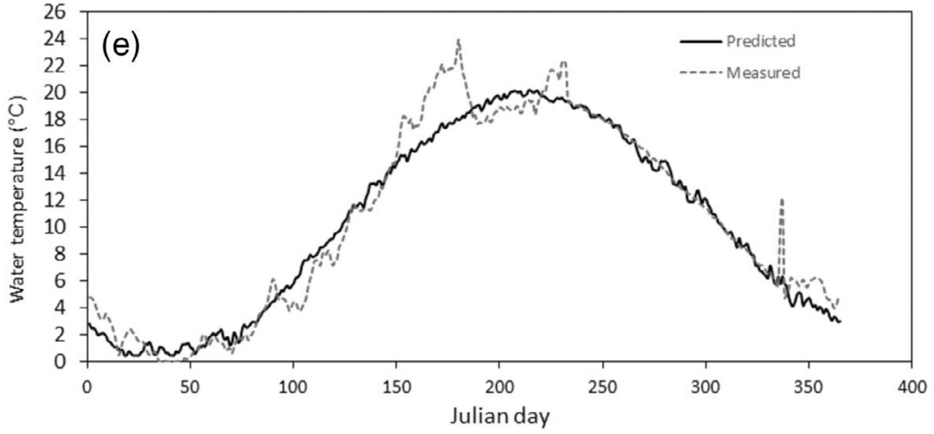
Flow scenarios







Project Objective

To demonstrate the application of IBM in large hydropeaking regulated river-reach

Population dynamics: Atlantic salmon and brown trout (growth, survival and distribution)

Model Capability: To handle hydropeaking simualtions

inSTREAM 7-SD (“SD” referring to the sub-daily flow fluctuations)

The first application of inSTREAM 7.2-SD

Main features

1. Architecture: ODD protocol from(Grimm et al. 2006, 2010, 2020)

Overview	Purpose
	State variables and scales
	Process overview and scheduling
Design concepts	Design concepts
Details	Initialization
	Input
	Submodels

Download : Download full-size image

Fig. 1. The seven elements of the ODD protocol, which can be grouped into the three blocks: Overview, Design concepts, and Details.

General advantages of inSTREAM 7

- Mechanistic
- Can make testable predictions of population responses to management
- Does not use WUA like PHABSIMs
- Growth, reproduction, mortality
- Sympatric and allopatric

High ecological realism than convensional methods

inSTREAM 7_SD

Key Model inputs:
- Habitat cell geometery
- Detailed 2-D hydraulic model output (water depth and velocity)
- time series of flow, temperature and turbidity
- initial fish population characteristics (species, fish size, number of fish)
- site- and species-specific parameters

Model outputs:
- Population (after hydropeaking)
- Growth (based on net energy intake rate)
- Survival (based fish size and predation risk)
- Behaviour (Activities: drift feeding, search feeding, and hiding)
- Fish distribution

InSTREAM simulations and analysis methods

One-year model runs, with five replicate simulations for each flow experiment.

01 Model calibration

Food availability, and fish predation risk parameters

02 Flow scenarios

- Baseline scenario: HP-MinFlow9
- Five HP scenarios: HP-MinFlow12, HP-MinFlow15, HP-MinFlow18 and HP-MinFlow21
- natural flow regime (S-HYPE)
- steady-flow scenarios: Steady-Flow9, Steady-Max, Steady-AAF, and Steady-Flow21

03 Daily light cycle

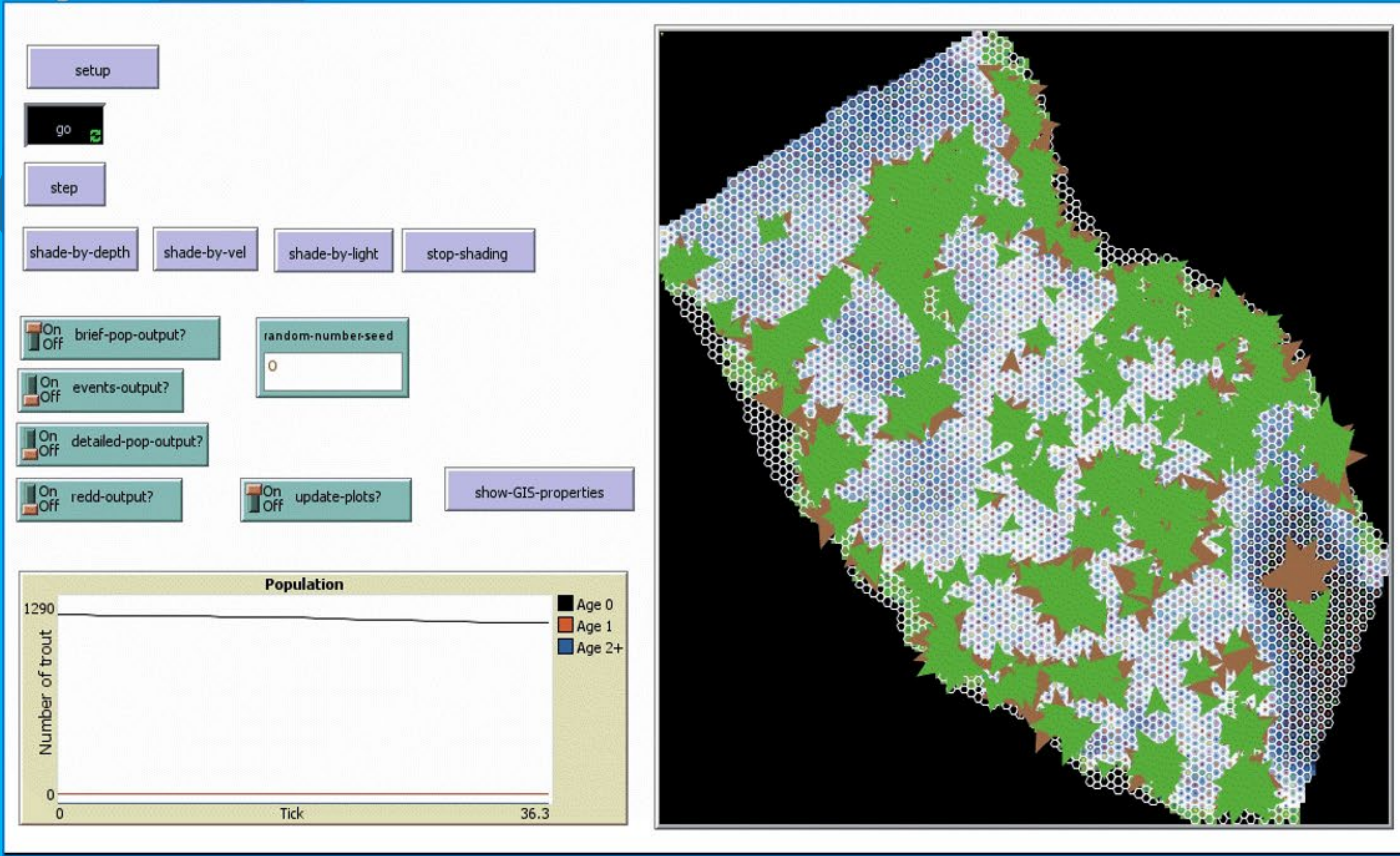
Feeding behavior during each light phase (night, day, dawn and dusk)

Selected flow scenarios:
Steady-Flow9, Steady-Flow21, HP-MinFlow9, and HP-MinFlow21,

04 Parameter uncertainty (Robustness analysis)

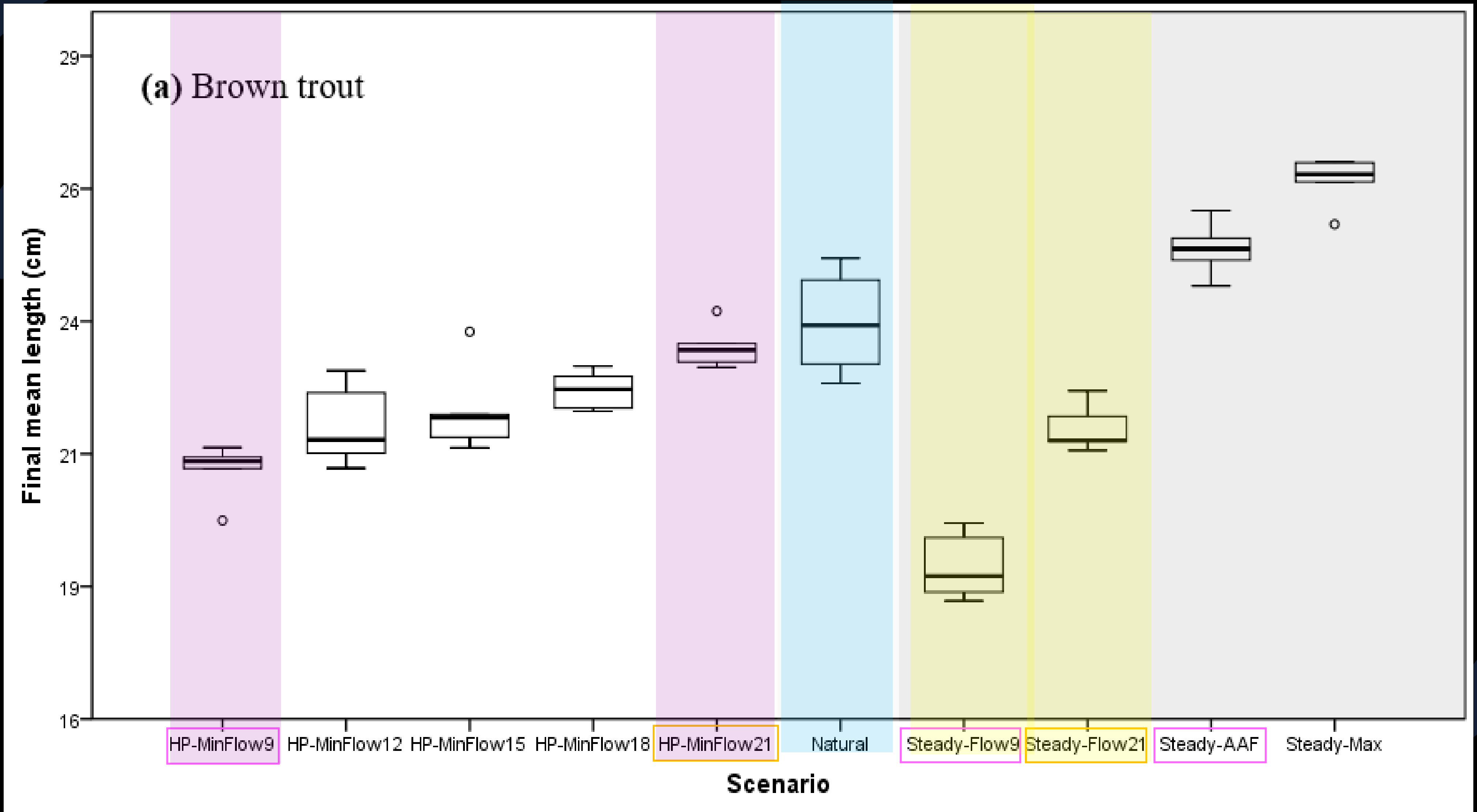
Three parameters:
food availability, survival from terrestrial and aquatic predation

InSTREAM simulation experiments

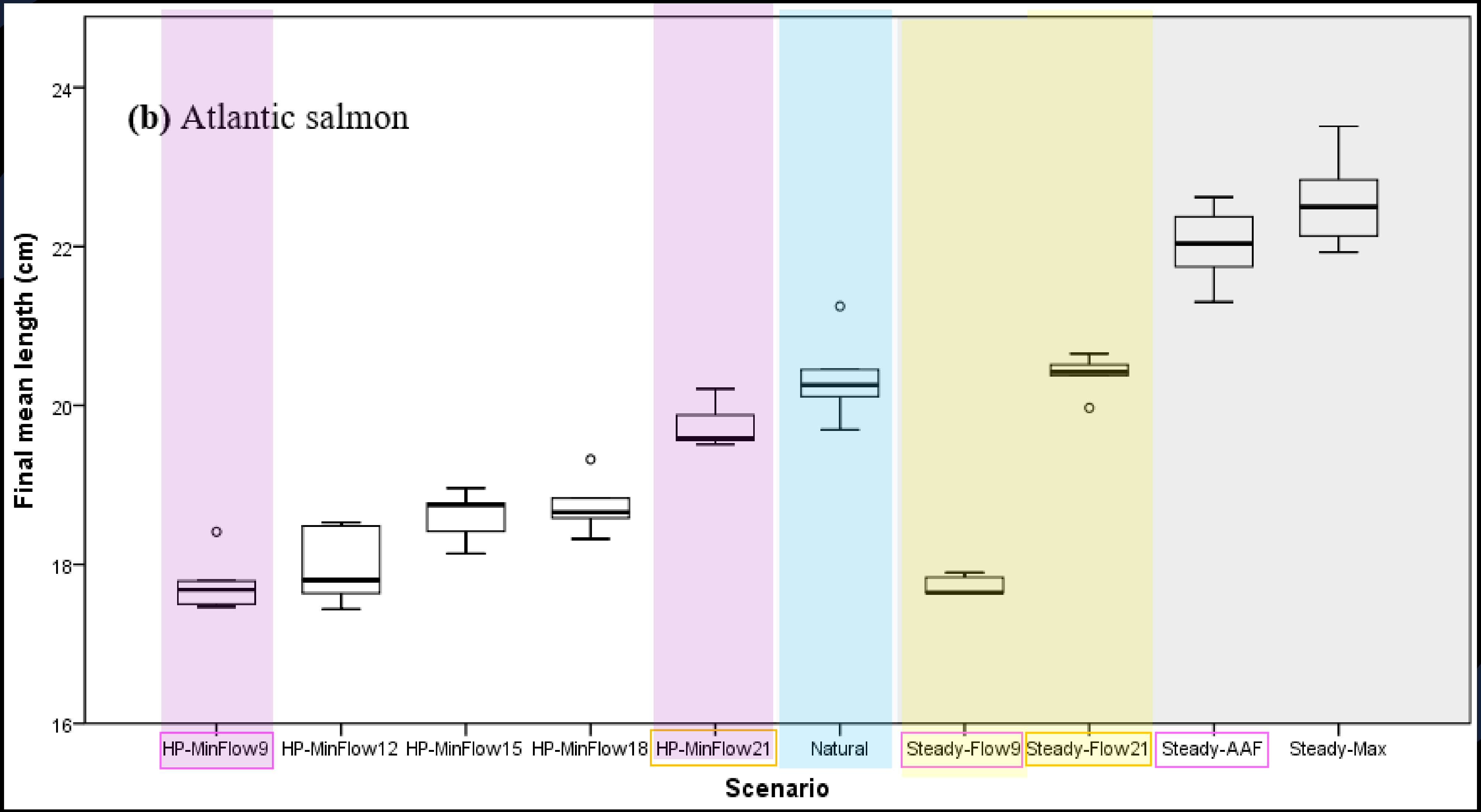


inSTREAM 7.2-SD model runs for LÅ

Results: Growth

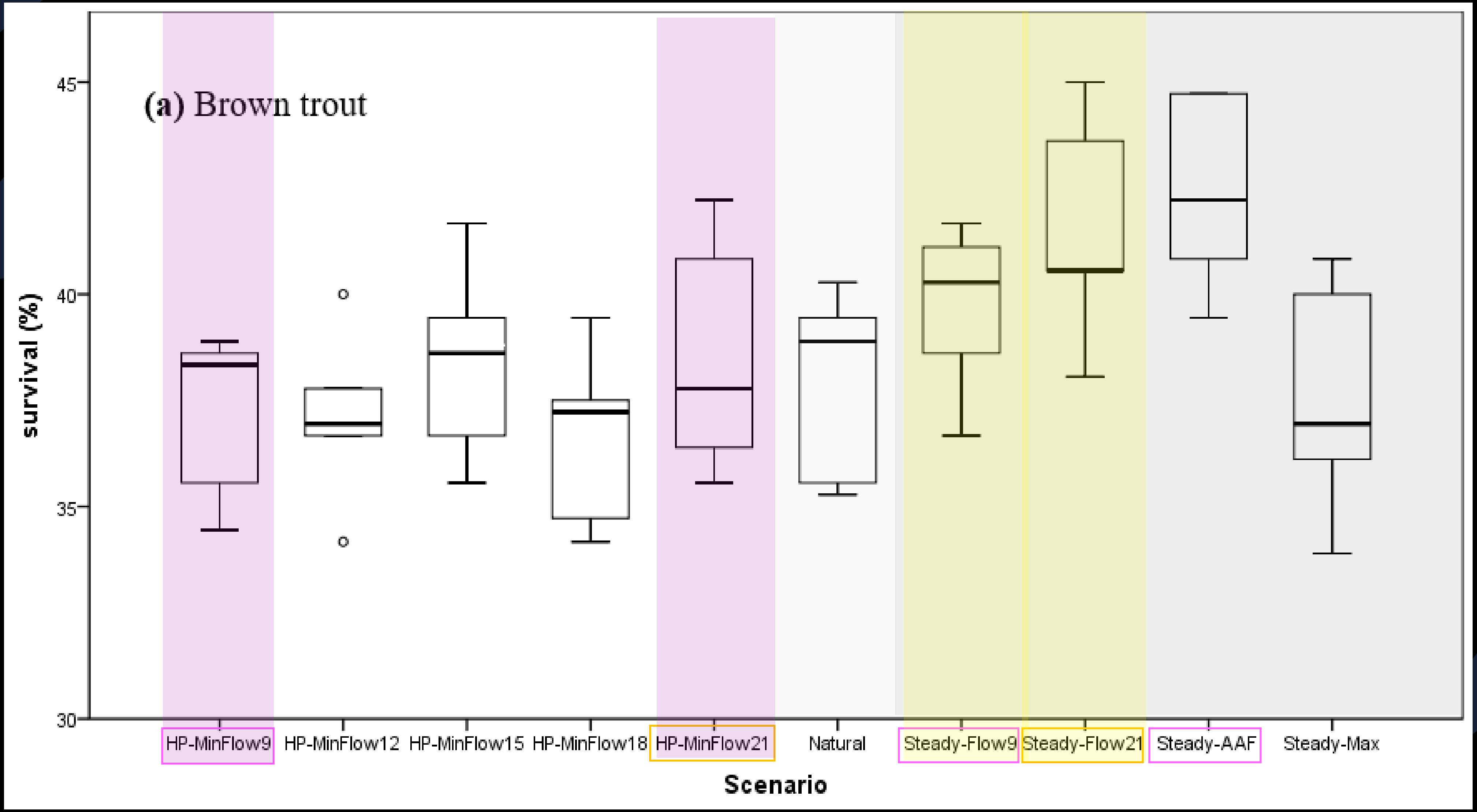


Growth

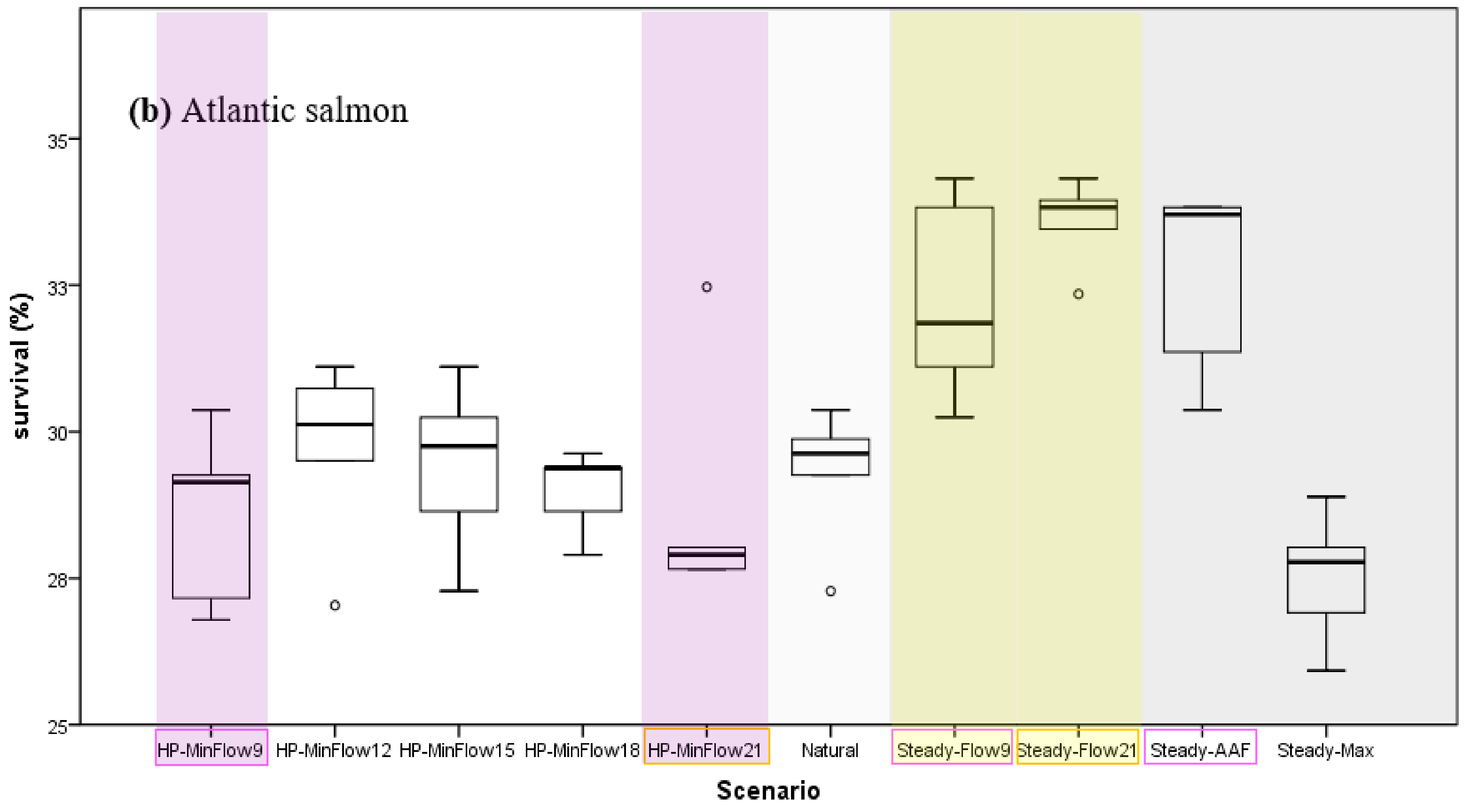


(b) Atlantic salmon
Final mean length (cm)
24
22
20
18
16
HP-MinFlow9
HP-MinFlow12
HP-MinFlow15
HP-MinFlow18
HP-MinFlow21
Natural
Steady-Flow9
Steady-Flow21
Steady-AAF
Steady-Max
Scenario

Survival

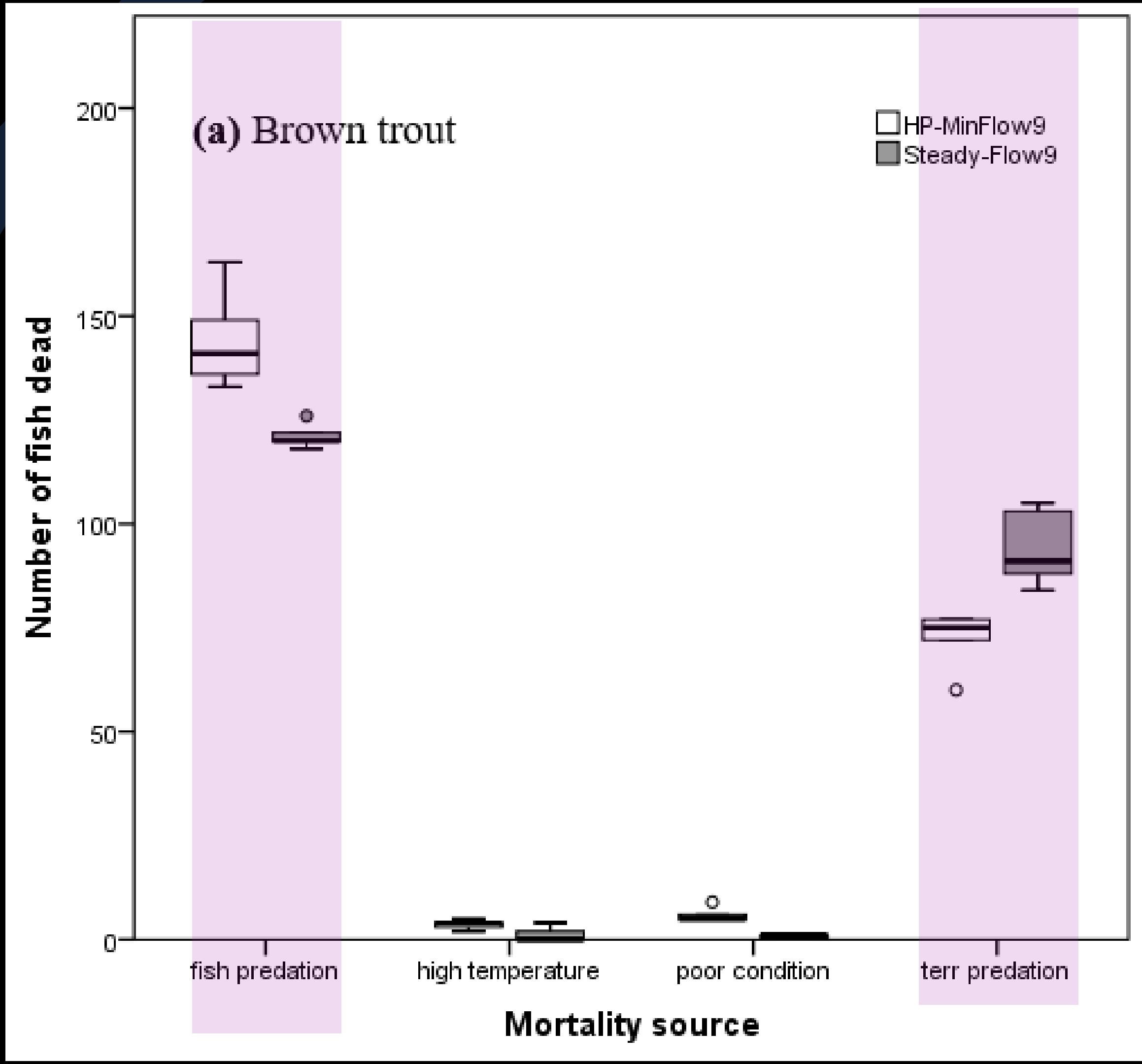

(a) Brown trout
survival (%)
45
40
35
30
HP-MinFlow9
HP-MinFlow12
HP-MinFlow15
HP-MinFlow18
HP-MinFlow21
Natural
Steady-Flow9
Steady-Flow21
Steady-AAF
Steady-Max
Scenario

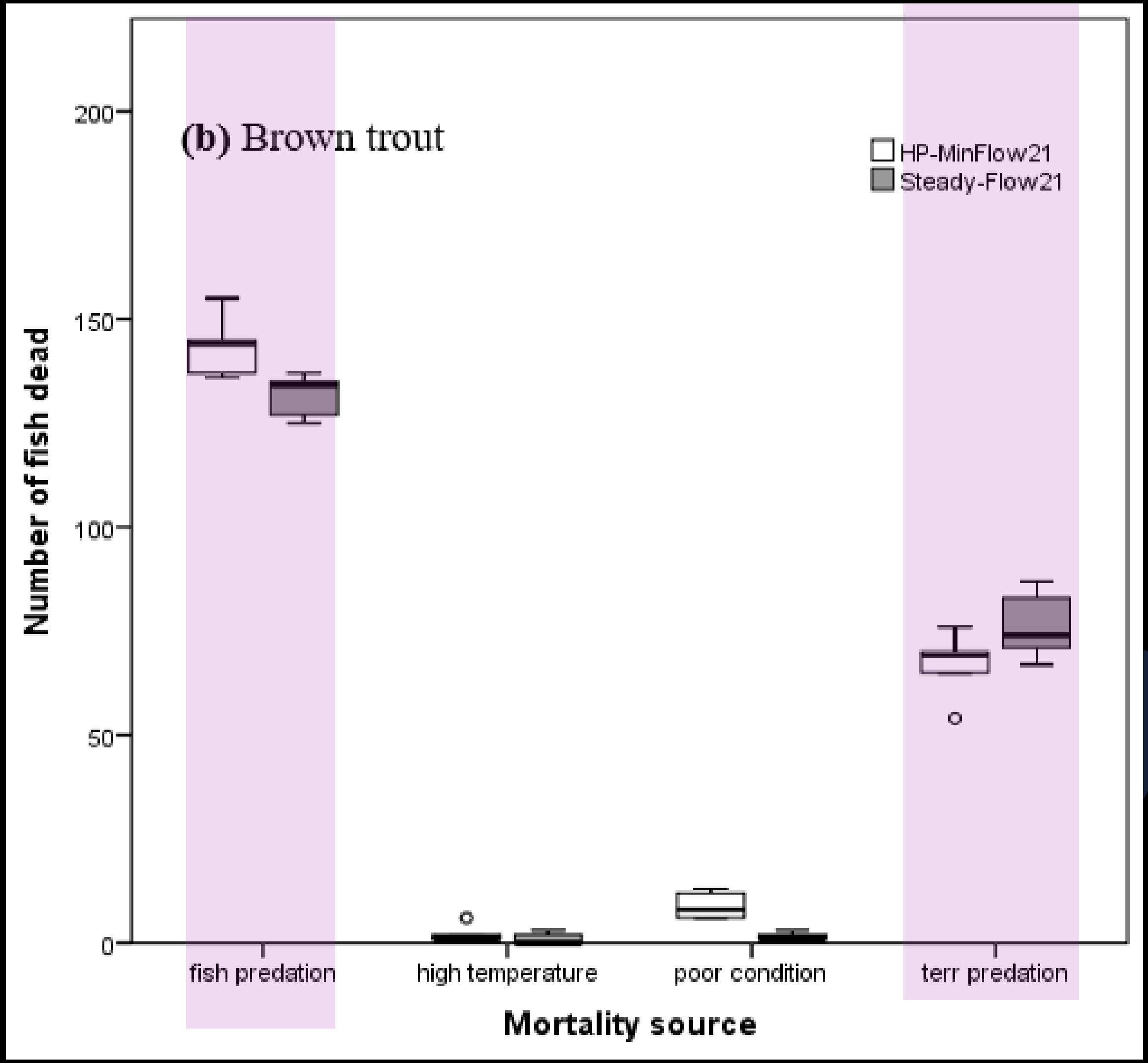
Survival

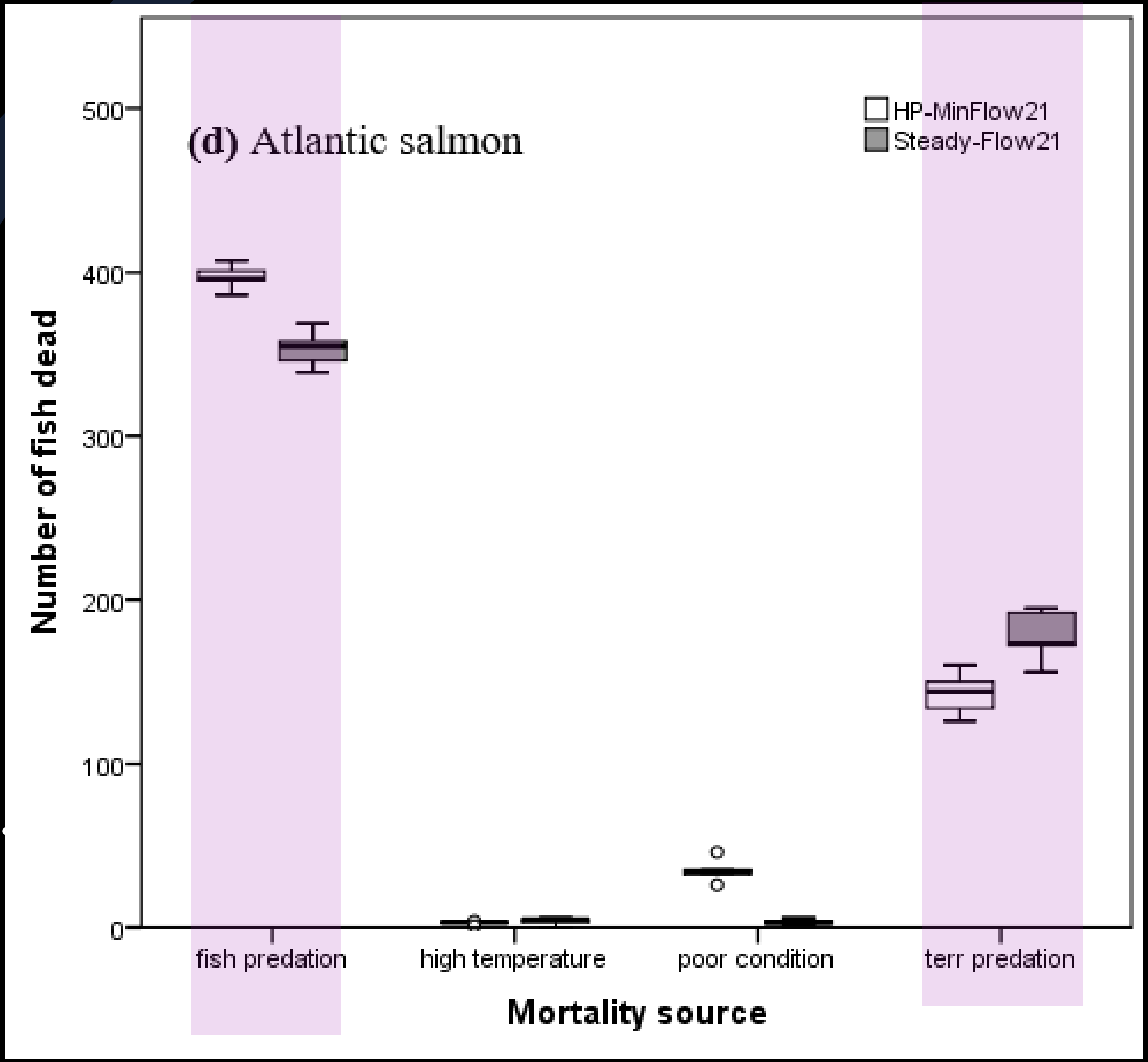


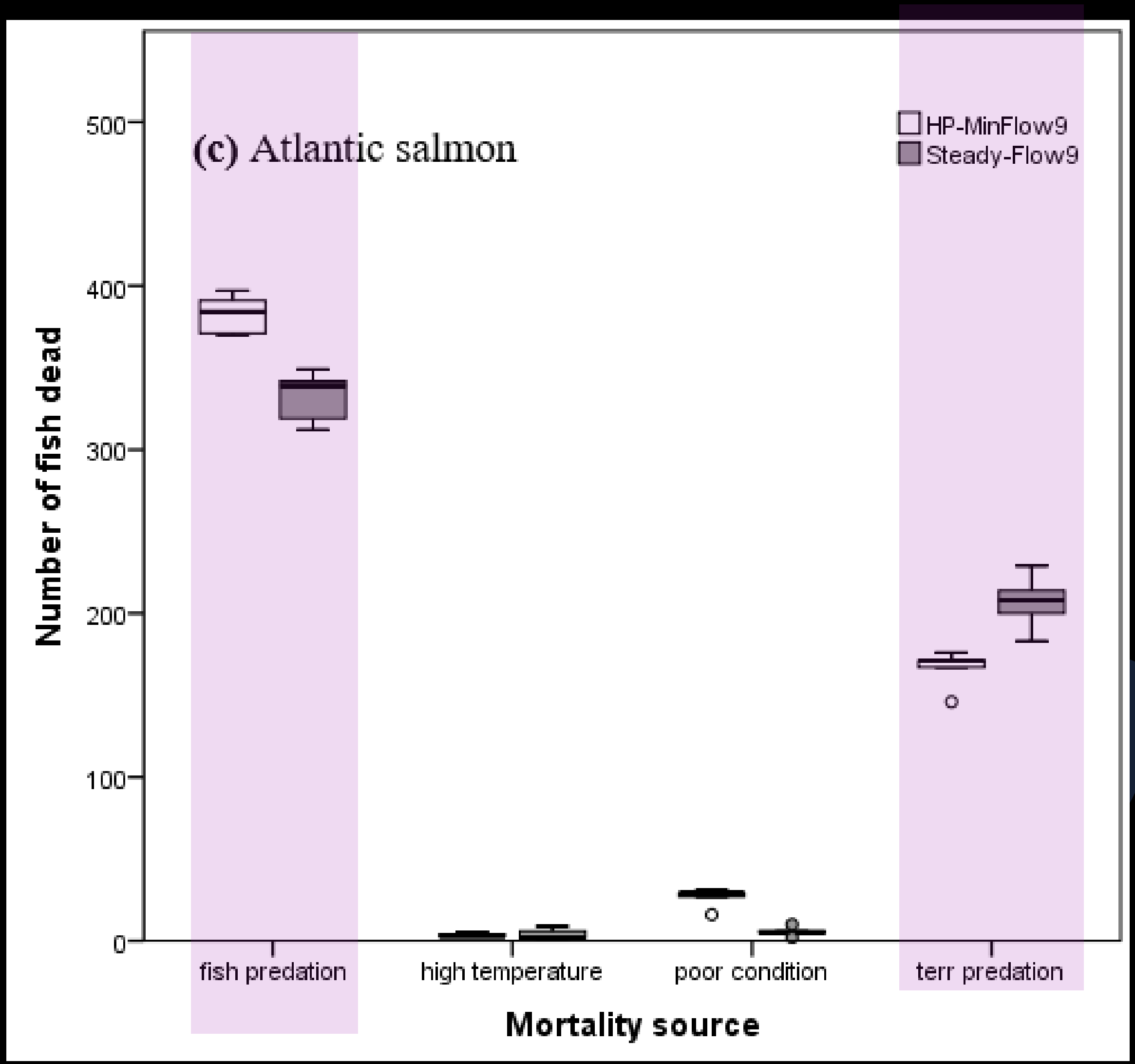
(b) Atlantic salmon
survival (%)
35
33
30
28
25
HP-MinFlow9
HP-MinFlow12
HP-MinFlow15
HP-MinFlow18
HP-MinFlow21
Natural
Steady-Flow9
Steady-Flow21
Steady-AAF
Steady-Max
Scenario

Mortality outputs



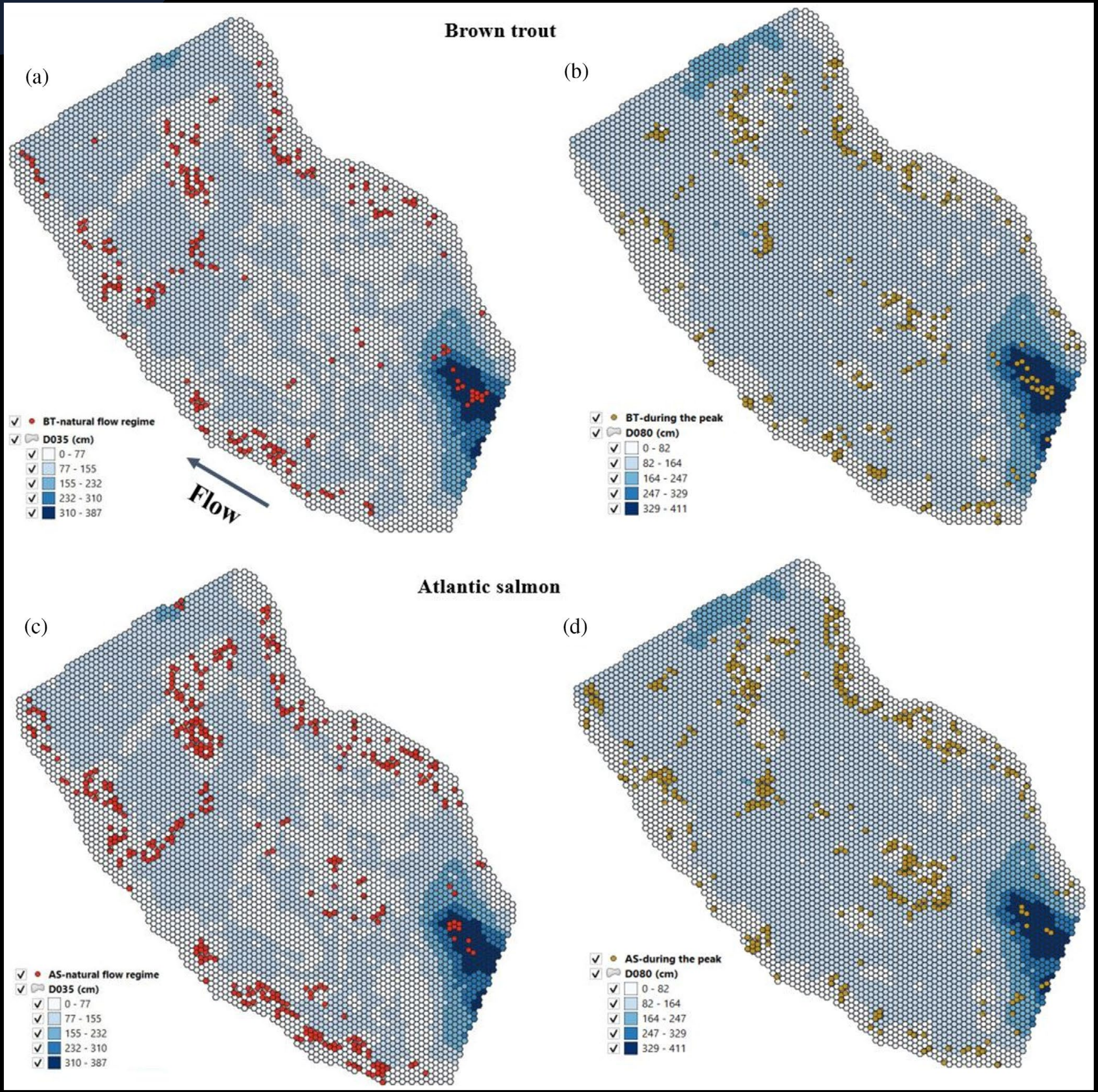



(d) Atlantic salmon
HP-MinFlow21
Steady-Flow21
Number of fish dead
500
400
300
200
100
0
fish predation
high temperature
poor condition
terr predation
Mortality source

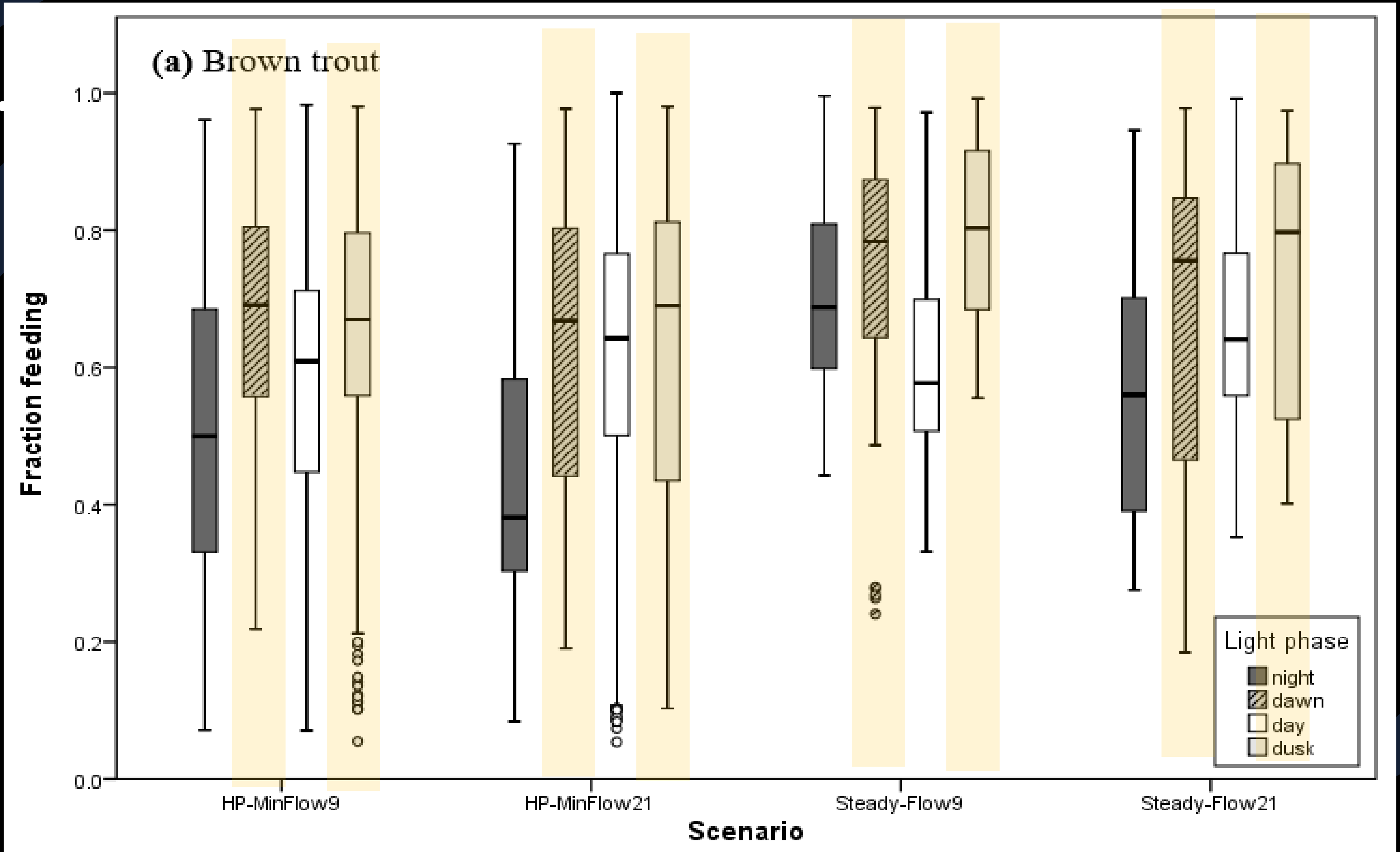

(c) Atlantic salmon
HP-MinFlow9
Steady-Flow9
Number of fish dead
500
400
300
200
100
0
fish predation
high temperature
poor condition
terr predation
Mortality source

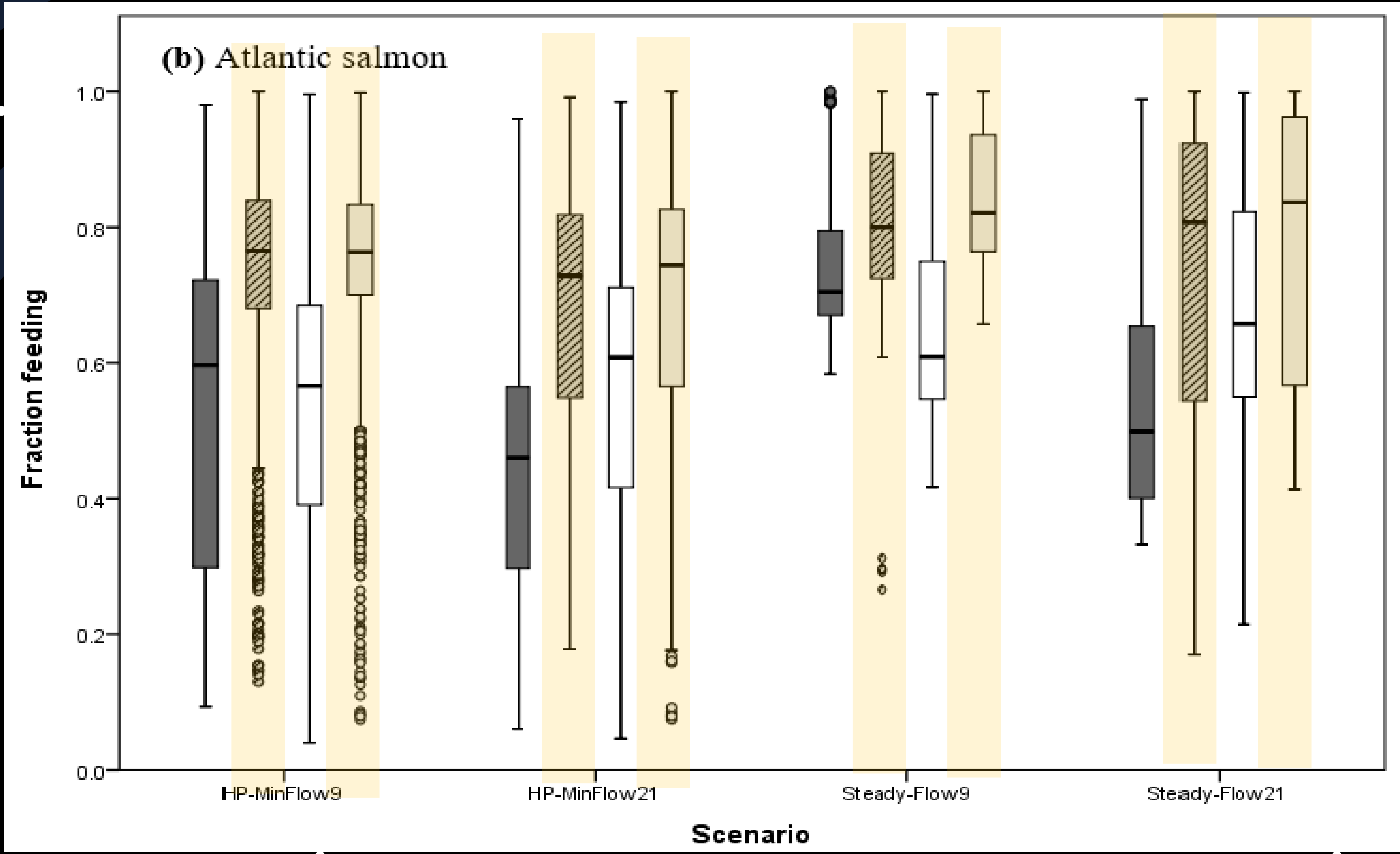
Fish distribution

- Distribution of brown trout (top) and Atlantic salmon (bottom) distribution along the river *under natural flow regime (a-c)* and during (b-d) a summer peak flow at the HP-MinFlow9 (baseline) scenario



Daily light cycle: feeding behavior




(b) Atlantic salmon
Fraction feeding
1.0
0.8
0.6
0.4
0.2
0.0
HP-MinFlow9
HP-MinFlow21
Steady-Flow9
Steady-Flow21
Scenario

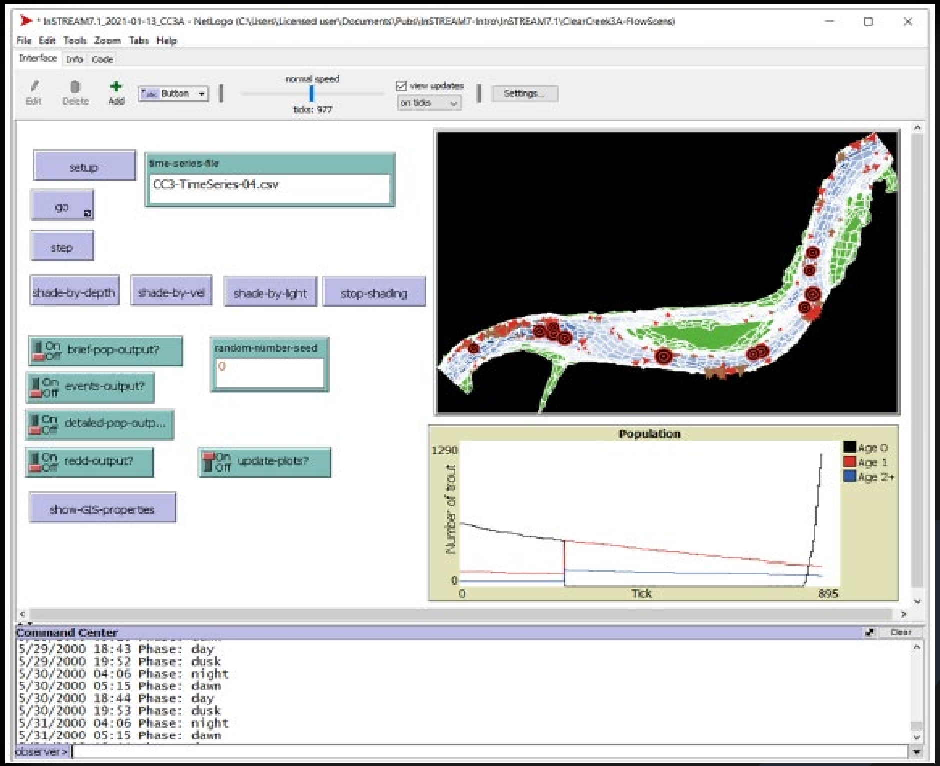
Summary

- Hydropeaking generally produced modest (~10%) negative effects on growth and survival of both species
- Survival was more affected than was growth; smaller fish were more affected than larger fish.
- On-peak (high) flows provided less profitable feeding conditions and more predation (lower survival).
- Predictions of potential benefits to the local trout and salmon populations are useful for assessing different scenarios using a cost-benefit analysis.

Gullspångsälven

Conclusion

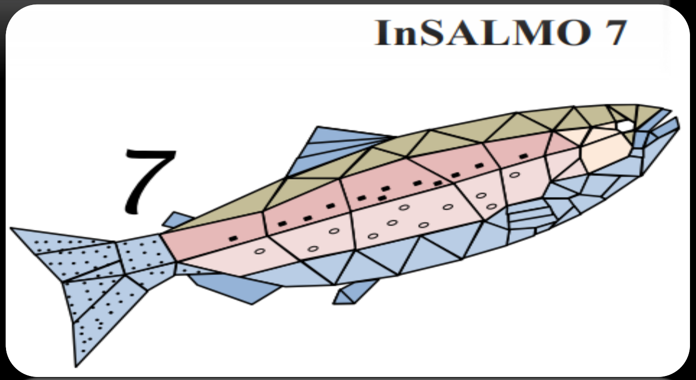
- InSTREAM 7.2-SD appears to capture ecologically-relevant behavioral patterns under hydropeaking.
- InSTREAM 7.2-SD includes the functionality necessary to address common hydropower management questions in northern rivers.
- Modelling studies have the potential to prioritize field studies.

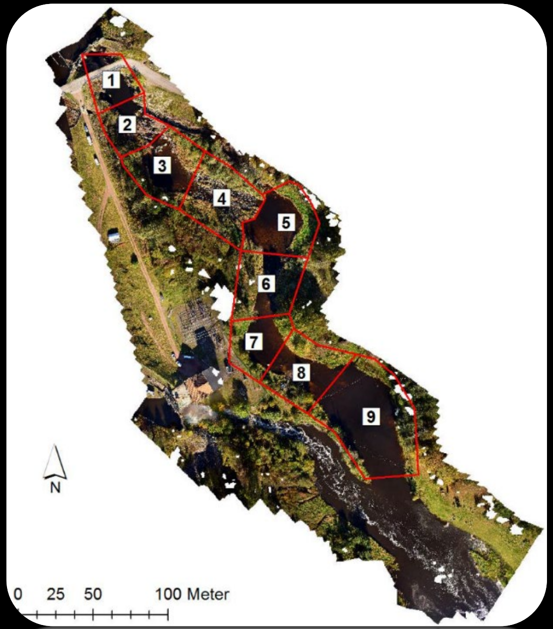


InSTREAM 7 interface (Railsback et al., 2021)

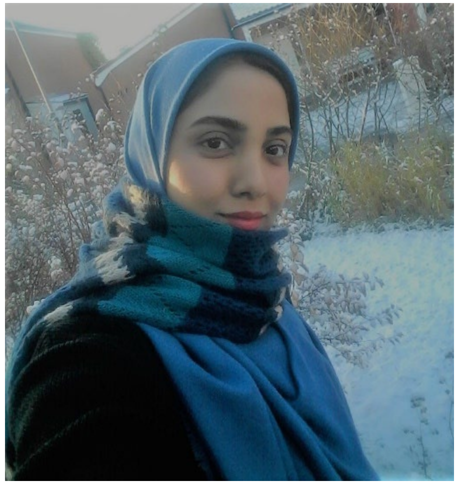
Future resesearch

- ✓ Greyling InSTREAM
- ✓ Lower Gullspångsälven
  - InSTREAM 7-SD (Stora Å): addition of features, climate changes, other operational measures.





Thank you



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SPECIAL ISSUE PAPER

WILEY

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

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Abstract

We developed an individual-based model (IBM) to understand the effects of hydropeaking on growth, survival and distribution of age 0+ to 1+ juveniles for high-conservation value populations of native brown trout (*Salmo trutta*) and Atlantic salmon (*S. salar*) in river Gullspång, Sweden. We parameterized and applied inSTREAM (7.2-SD) and calibrated the model by comparing predicted versus observed growth under the current hydropeaking regime (*n*=>1,200 model fish for 365 days). Our objective was to model growth, survival and distribution under flow scenarios with and without hydropeaking. We observed that hydropeaking generally resulted in modest (~10%) negative effects on growth and survival of both species. Survival was more affected than was growth, smaller fish more affected than larger fish. On-peak (high) hydropeaking flows resulted in less profitable feeding conditions (less growth) and higher predation (lower survival). Thus, inSTREAM 7.2-SD appears to capture ecologically-relevant behavioral patterns under hydropeaking, for example, habitat selection, in response to rapid flow changes. Understanding such patterns for large rivers via manipulative field studies, even if possible, would be time-consuming and costly. Our study demonstrates the potential of IBMs as powerful tools for testing research questions and assessing and prioritizing alternative management strategies in regulated rivers.

KEYWORDS
growth, habitat selection, hydropeaking, individual-based modelling, inSTREAM, salmonid, survival

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