SVENSKT CENTRUM FÖR HÅLLBAR VATTENKRAFT

Tools for successful river restoration

Olle Calles and colleagues

River Ecology and Management (RivEM)

Karlstad University, Sweden

FORMAS

Improve Aquatic LIFE

Swedish Energy Agency

Foton: Jörgen Wiklund ©

Outline for restoration tools talk

- ✓ River Ecology and Management (RivEM)
- ✓ NAP and the need for evidence-based river restoration tools
- ✓ 5 tools and 10 FAQ for successful restoration of regulated rivers
- ✓ Toolbox take home message

FAQ #1-10

KARLSTAD UNIVERSITY

FOR STUDENTS FOR EMPLOYEES FOR ALUMNI FOR MEDIA

THE FACULTY OF HEALTH, SCIENCE AND TECHNOLOGY MENU

THE FACULTY OF HEALTH, SCIENCE AND TECHNOLOGY

DEPARTMENT OF ENVIRONMENTAL AND LIFE SCIENCES

Geomatics
(GIS)

Biology

Landscape ecology (Terrestrial ecology)	**RivEM** (Aquatic ecology)	**Evolution** (Evolutionary ecology)	**Biology didactics** (Teaching science)

Collaborative research projects

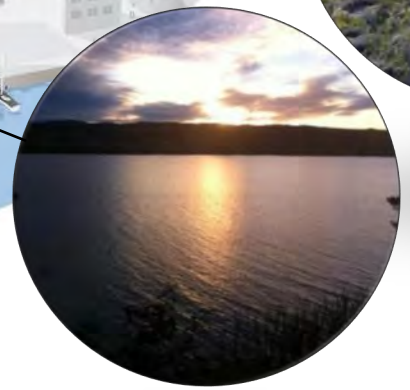
Aquatic ecology

River Ecology & Management







10 PhD students
5 postdocs
10 researchers
Students & trainees

Illustration: Kjell Ström

Environmental effects of river regulation

Dry stretches
- Lost lotic habitat
- Reduced flow

Floodplains
- Flow regulation

Impounded area
- Altered riparian zone
- Lost lotic habitat
- Barriers to migration
- Reduced exchange land/water
- Increased sedimentation

Dams
- Fragmentation
- Modified flows

Tail-race
- Reduced lotic habitat
- Deep & straight

Braided channels
- Flow regulation

Miljösamverkan Sverige

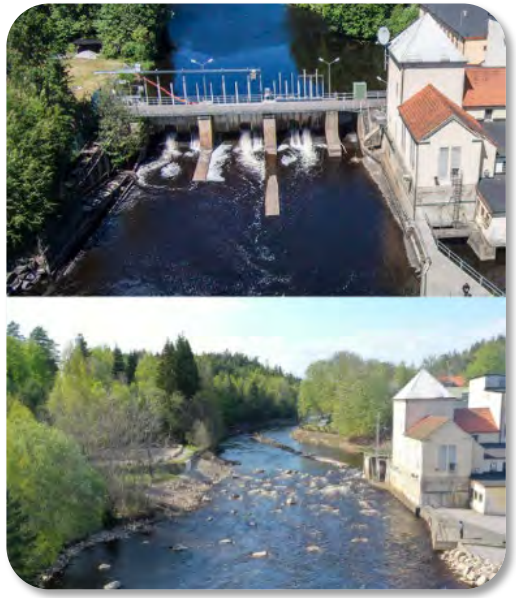
Illustration: Dietmar Kämmerling

The river restoration toolbox

Upstream passage

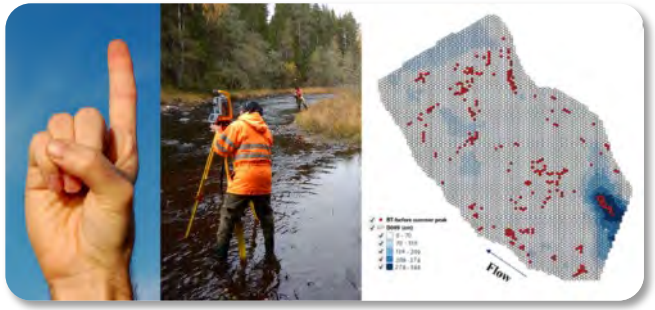
Habitat restoration

Dam removal



Downstream passage

Flow regimes



Evaluation

The river restoration toolbox

Upstream passage

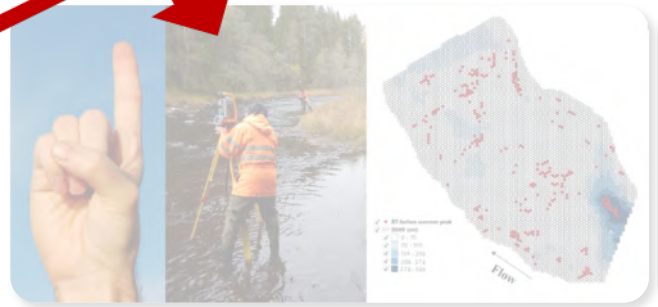
Habitat restoration

Dam removal

EVIDENCE-BASED TOOLS!
→What? →Where? →When?

Downstream pa

ow regimes



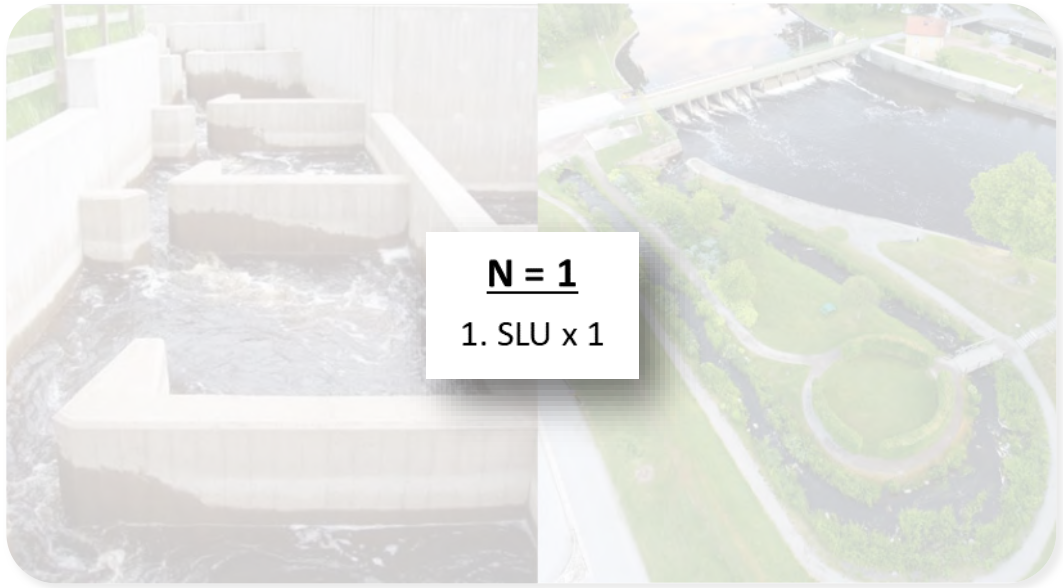
Evaluation

SVENSKT CENTRUM FÖR HÅLLBAR VATTENKRAFT

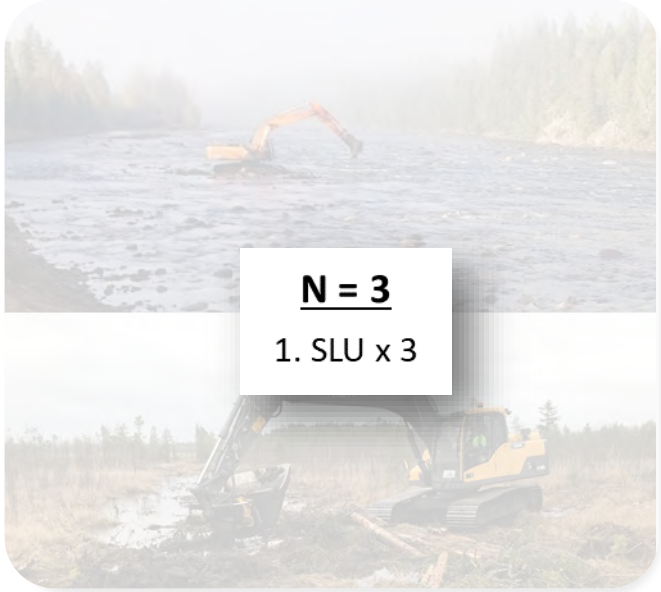
The river restoration toolbox

N = 3
1. LTU x 3

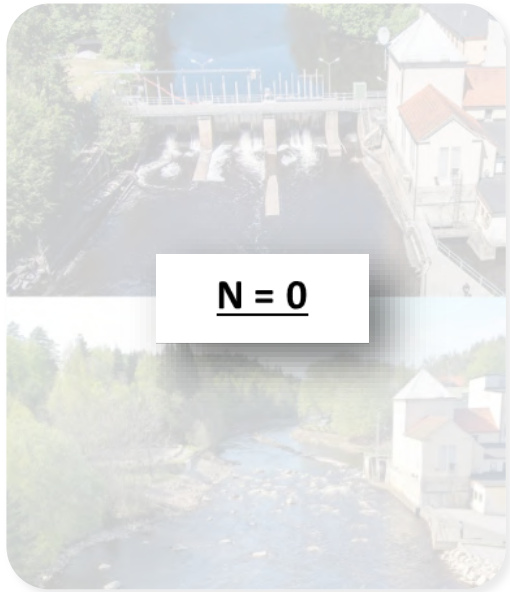
Upstream passage



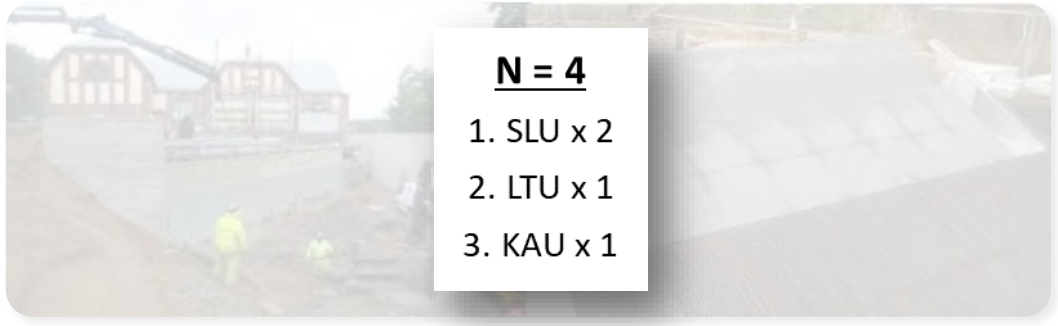
Habitat restoration



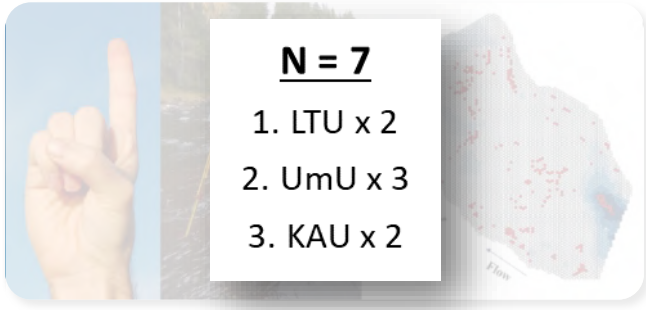
Dam removal



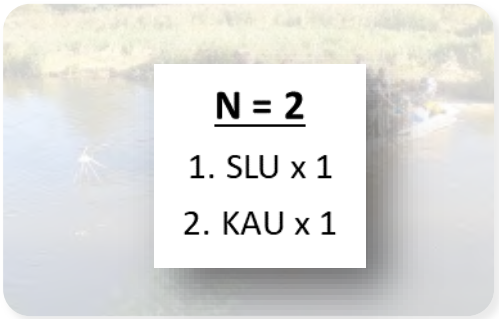
Downstream passage



Flow regimes



Evaluation



Tool 1

Fish passage

Niclas Carlsson

FAQ #1

Innovative (!) solutions

Sam Shry

fortum fishheart eurostars

uniper LIFEConnects TiVA

PhD Shry (2026)

Functionality of Depth Restricted Inclined Fish Screens (DRIFS) for downstream passage of brown trout at hydropower plants

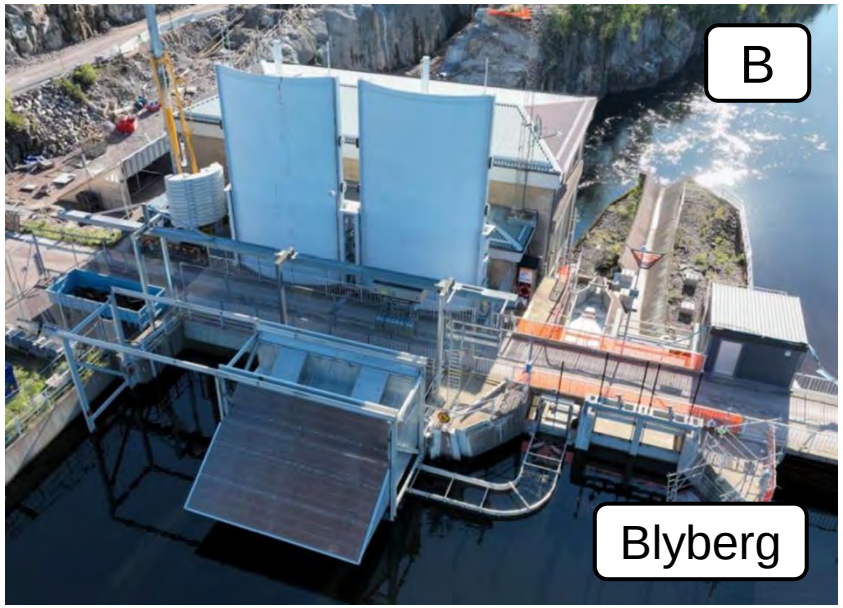
FAQ #2

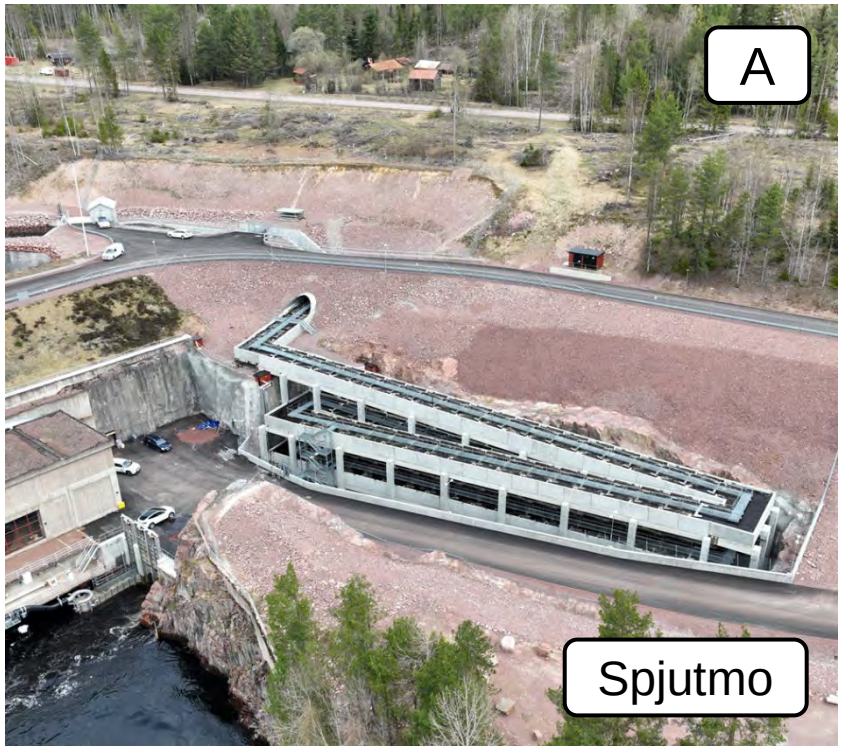
Daniel Palm, Johan Leander, Petter Lundberg, Gustav Hellström, Tomas Brodin

Dept. Wildlife, Fish and Environmental Studies, SLU, Umeå

SVENSKT CENTRUM FÖR HÅLLBAR VATTENKRAFT

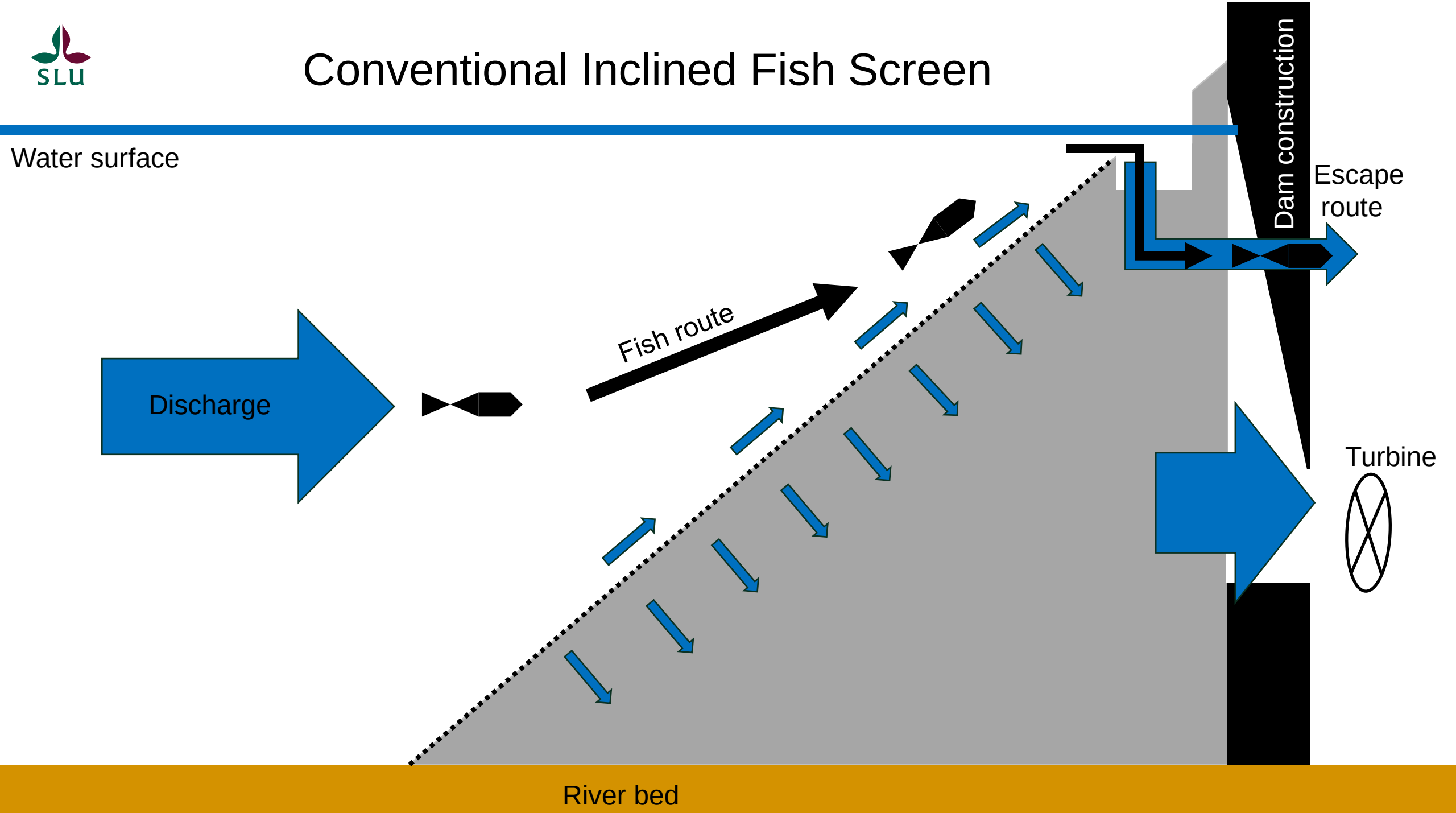
SCIENCE AND EDUCATION FOR SUSTAINABLE LIFE


B
Blyberg

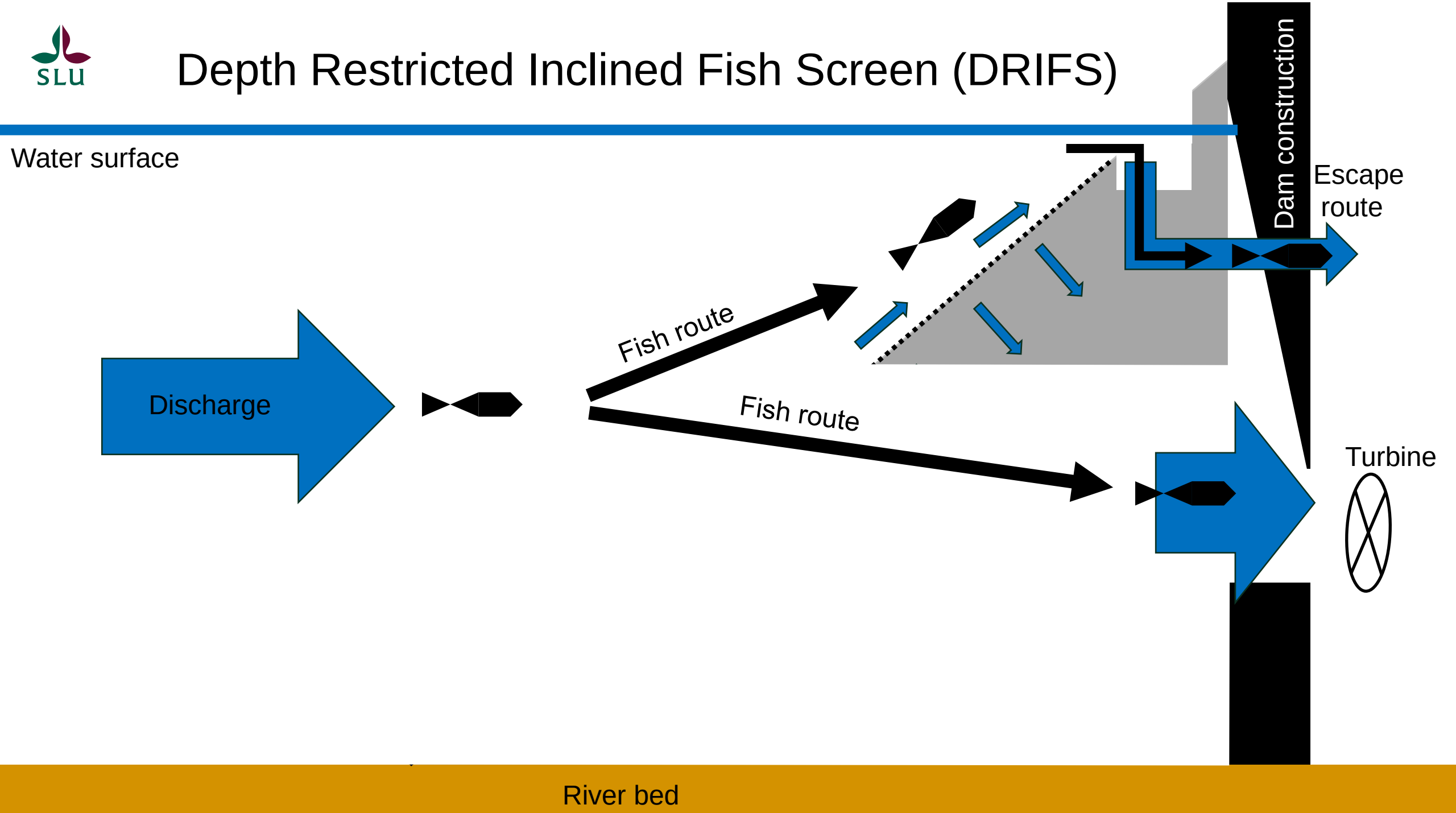

A
Spjutmo


Study site
Rot
Västermyckeläng
C
Evertsberg
B
A
Våmhus
Orsa
Vattnäs
Mora
Venjan
Vinäs
Sollerön
Gesunda
Nedre Gär
70
Rättvik
Tällberg
Siljansnäs
Leksand
Västanvik
E45
E45
Sverige
Norge
Finland
Oslo
Estland
Lettland
Danmark
Litauen
Österdalälven - Siljan

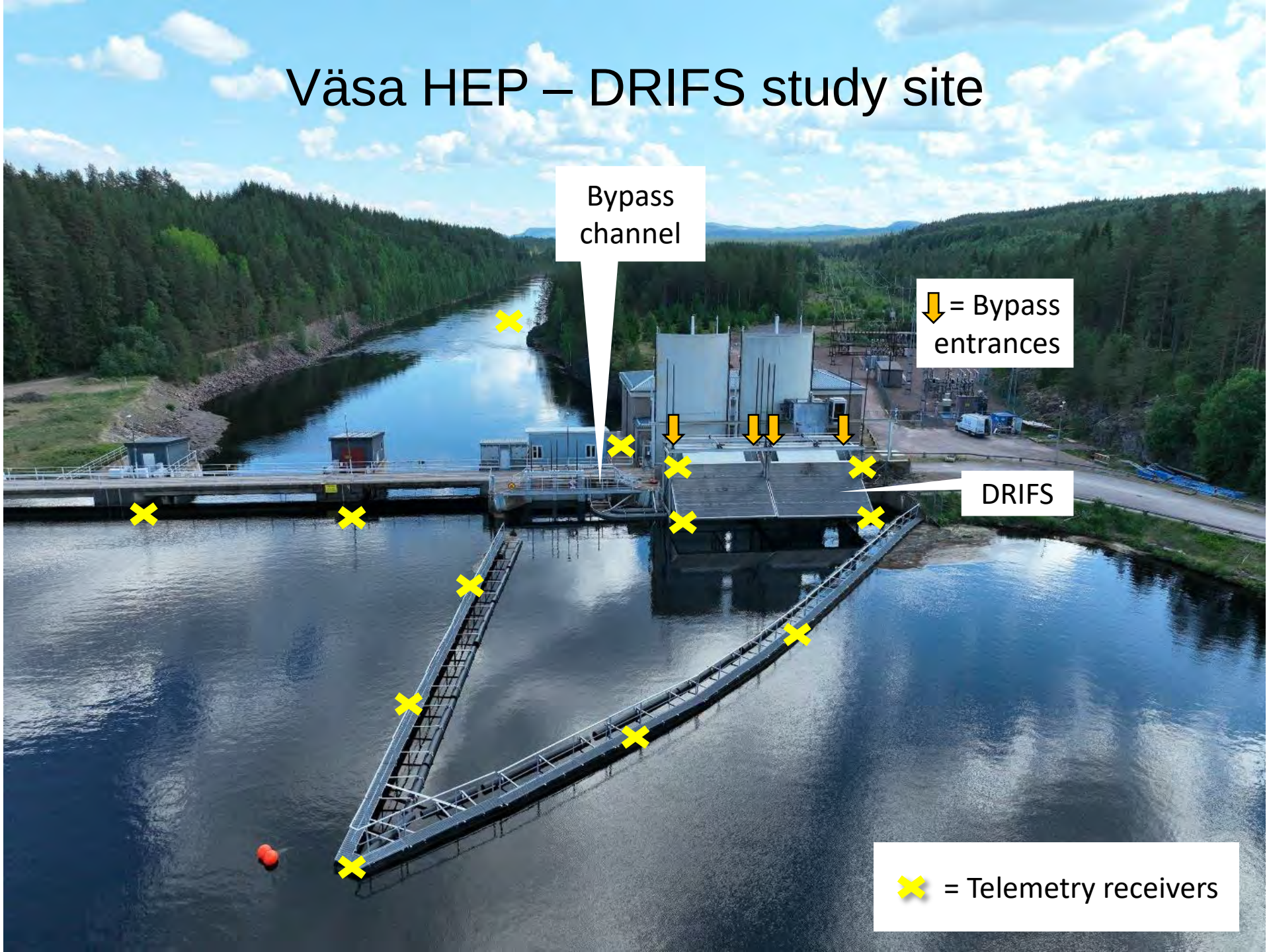
Conventional Inclined Fish Screen



Depth Restricted Inclined Fish Screen (DRIFS)



Väsa HEP – DRIFS study site



Florian Eggers

FAQ
#3

Nature-like versus technical fishways:

Combining fish counter and electrofishing data to evaluate passage effectiveness at the community level

Florian Eggers, Johan Watz, Martin Österling, Viktor Hebrand & Olle Calles

Department of Environmental and Life Sciences
Karlstad University, Sweden

RIBES

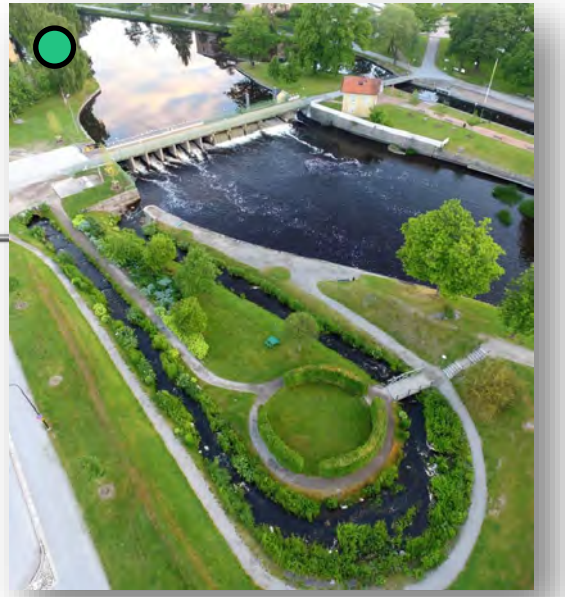
Fiskevårdsteknik AB

This project has received funding from the European Union Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Actions, Grant Agreement No. 860800

The study

- Fish counter data (Fiskdata.se)
  - Nature-like: 20
  - Technical: 15 st
- Fishway information

  https://viss.lansstyrelsen.se/
- Electrofishing data (slu.se)
  - Sampling after the year 2000
  - ± 25 km … etc



Eggers *et al.* (*submitted*)

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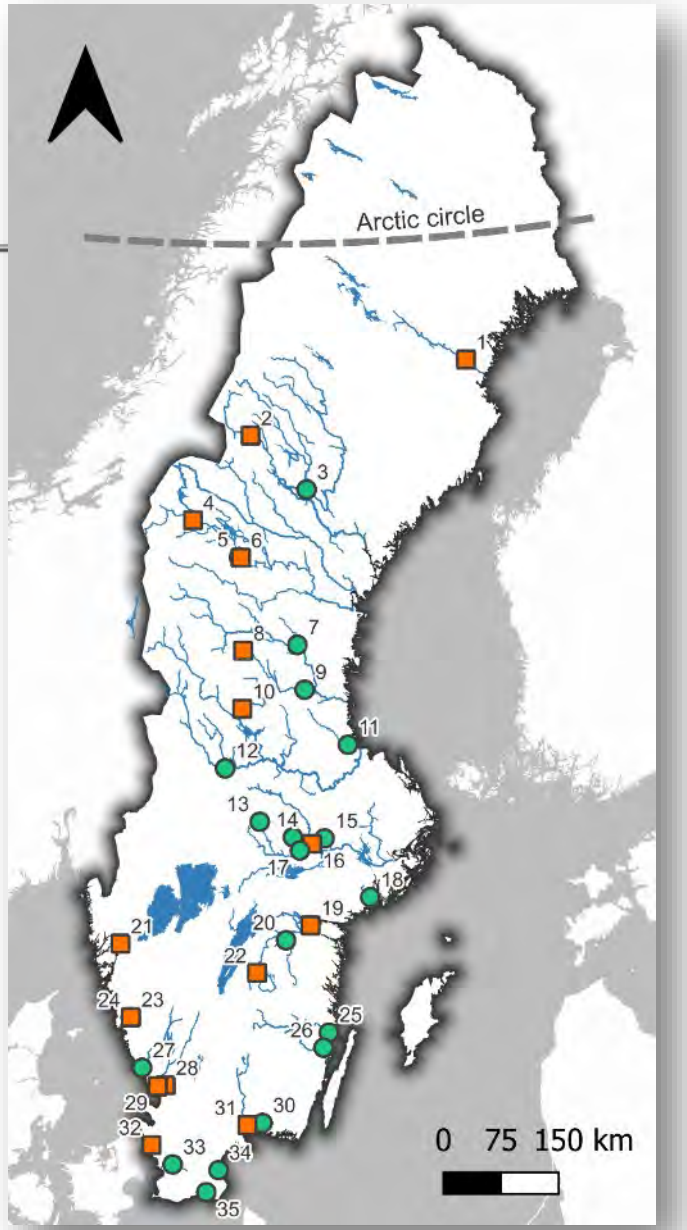
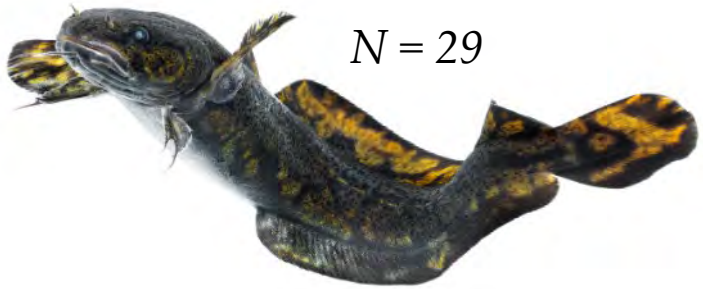


Eggers *et al.* (*submitted*)

The most commonly detected species

$N = 20$

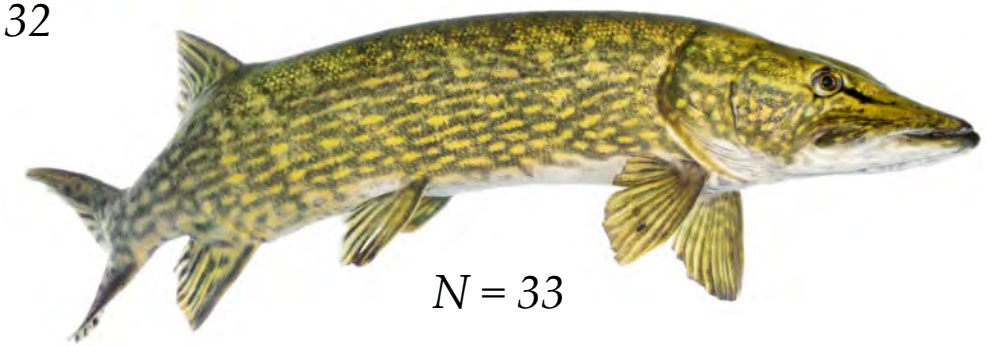
$N = 35$



$N = 29$

$N = 32$

$N = 32$



$N = 33$

Eggers *et al.* (*submitted*)

Joschka Wiegleb

FAQ #4

Using machine learning for improved eel downstream passage design

Olle Calles, Stefanos Georganos & Joschka Wiegleb - Karlstads universitet

Ana Silva, Benjamin Cretois, Kim Magnus Bærum & Torbjørn Forseth - NINA

David Aldvén - Vattenfall

Karlstads Universitet

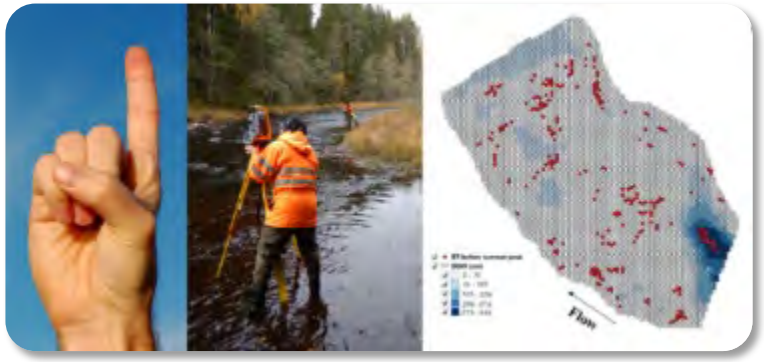
RivEM

NINA Norwegian Institute for Nature Research

Energiforsk

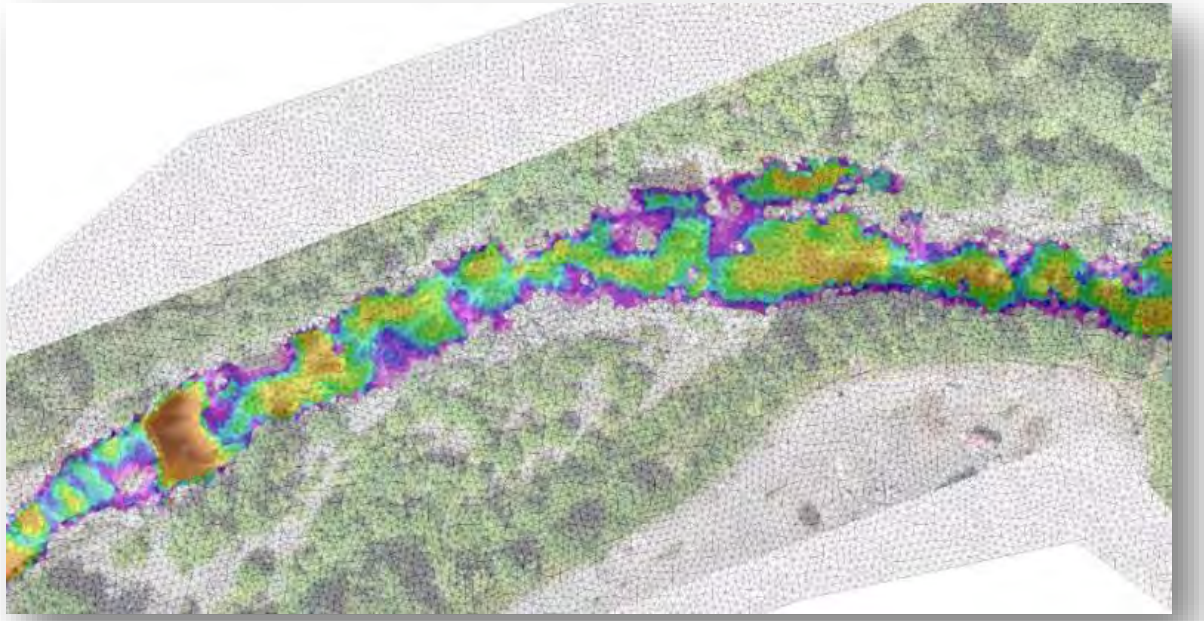
Svenskt Vattenkraftcentrum

Vattenfall



Tool 2

Flow regimes



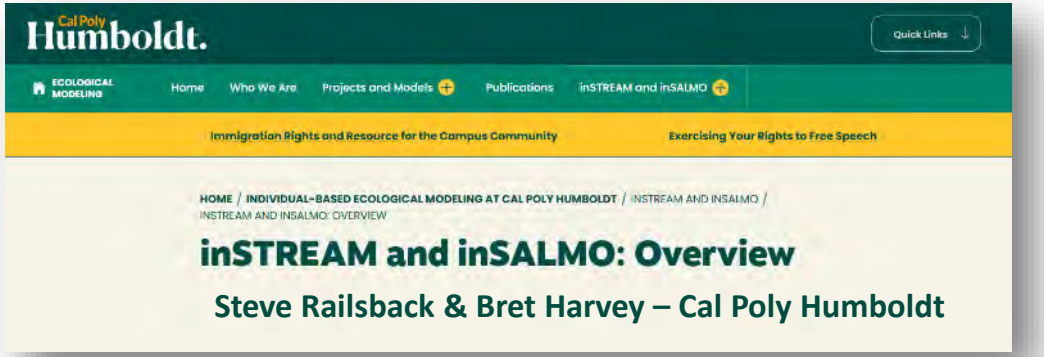
Mahboobeh
Hajiesmaeili

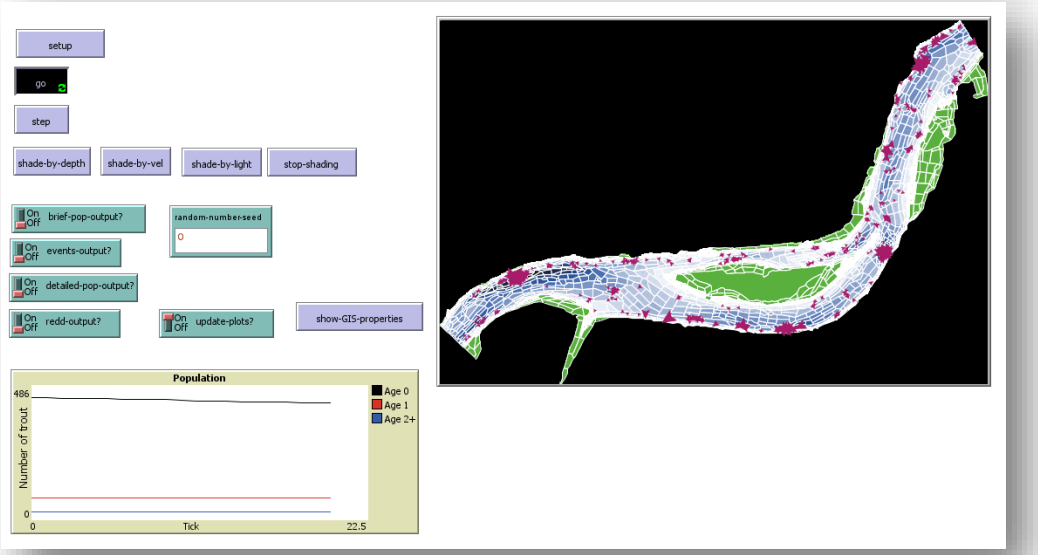
Individual-based modelling for assessing instream flow and habitat restoration measures - *inSTREAM* and *inSALMO*

Mahboobeh Hajiesmaeili, Fahimeh Rashidabadi,
Louis Addo, Johan Watz, & John Piccolo

Karlstad University

The IBMs inSTREAM and inSALMO





- IBMs developed over a 30-year period
- Fitness-based measures of habitat quality
- Applying ecological theory to ecohydraulics:
  - GIS-based habitat maps
  - River bed topography
  - 2-D flow models
- Predict effects of stream flow and habitat restoration on fish populations

The IBMs inSTREAM and inSALMO

SVENSKT VATTENKRAFTCENTRUM

Hem » Events » Research School 2026: Introduction to Salmonid IBMs

9/03
10/03

PLATS: KARLSTAD UNIVERSITY
TID:

KOMMANDE

DELA

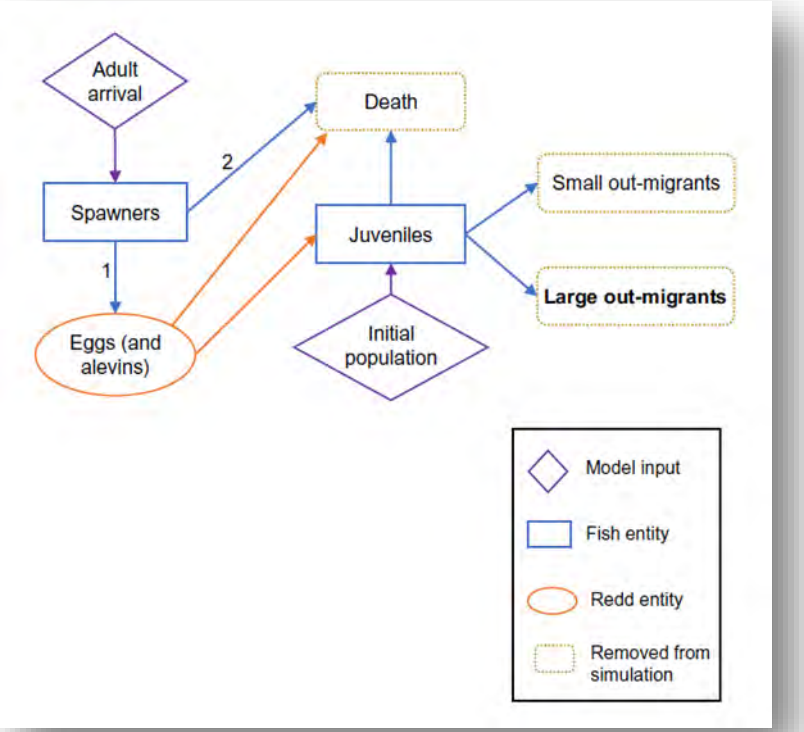
Research School 2026: Introduction to Salmonid IBMs

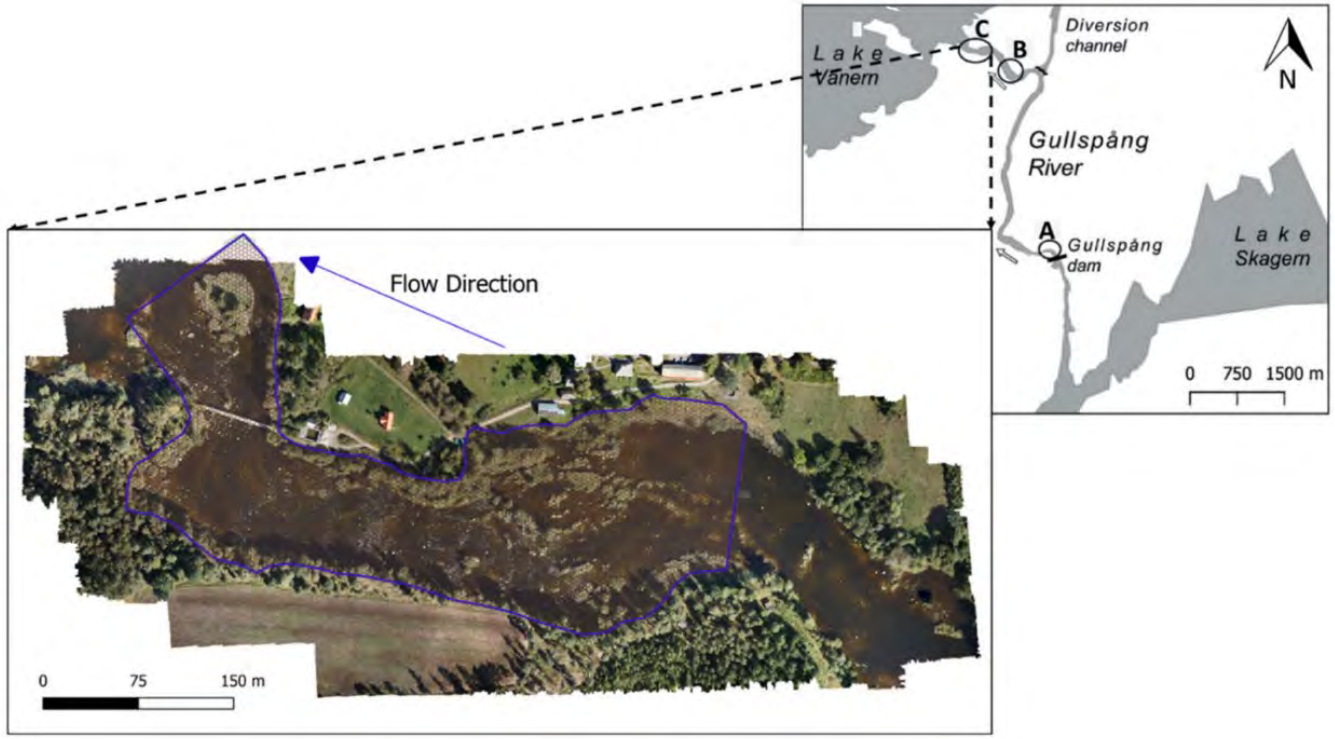
A PhD-course will be held by Mahboobeh Hajiesmaeili of Karlstad University on the 9th and 10th of March at Karlstad University and online. Upon completion of the course, participants will be able to apply individual-based models (IBMs) to assess how fish populations—particularly salmon and trout—respond to habitat alterations in hydropower-regulated rivers. During this course, we will be joined by Steve Railsback who together with Volker Grimm published the first monograph on IBMs in 2005.

- IBMs developed over a 30-year period
- Fitness-based measures of habitat quality
- Applying ecological theory to ecohydraulics:
  - GIS-based habitat maps
  - River bed topography
  - 2-D flow models
- Predict effects of stream flow and habitat restoration on fish populations

Calibrating IBMs with field data

- Predicted versus observed:
  - Redd locations
  - Growth of juveniles
  - Habitat use by juveniles





Addo *et al.* (2026)

Calibrating IBMs with field data

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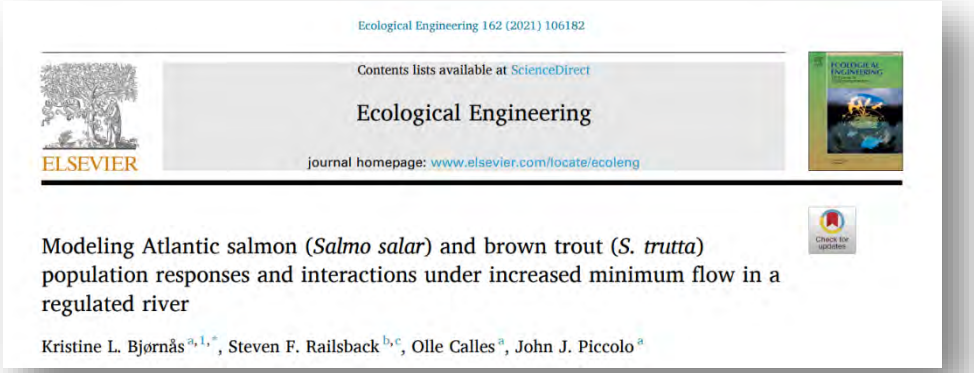
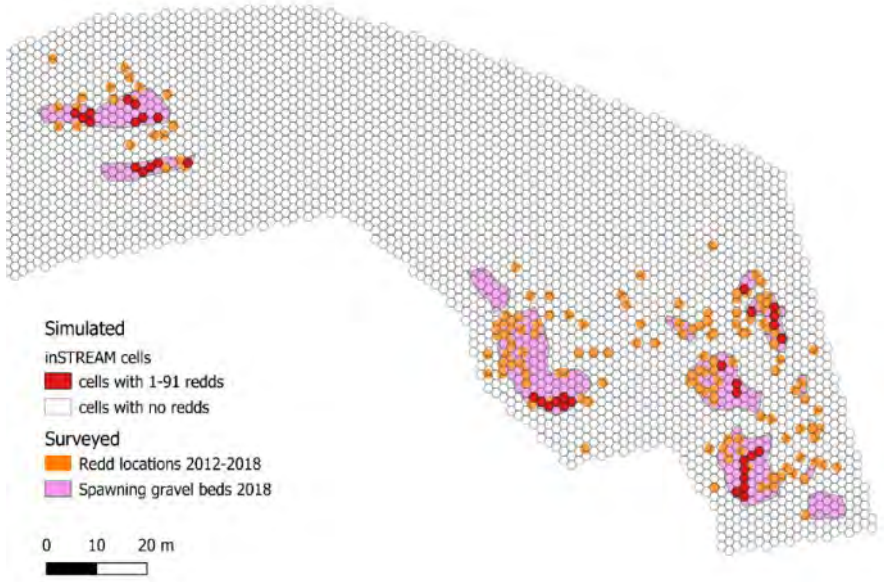
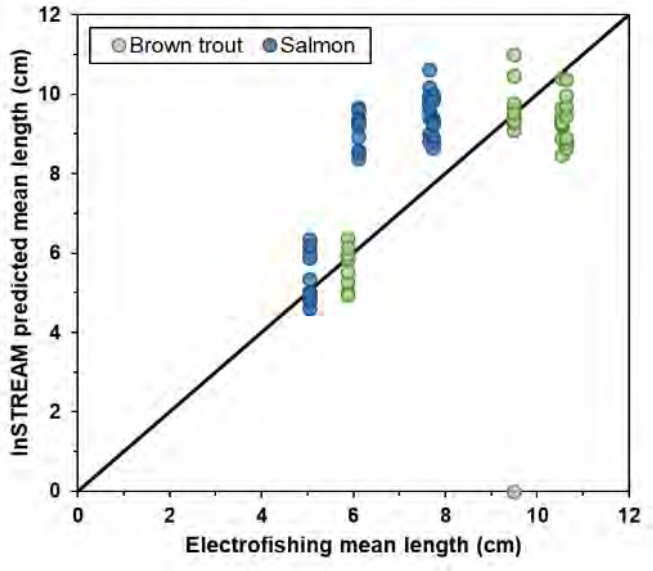
  - Redd locations
  - Growth of juveniles
  - Habitat use by juveniles



Bjørnås *et al.* (2021)



InSTREAM-predicted (red) versus observed (orange/pink) redd locations, Gullspångsforsen



InSTREAM-predicted versus observed mean length of juvenile salmon and trout

Ongoing mapping of observed habitat use for juvenile salmon and trout

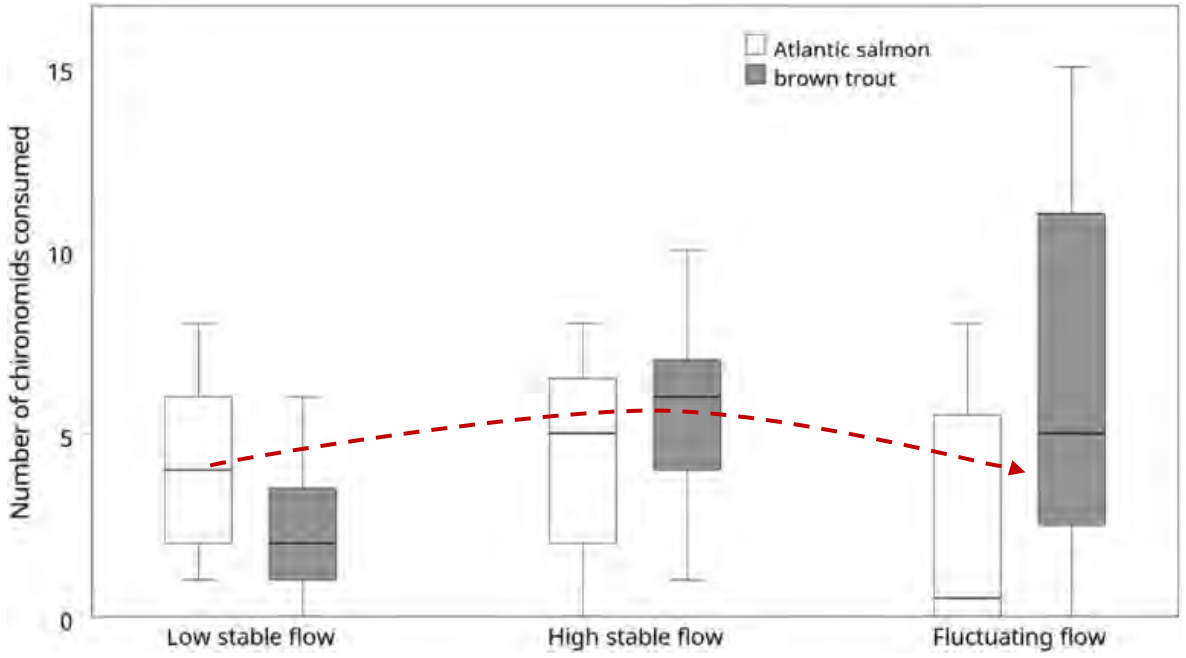
FAQ #5

How are fish populations affected by flow regulation?

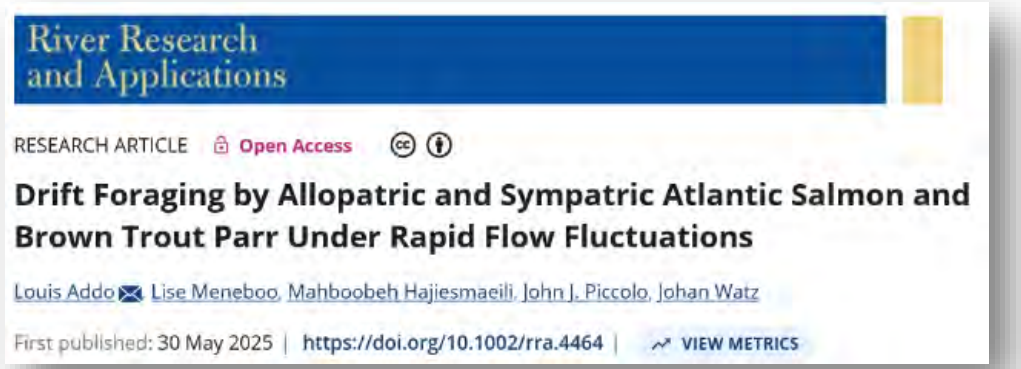
Lab experiment result example:

→ Limited effects of rapid flow fluctuations on growth (foraging) and survival (- - - - - →)

→ Is the model underestimating redd scouring?



Number of prey captured versus flow treatment for salmon and trout


River Research and Applications

RESEARCH ARTICLE Open Access

Drift Foraging by Allopatric and Sympatric Atlantic Salmon and Brown Trout Parr Under Rapid Flow Fluctuations

Louis Addo, Lise Meneboo, Mahboobeh Hajiesmaeili, John J. Piccolo, Johan Watz

First published: 30 May 2025 | https://doi.org/10.1002/rra.4464 | VIEW METRICS


Ecology of FRESHWATER FISH

ORIGINAL ARTICLE Open Access

Growth and mortality of sympatric Atlantic salmon and brown trout fry in fluctuating and stable flows

Louis Addo, Mahboobeh Hajiesmaeili, John J. Piccolo, Johan Watz

First published: 25 October 2022 | https://doi.org/10.1111/eff.12685 | VIEW METRICS

Addo *et al.* (2022, 2025)

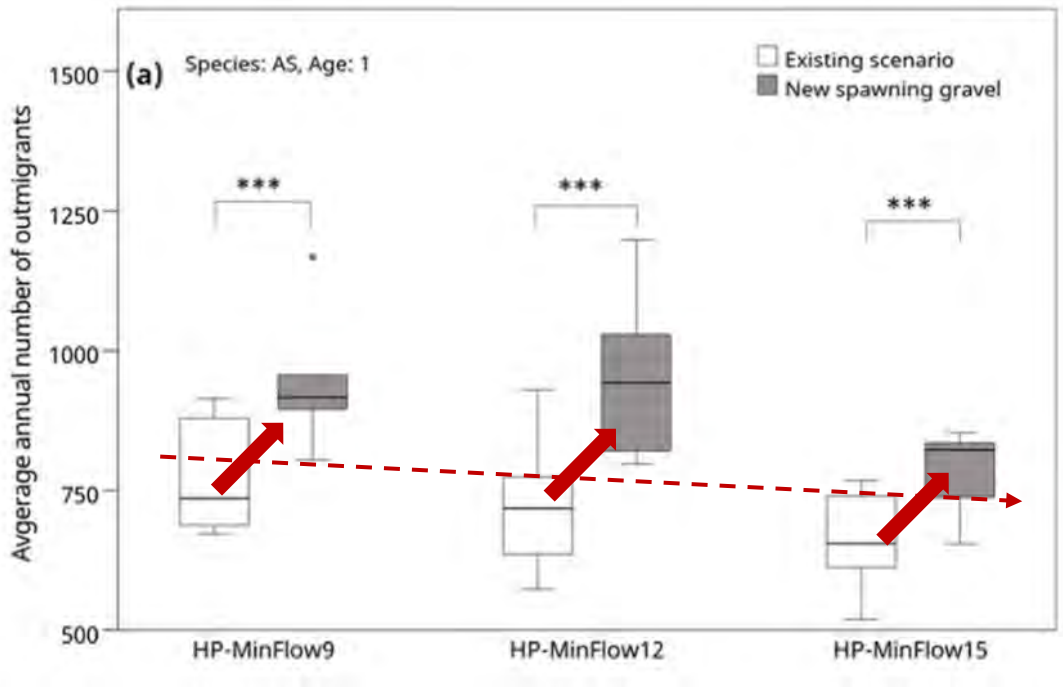
FAQ #5

How are fish populations affected by flow regulation?

inSALMO result example - River Gullspång smolt production:

→ Limited effects of increased minimum flow (- - - - →)

→ Positive effect of improved spawning habitat (↗)



Predicted number of outmigrants of Atlantic salmon smolts versus min. flow and gravel addition

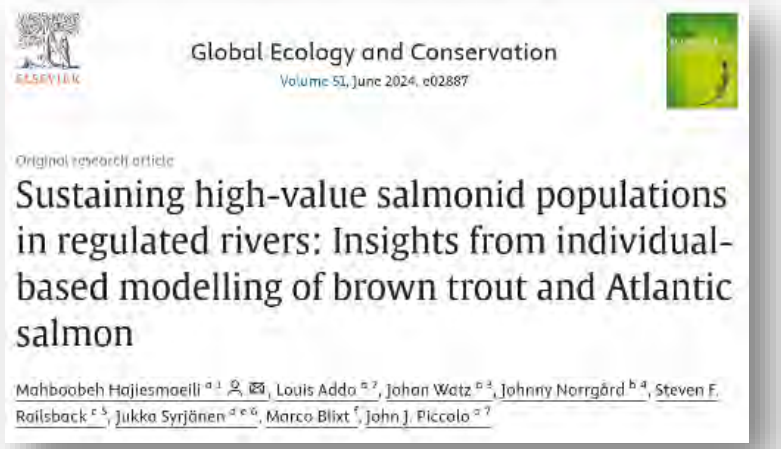
Louis Addo


Global Ecology and Conservation
Volume 55, April 2026, e04111

Original Research Article

Individual-based modeling of Atlantic salmon and brown trout outmigrants in a hydropeaking-regulated river: Effects of minimum baseflow and gravel augmentation on smolt production

Louis Addo [a,1], Johan Watz [a,2], John J. Piccolo [a,1], Johnny Norrgård [b,4], Jukka T. Syrjänen [c,d,5], Steven F. Railsback [e,6], Mahboobeh Hajiesmaeili [a,1]


Global Ecology and Conservation
Volume 51, June 2024, e02887

Original research article

Sustaining high-value salmonid populations in regulated rivers: Insights from individual-based modelling of brown trout and Atlantic salmon

Mahboobeh Hajiesmaeili [a,1], Louis Addo [a,2], Johan Watz [b,3], Johnny Norrgård [b,4], Steven F. Railsback [c,5], Jukka Syrjänen [d,e,6], Marco Blixt [f], John J. Piccolo [a,7]

Addo *et al.* (2026)

Hajiesmaeili *et al.* (2024)

Ecologcial status of aquatic and riparian habitat in relation to hydropeaking in winter

Emil Nordström

Tomorrow at 0900 hrs!

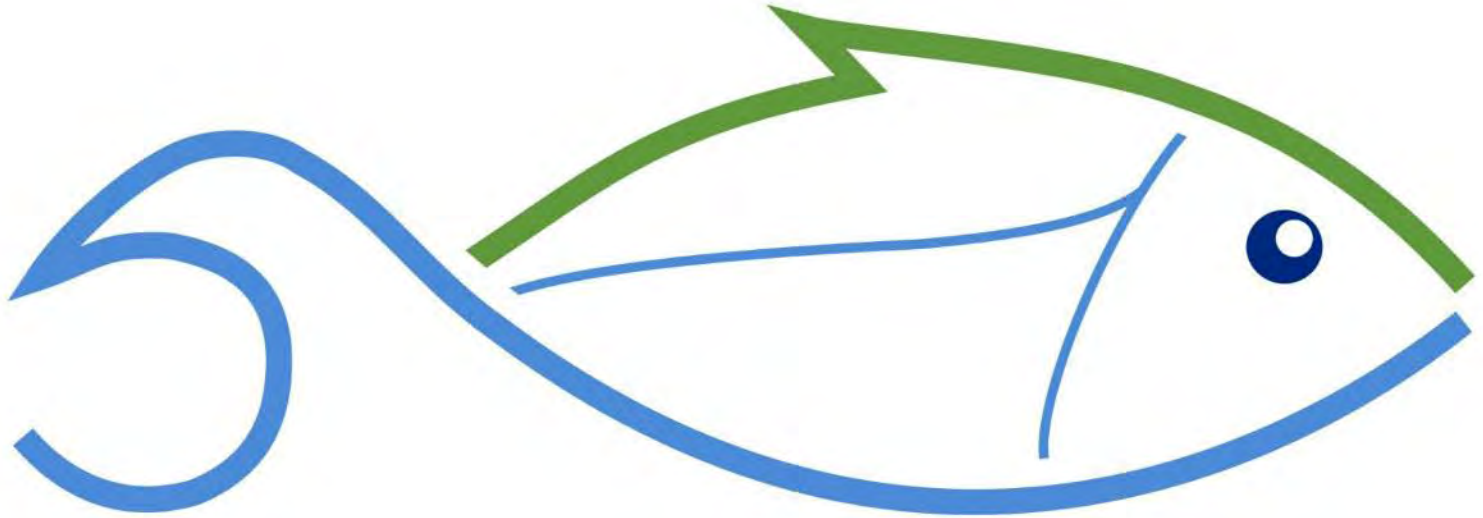
UMEÅ UNIVERSITET

SVENSKT CENTRUM FÖR HÅLLBAR VATTENKRAFT

KARLSTADS UNIVERSITET

Tool 3

Habitat restoration



Improve Aquatic LIFE

Co-funded by the European Union

Havs och Vattenmyndigheten

NATURVÅRDSVERKET

Länsstyrelserna

HELSINGBORG

Tingsryds kommun

KARLSTADS UNIVERSITET

GÖTEBORGS UNIVERSITET

LUNDS UNIVERSITET

SportFiskarna

Partners:

CAB (Lst): **Skåne***, Värmland, Västra Götaland, Halland, Blekinge, Kalmar, Östergötland, Jönköping, Kronoberg,

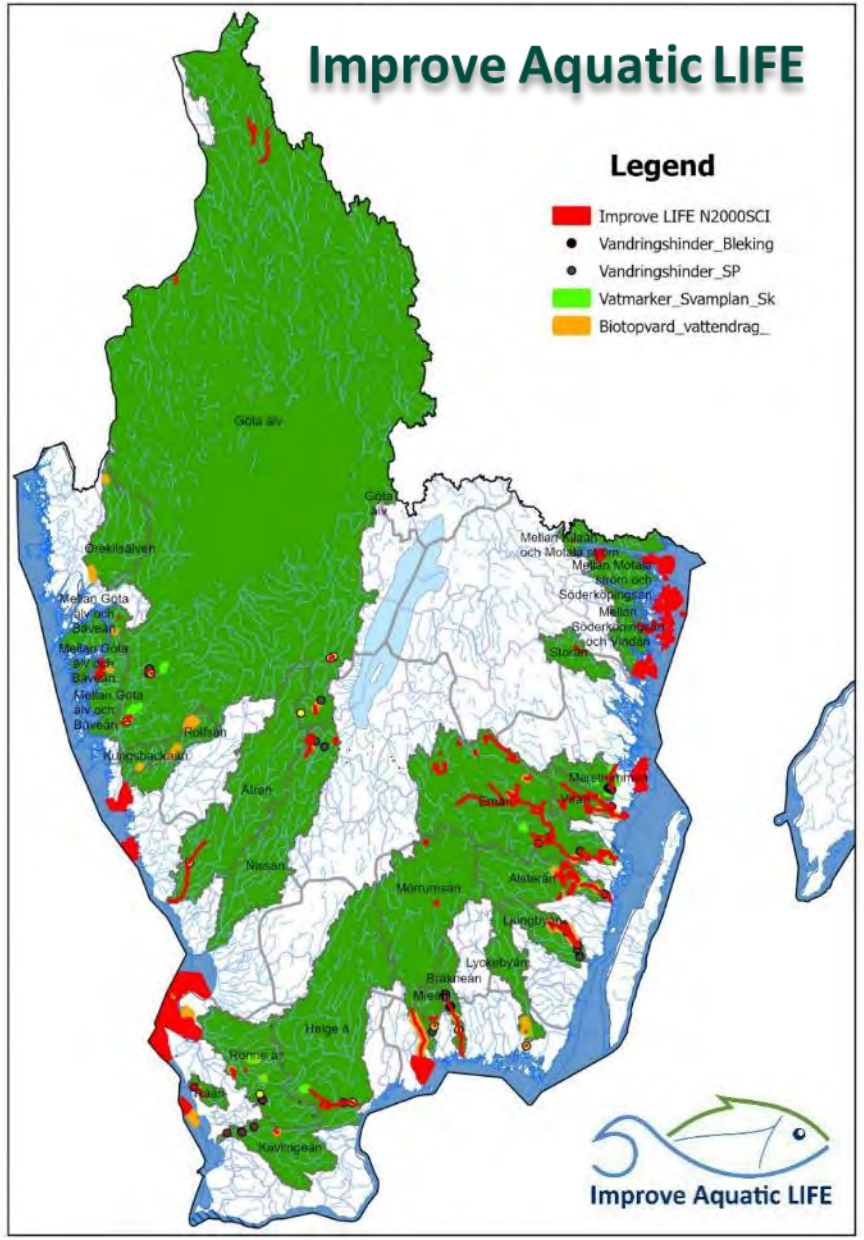
Gov. agencies: Naturvårdsverket & Havs- och vattenmyndigheten

Other: Helsingborgs stad, Tingsryds kommun, Sportfiskarna,

Universities: Karlstad, Göteborg & Lund

* Coordinating partner

Project time:
1 September 2024
- 31 August 2031



Habitat restoration

→ 500 restoration activities

- Coastal habitats (16 sites)
  - Stone reefs
  - Create artificial reefs
  - Eel grass meadows
- Hydrology (68 sites)
  - Wetlands
  - Bogs and peatlands
  - Floodplains & lake outlets

FAQ #6

Bianca Andrade

Partners:

CAB (Lst): **Skåne***, Värmland, Västra Götaland, Halland, Blekinge, Kalmar, Östergötland, Jönköping, Kronoberg,

Gov. agencies: Naturvårdsverket & Havs- och vattenmyndigheten

Other: Helsingborgs stad, Tingsryds kommun, Sportfiskarna,

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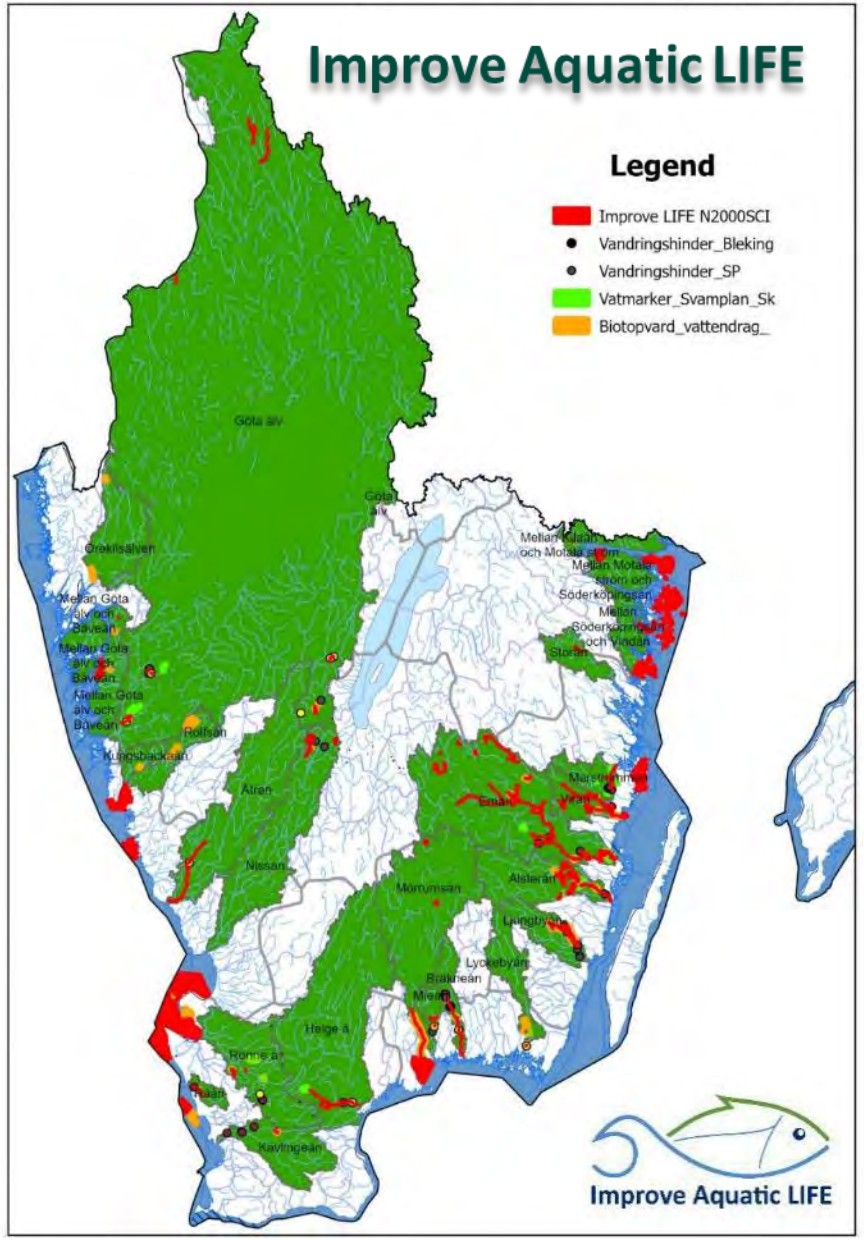


Habitat restoration

→ 500 restoration activities

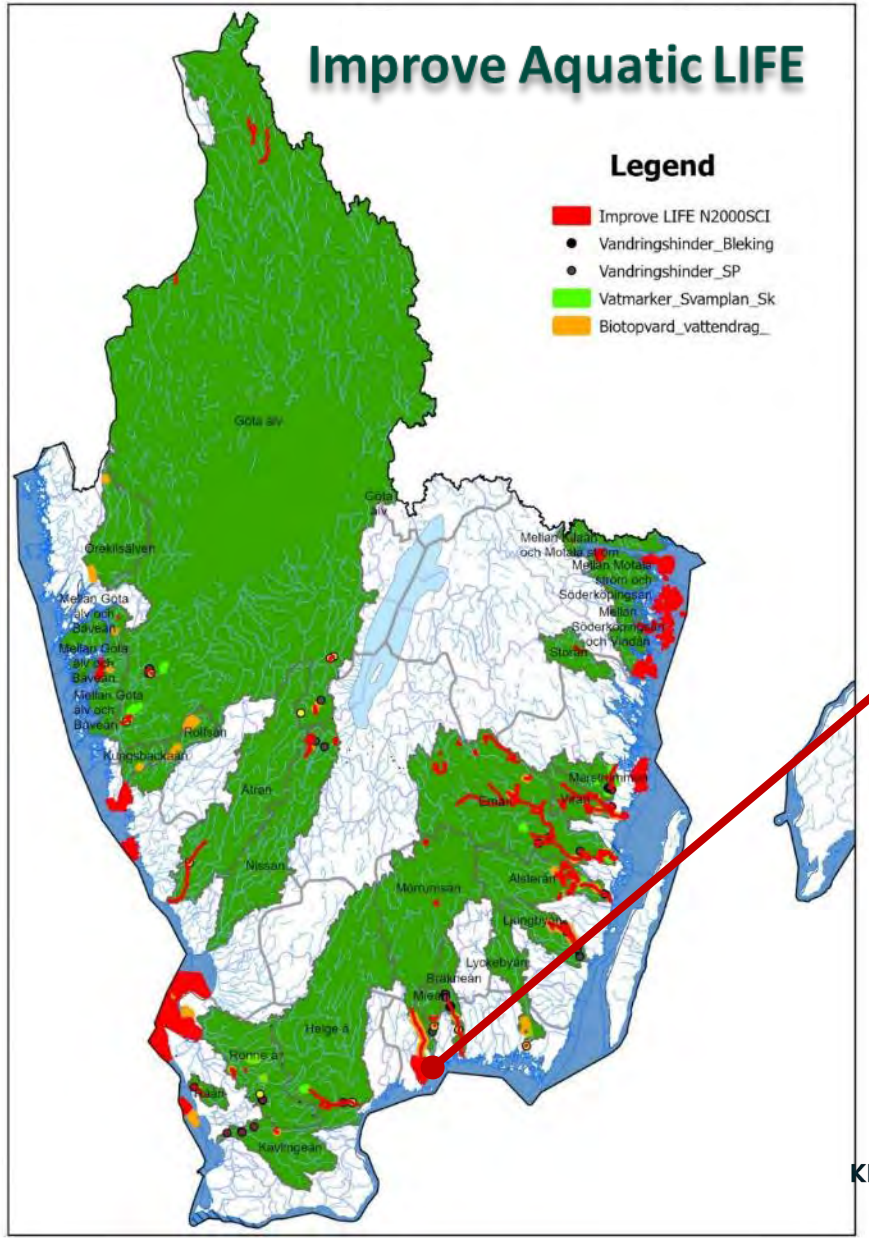
- Coastal habitats (16 sites)
  - Stone reefs
  - Create artificial reefs
  - Eel grass meadows
- Hydrology (68 sites)
  - Wetlands
  - Bogs and peatlands
  - Floodplains & lake outlets
- Rivers (19 basins)
  - Habitat restoration (500 km)
  - Connectivity
    - Culverts (N=40)
    - Barrier removals (N=56)

Tool 4

Dam removal

FAQ #7

Dam removal



Mörrumsån

Harbicht *et al.* (2021)

Shry *et al.* (2025)

KK-stiftelsen

uniper

LIFEConnects

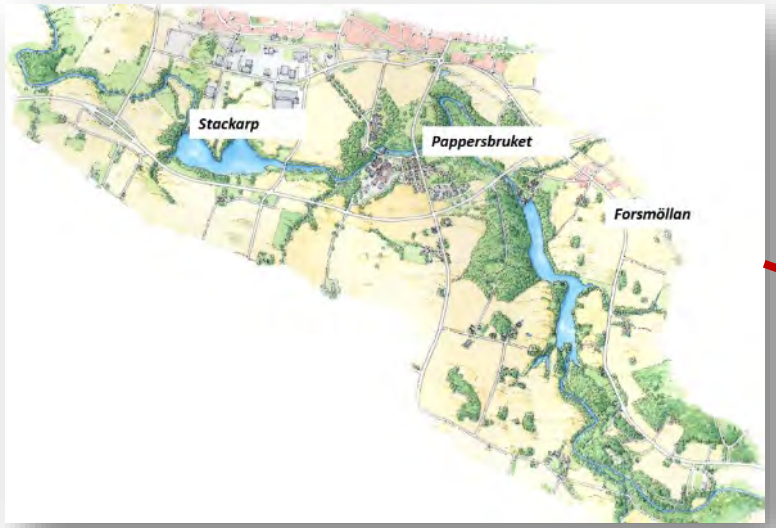
FAQ #7

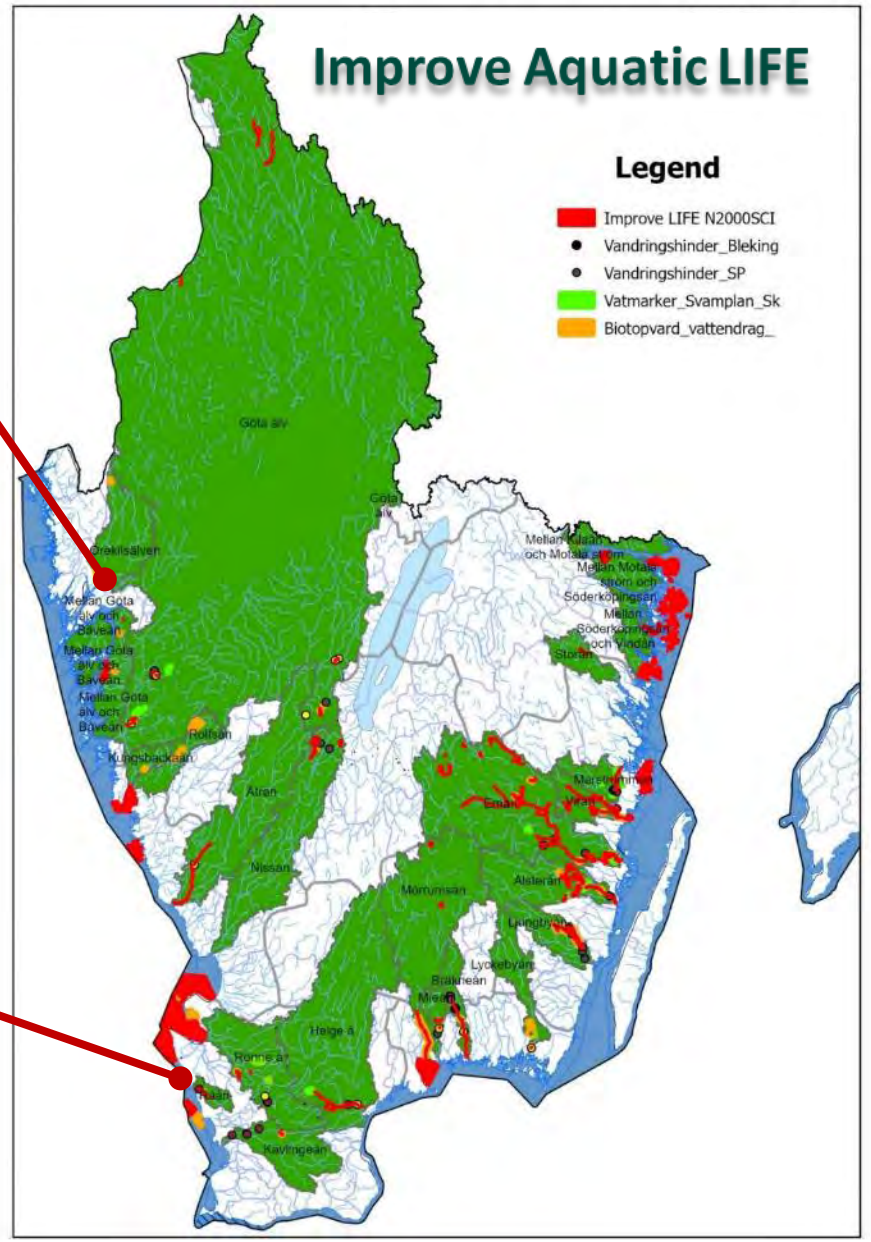
Dam removal

Mattias Hansson

Örekilsälven

Rönne å





Improve Aquatic LIFE

LIFEConnects

Removal of lake outlet dams in Sweden, 2021-2023

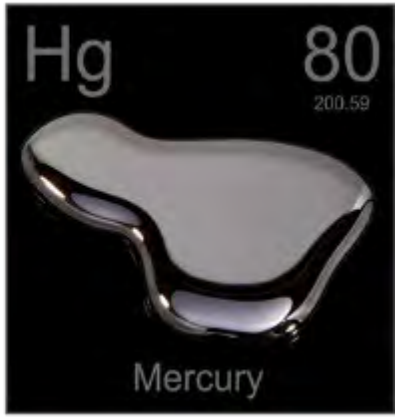
Johan Watz, Eva Bergman, Olle Calles, Lutz Eckstein,
Miguel Gómez, Anders Nilsson

Johan Watz

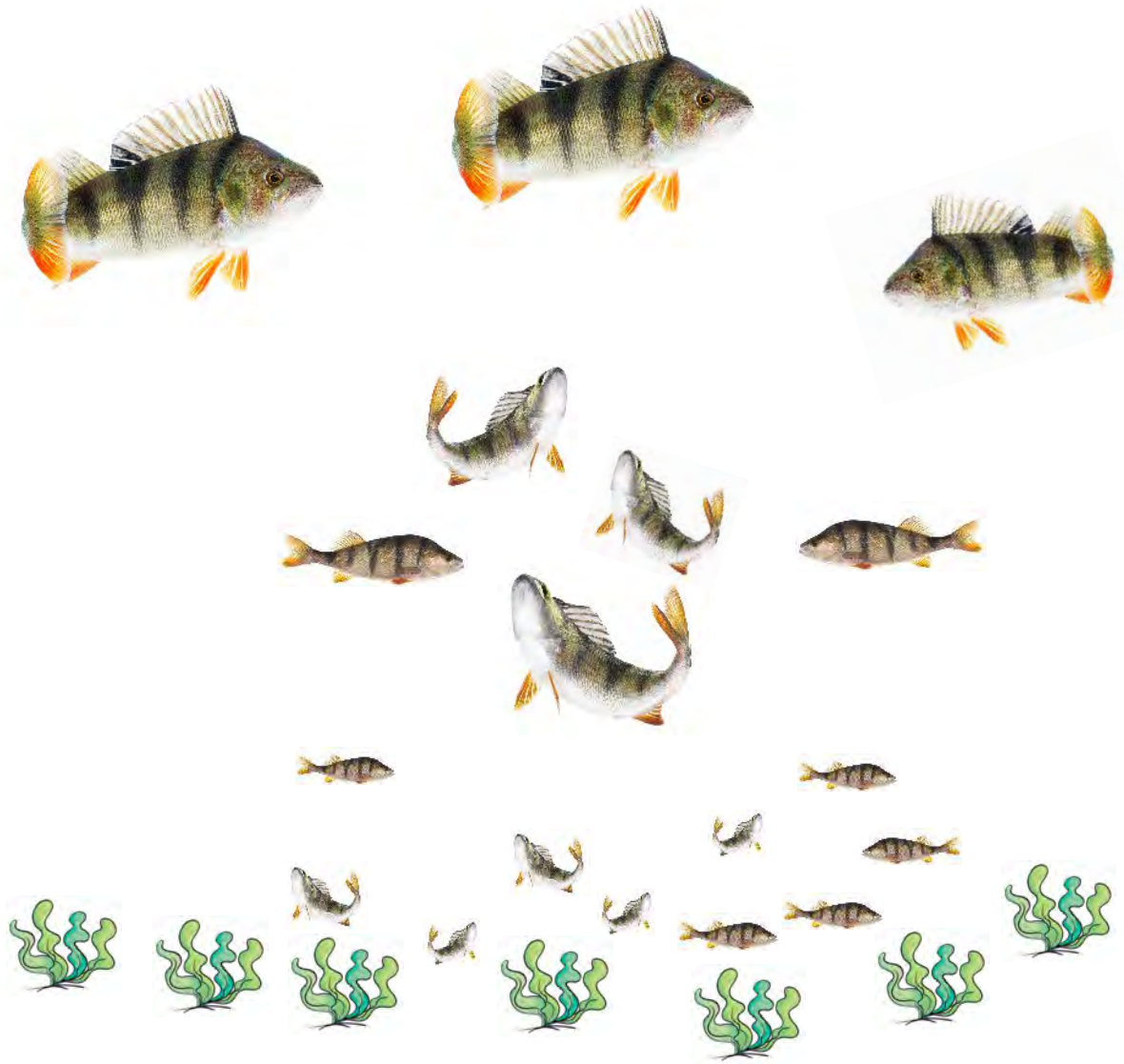
Outlet of Lake Kollsjön

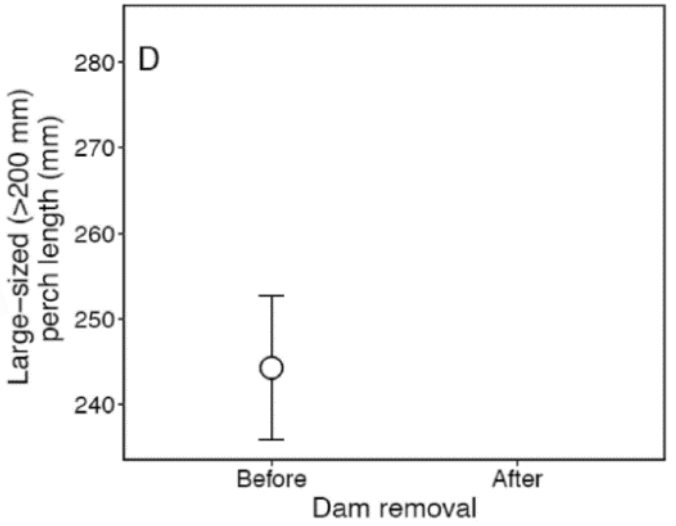
Lake outlet dams project

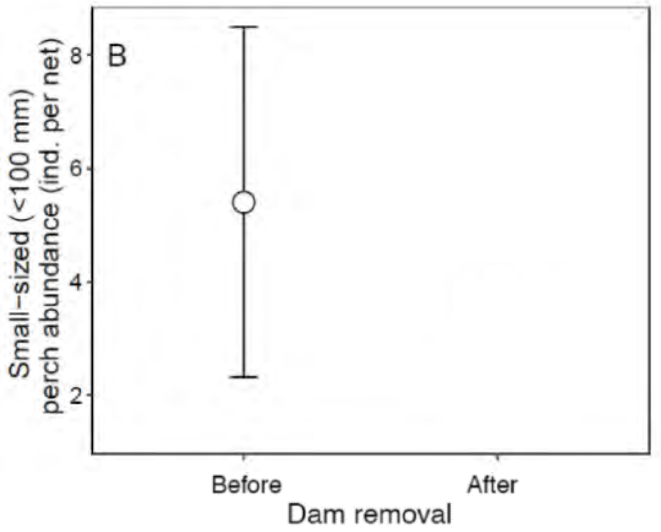
1. Ecosystem responses
    a) Water chemistry
    b) Phyto- and zooplankton
    c) Aquatic plant
    d) Fish (– perch demography)
2. Effects on pike
    a) Mercury concentration (biomagnification)
    b) Movements before, during and after removal



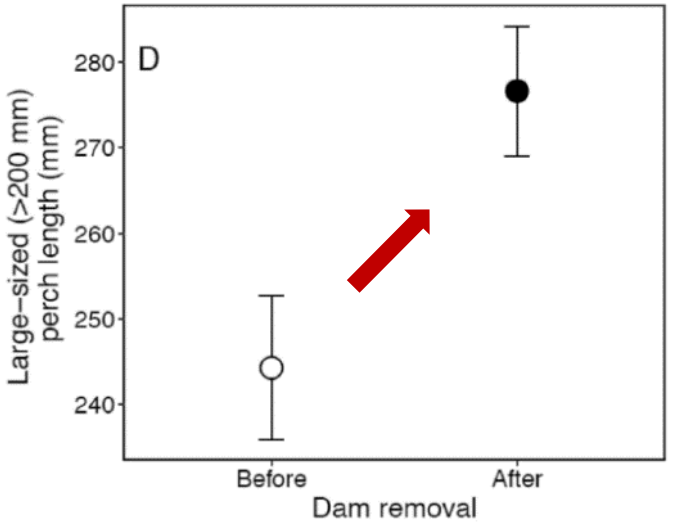
Perch demography – Length & abundance

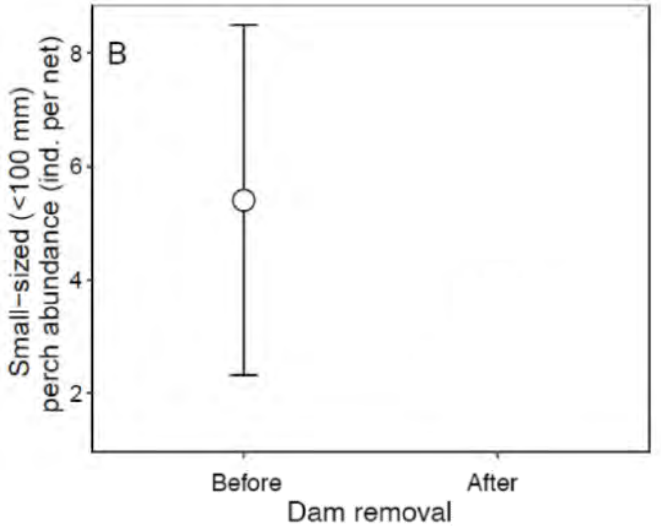




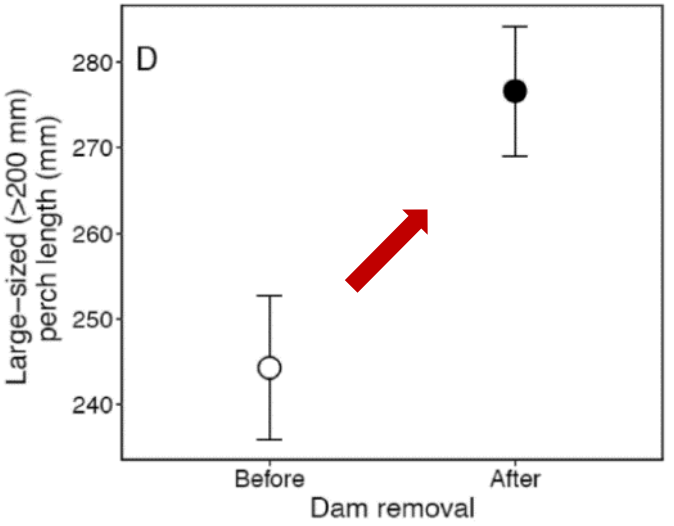


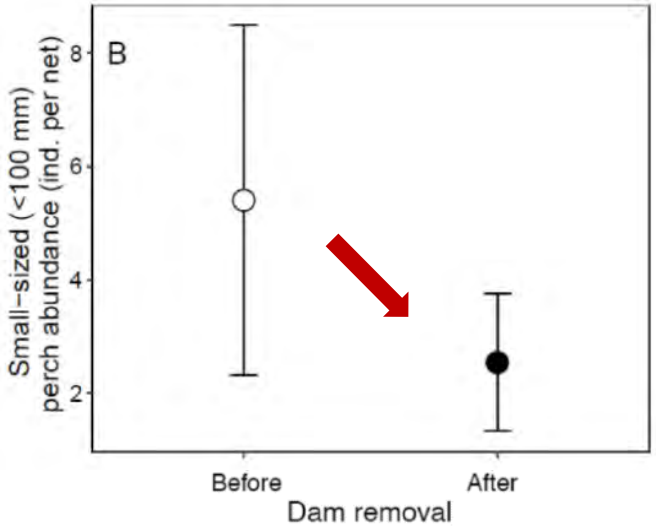
Perch demography – Length & abundance



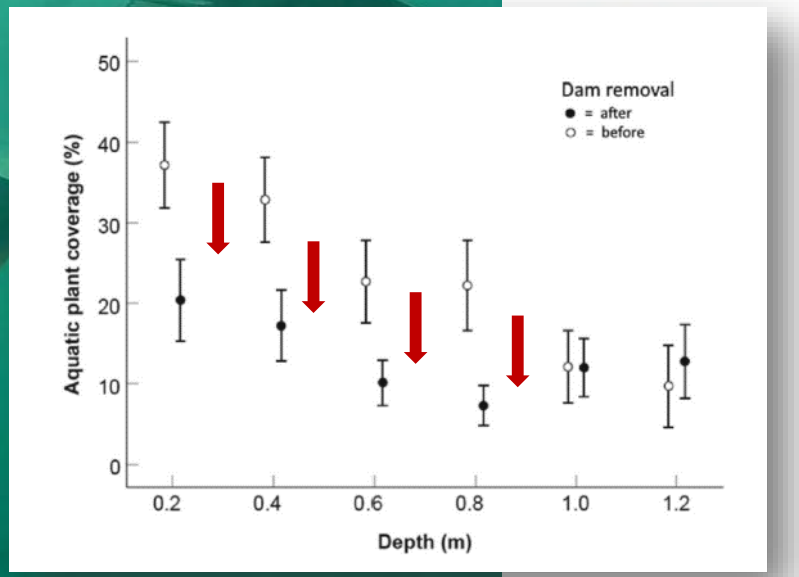


Perch demography – Length & abundance





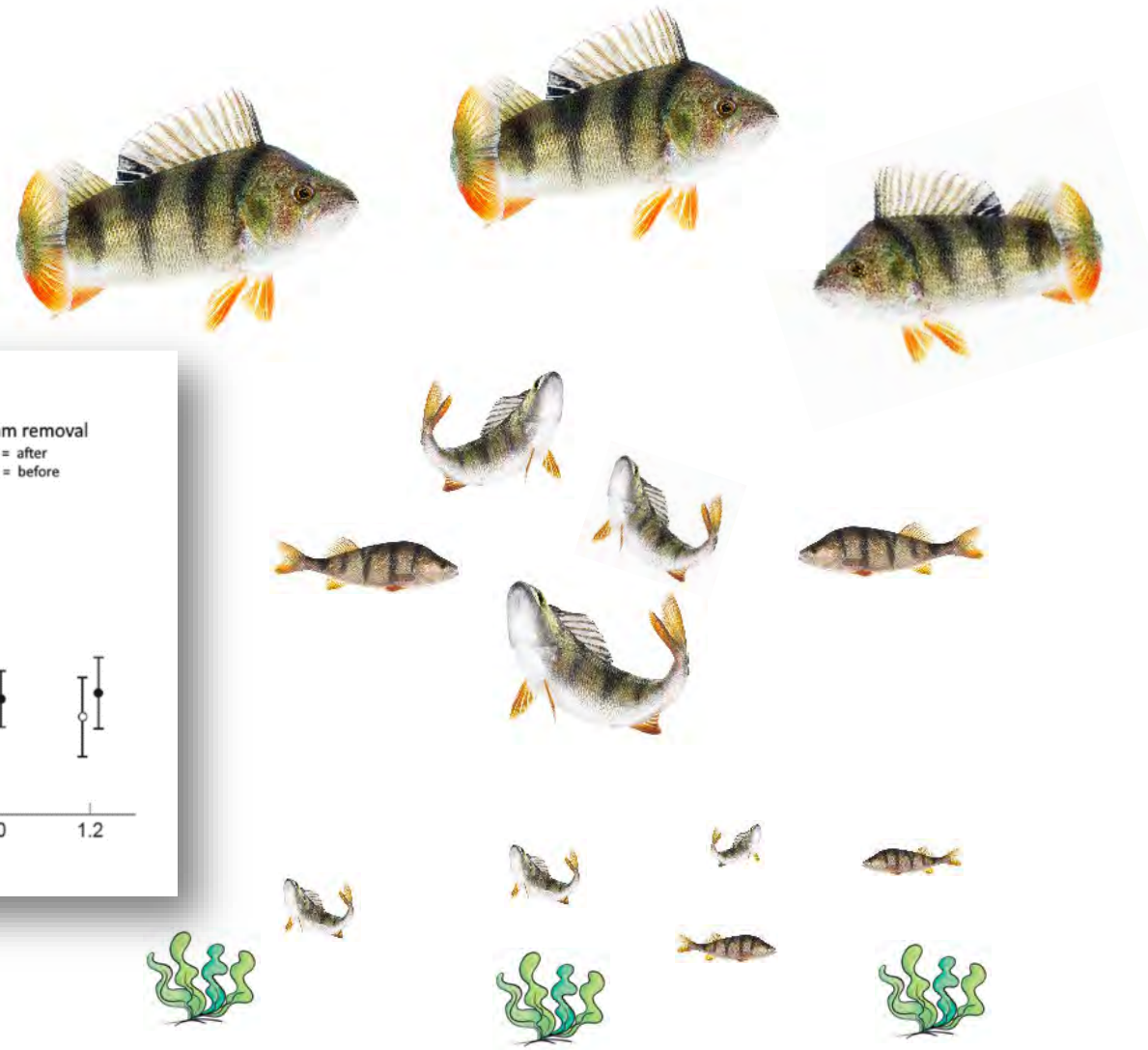
Perch demography – Length & abundance

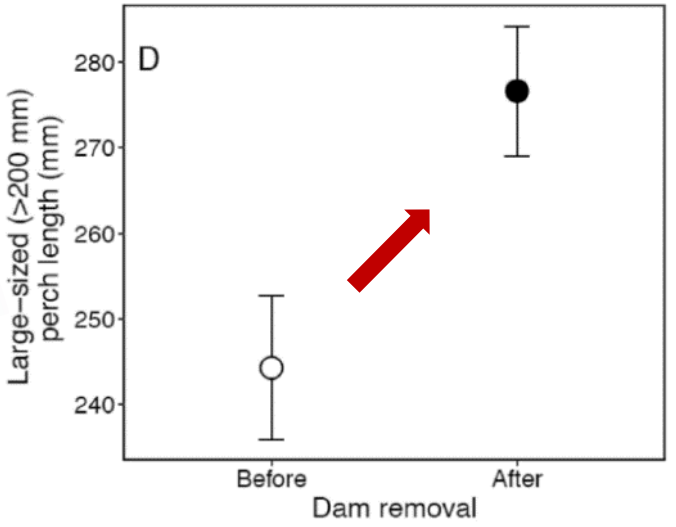


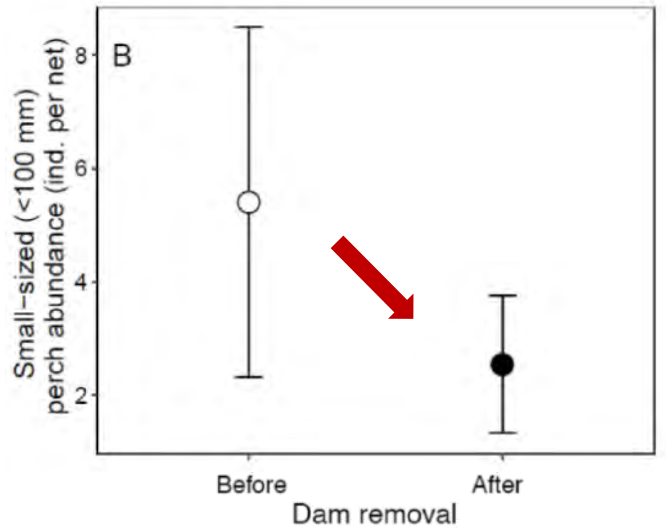
Less aquatic plants

→ Less rearing habitat

→ Shorter food chains?







Perch demography – Length & abundance

Less aquatic plants

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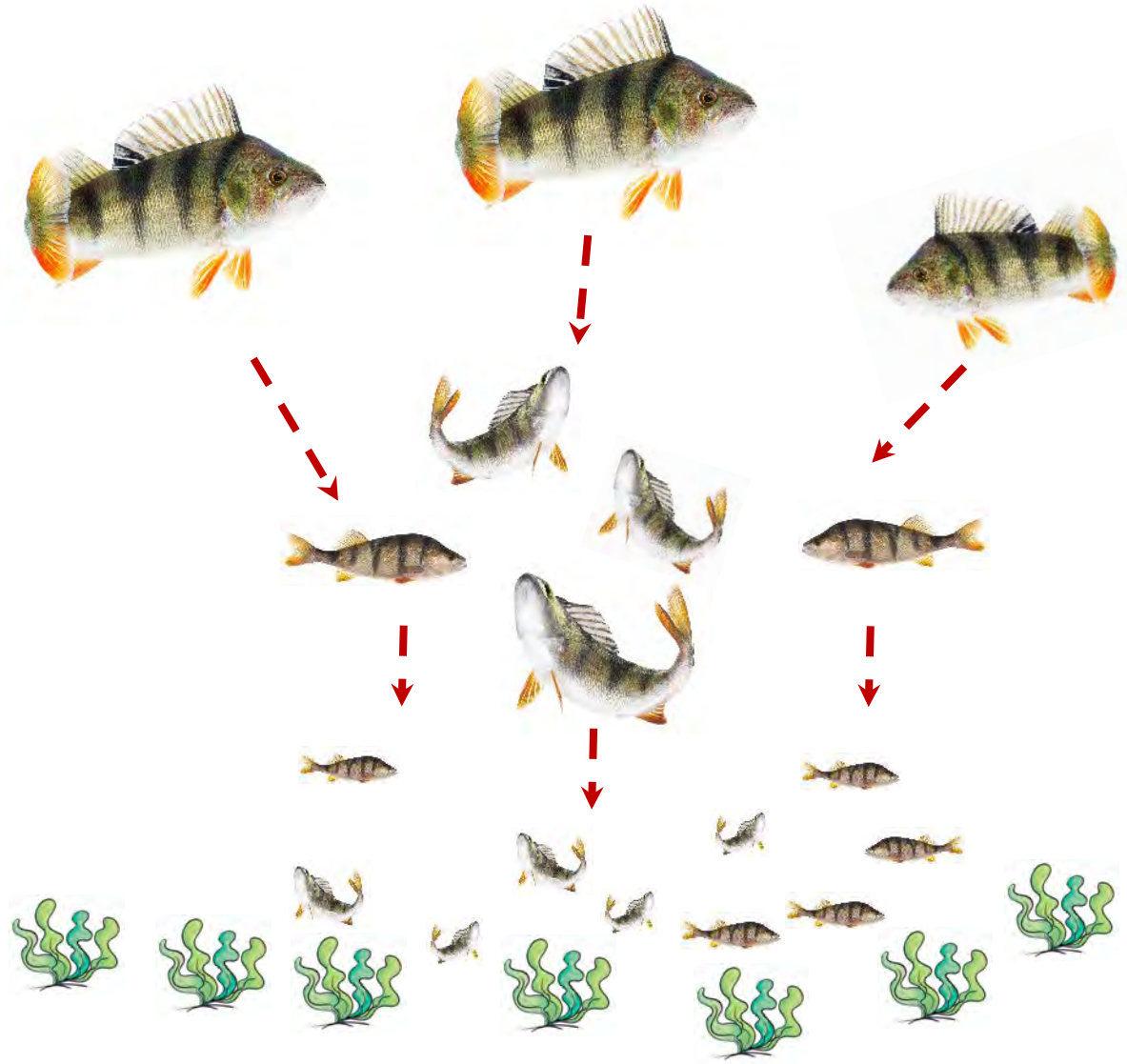
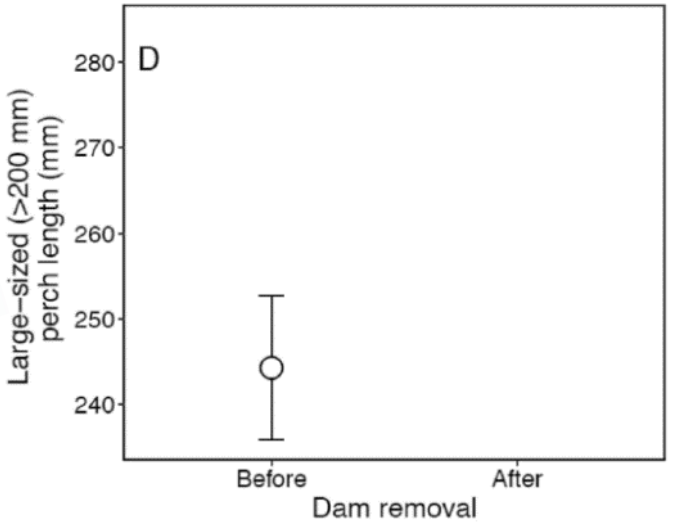
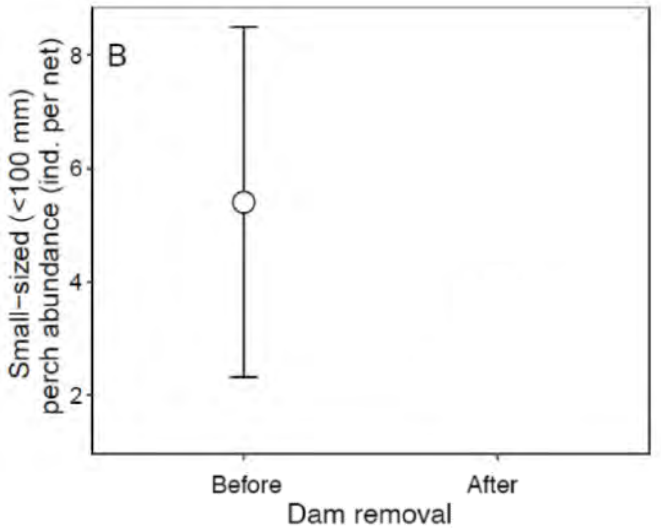
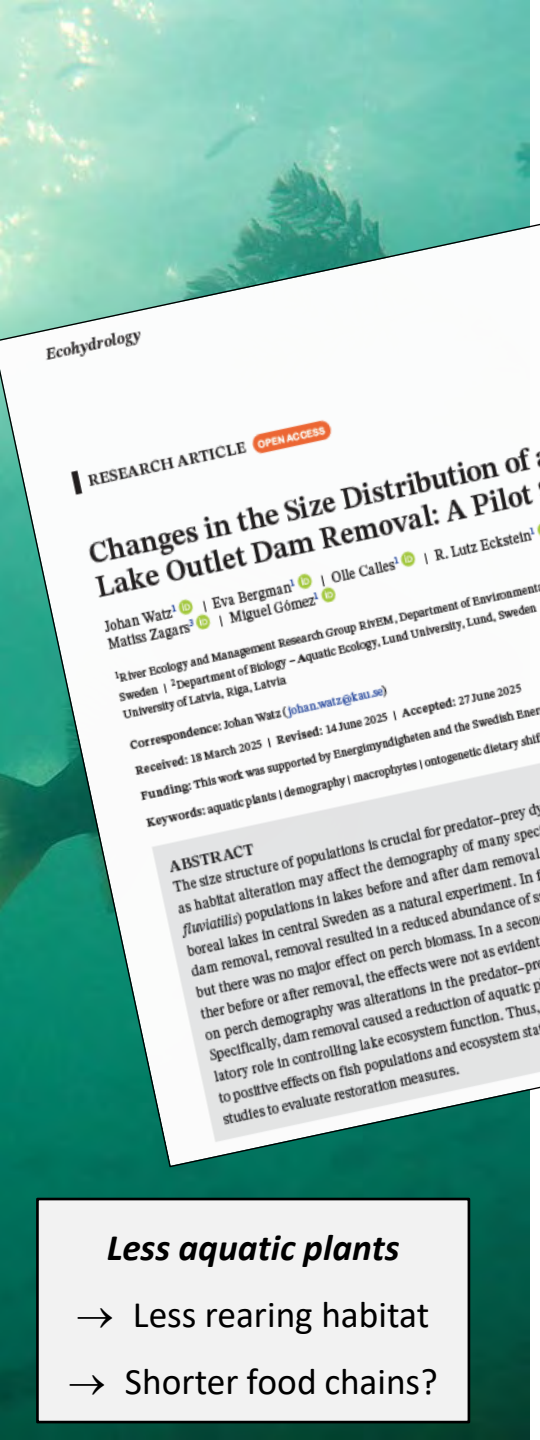






Perch demography – Length & abundance



WILEY

Ecohydrology

RESEARCH ARTICLE OPEN ACCESS

Changes in the Size Distribution of a Freshwater Fish After Lake Outlet Dam Removal: A Pilot Study

Johan Watz[1] | Eva Bergman[1] | Olle Calles[1] | R. Lutz Eckstein[1] | P. Anders Nilsson[2] | Niclas Carlsson[1] | Matiss Zagars[3] | Miguel Gómez[1]

[1]River Ecology and Management Research Group RIVEM, Department of Environmental and Life Sciences, Karlstad University, Karlstad, Sweden | [2]Department of Biology – Aquatic Ecology, Lund University, Lund, Sweden | [3]Department of Ecology, Faculty of Medicine and Life Sciences, University of Latvia, Riga, Latvia

Correspondence: Johan Watz (johan.watz@kau.se)

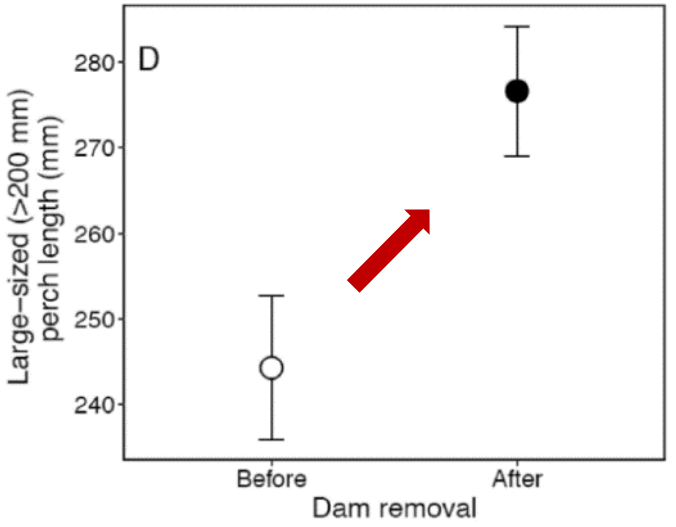
Received: 18 March 2025 | Revised: 14 June 2025 | Accepted: 27 June 2025

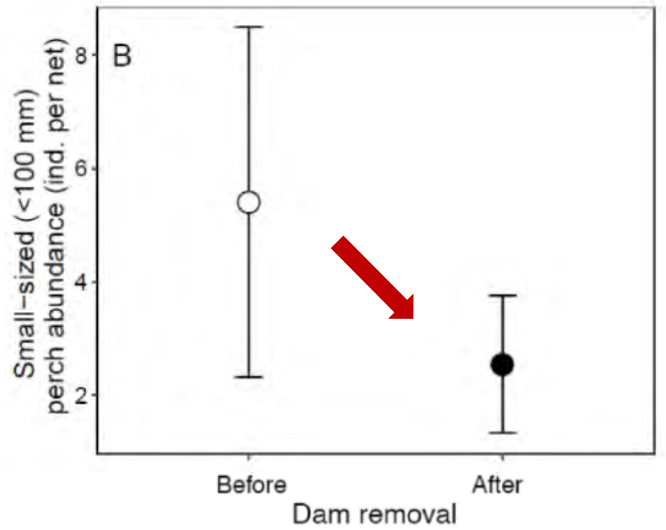
Funding: This work was supported by Energimyndigheten and the Swedish Energy Agency (Grant Numbers 52091-1 and P2023-01155).

Keywords: aquatic plants | demography | macrophytes | ontogenetic dietary shift | *Perca fluviatilis* | perch | size structure

ABSTRACT

The size structure of populations is crucial for predator–prey dynamics and ecosystem function. Anthropogenic pressures such as habitat alteration may affect the demography of many species. We investigated the size structure of European perch (*Perca fluviatilis*) populations in lakes before and after dam removal by using the planned removals of multiple dams in the outlets of boreal lakes in central Sweden as a natural experiment. In five lakes from which we had obtained data both before and after dam removal, removal resulted in a reduced abundance of small perch and an increase in body size of large, piscivorous perch, but there was no major effect on perch biomass. In a second comparison of 22 lakes where we only had access to data from either before or after removal, the effects were not as evident. We suggest that a plausible mechanism explaining a potential effect on perch demography was alterations in the predator–prey dynamics caused by changes in refuge habitat area for small fish. Specifically, dam removal caused a reduction of aquatic plant coverage. Large piscivorous fish are known to play a crucial regulatory role in controlling lake ecosystem function. Thus, we suggest that lake outlet dam removal may induce processes leading to positive effects on fish populations and ecosystem state. Moreover, our study emphasises the importance of before versus after studies to evaluate restoration measures.





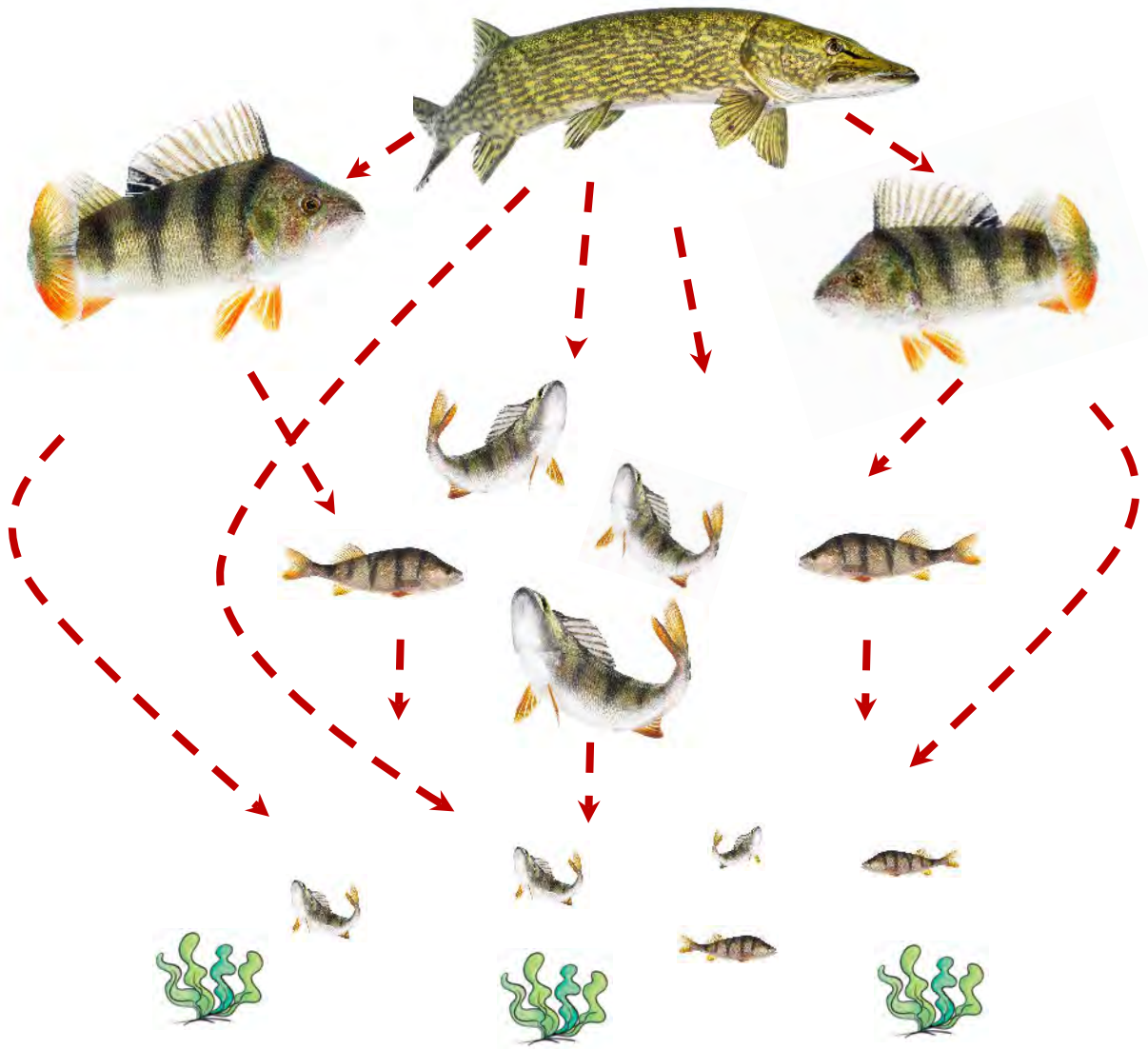
Less aquatic plants

→ Less rearing habitat

→ Shorter food chains?

Watz *et al.* (2025a)

Dam removal & biomagnification?



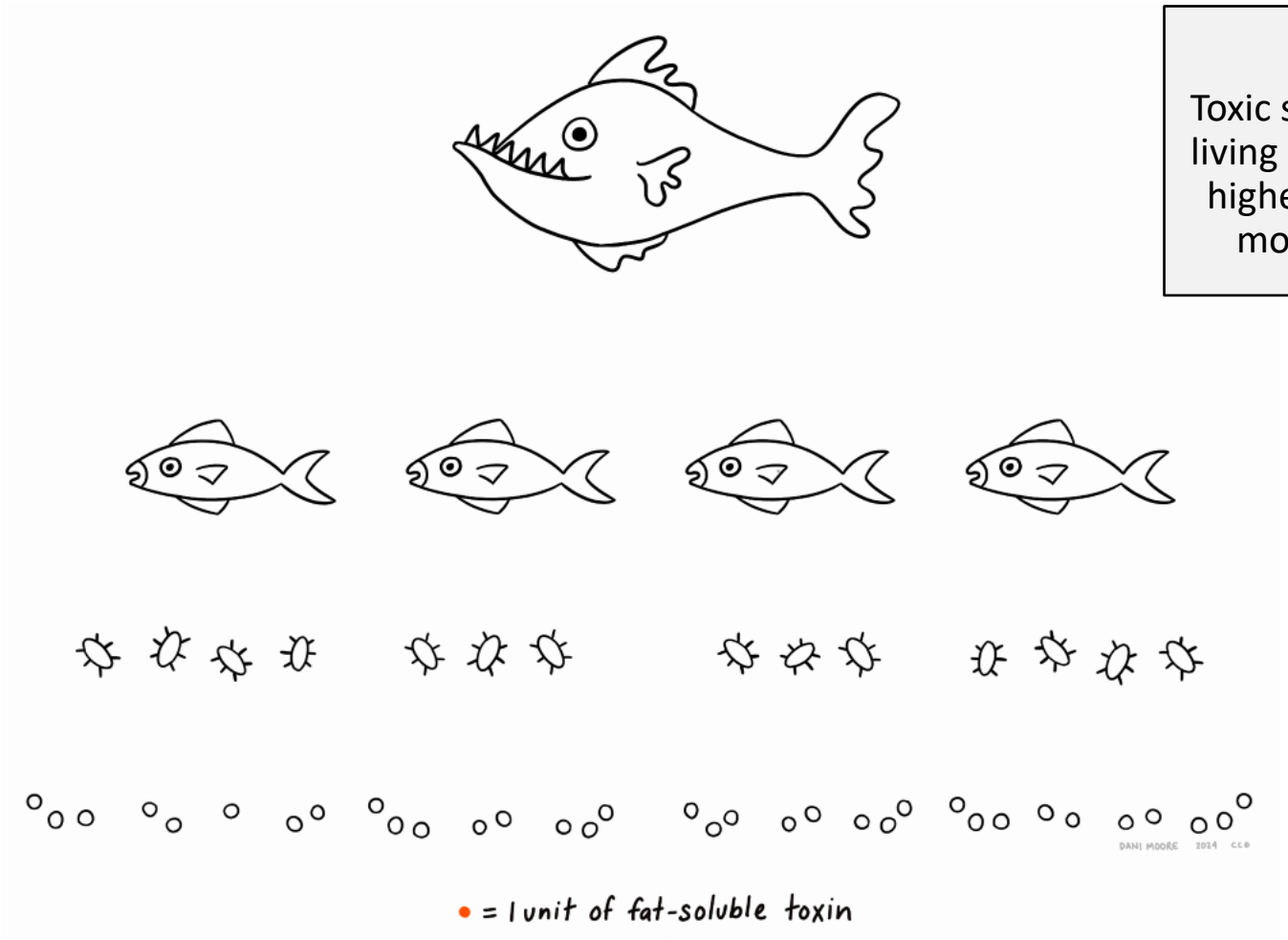
Lake outlet dam removal …

→ Less aquatic plants

→ Shorter food chains, predators feed from lower trophic levels

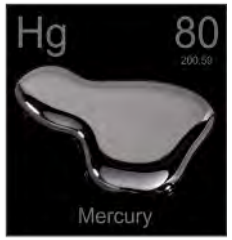
→ Less biomagnification? E.g. mercury

Dam removal & biomagnification?



Biomagnification

Toxic substances accumulate in living organisms at increasingly higher concentrations as one moves up the food chain.



Dam removal & biomagnification?

Aquatic Conservation: Marine and Freshwater Ecosystems

WILEY

SHORT COMMUNICATION OPEN ACCESS

Conservation Benefits of Lake Outlet Dam Removals: Reduced Mercury in an Apex Fish Predator

Johan Watz[1] | Niclas Carlsson[1] | Eva Bergman[1] | Per Anders Nilsson[2] | Olle Calles[1]

[1]River Ecology and Management Research Group RiverM, Department of Environmental and Life Sciences, Karlstad University, Karlstad, Sweden | [2]Department of Biology – Aquatic Ecology, Lund University, Lund, Sweden

Correspondence: Johan Watz (johan.watz@kau.se)

Received: 20 August 2025 | **Revised:** 3 September 2025 | **Accepted:** 3 October 2025

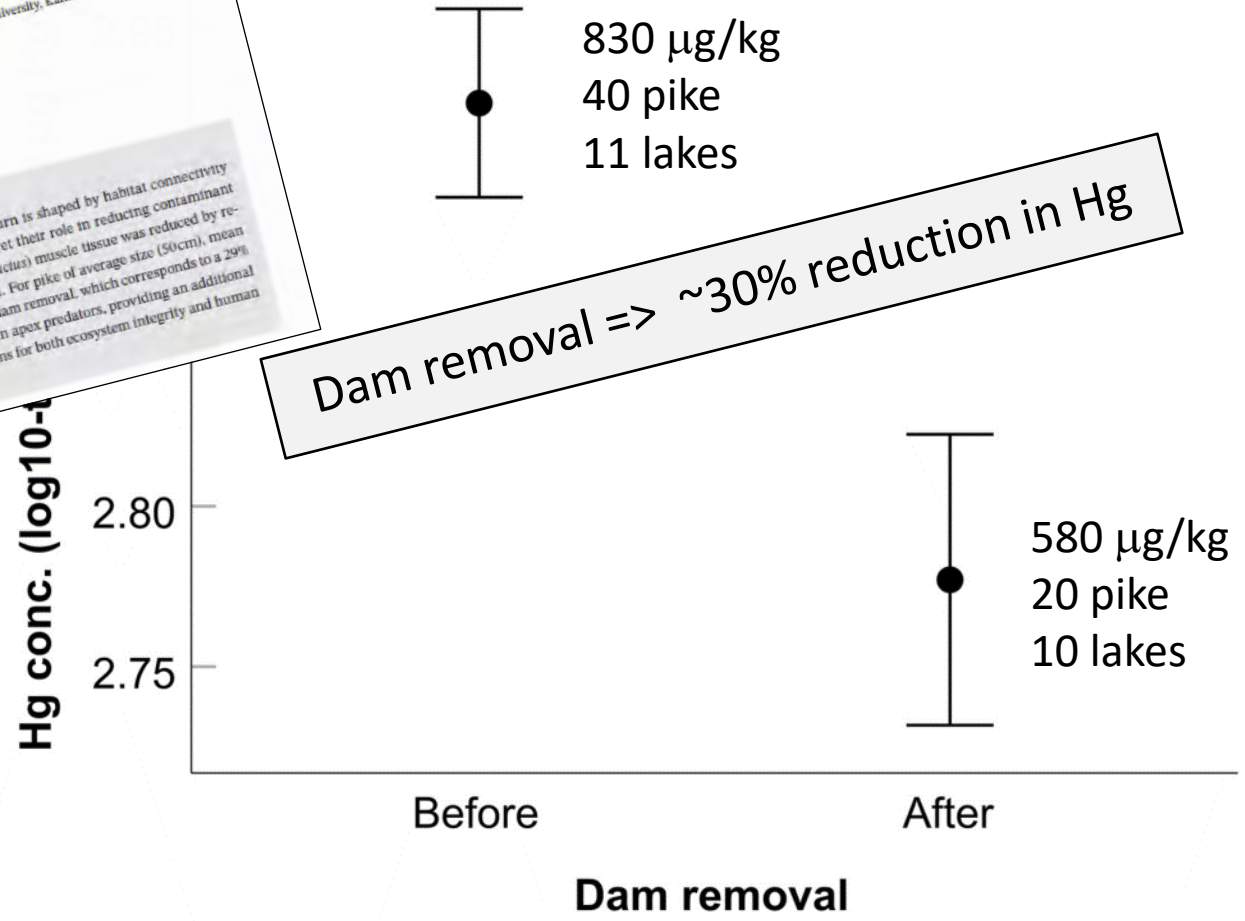
Funding: This study was funded by the Swedish Energy Agency, grant numbers 52091-1 and P2023-01155.

Keywords: food chain length | food web | Hg | MeHg | pike | toxin fish

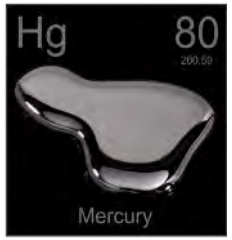
ABSTRACT

Biomagnification of environmental toxins is influenced by food chain length, which in turn is shaped by habitat connectivity and food web dynamics. Dam removals are increasingly used as restoration measures, yet their role in reducing contaminant exposure has rarely been quantified. We tested if mercury concentration in pike (*Esox lucius*) muscle tissue was reduced by removals of lake outlet dams in five oligotrophic, boreal lakes, using a before-after design. For pike of average size (50 cm), mean mercury concentration decreased from 843 to 598 µg Hg per kg muscle tissue following dam removal, which corresponds to a 29% reduction. These results show that dam removal can lower mercury bioaccumulation in apex predators, providing an additional conservation benefit of restoring natural aquatic connectivity, with positive implications for both ecosystem integrity and human health.

Watz *et al.* (2025b)



Mercury in pike



Watz *et al.* (2025b)

Pike movement before, during and after dam removal

INSLAGET
Karlstads universitets intranät

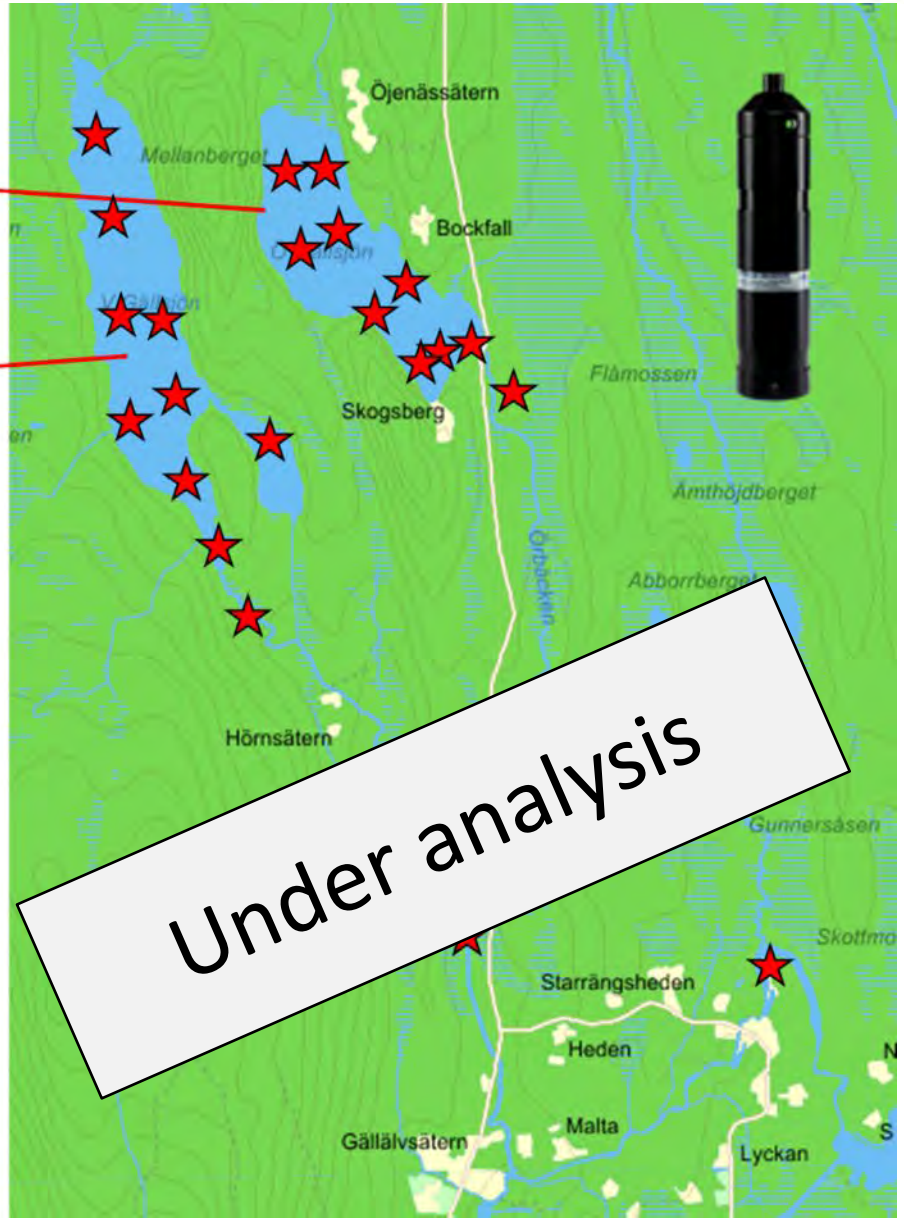
En samarbetsinsats mellan fors...

En samarbetsinsats mellan forskare och Sportfiskeakademin

Forskning om hur vi kan bevara ekosystem är avgörande för att uppnå en hållbar framtid. Ett spännande projekt, finansierat av Energimyndigheten (HåVa) och utfört i samarbete med Fortum, undersöker ekosystemeffekterna av dammutrivningar i inlandsvatten. I en delstudie inom detta projekt har forskare samarbetat med Sportfiskegymnasiet i Forshaga för att fånga och märka gäddor med akustiska sändare.

14 pike

30 pike

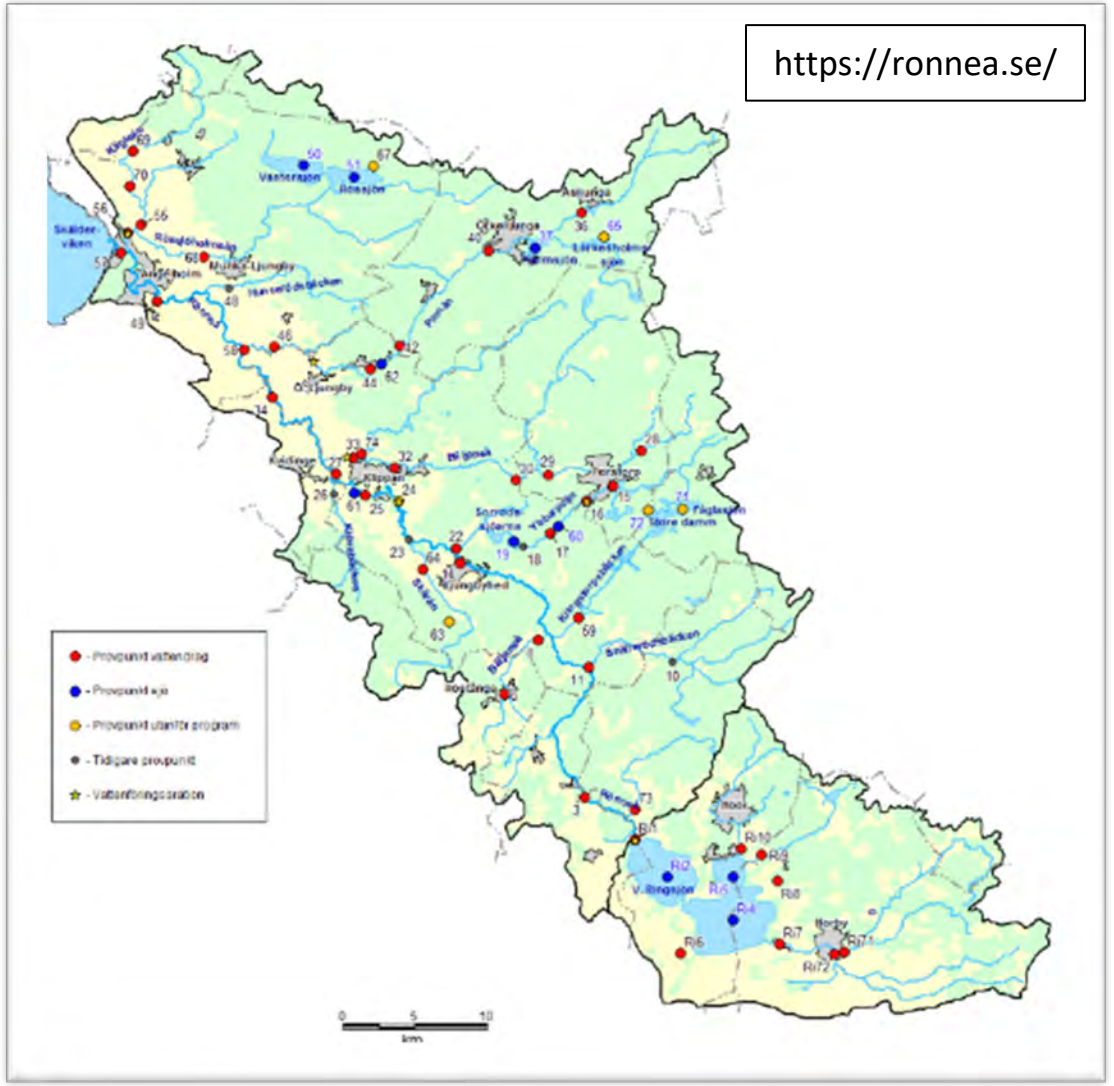


Tool 5

Evaluation

Freshwater monitoring & evaluation

- National monitoring programs
  - Fish
  - Benthic fauna
  - Hydrology
  - …
- EU Data Collection Framework (DCF)
- Self-monitoring by owners
- Applied research projects
  - Swe: SVC, HåVa, Formas…
  - EU: MSCA, LIFE, Eurostars



Freshwater monitoring & evaluation

- National monitoring programs
  - **Fish**
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https://www.slu.se/

Freshwater monitoring & evaluation

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  - **Benthic fauna**
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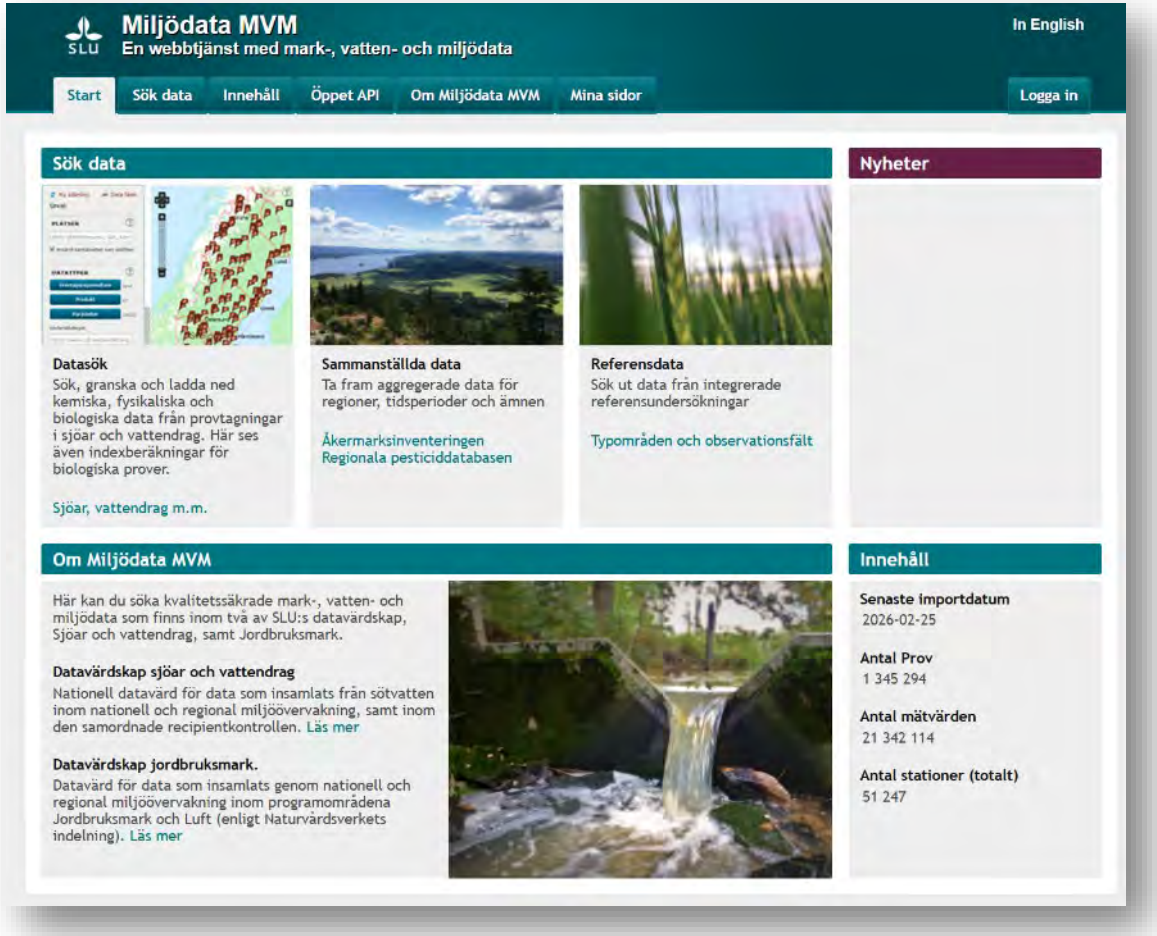

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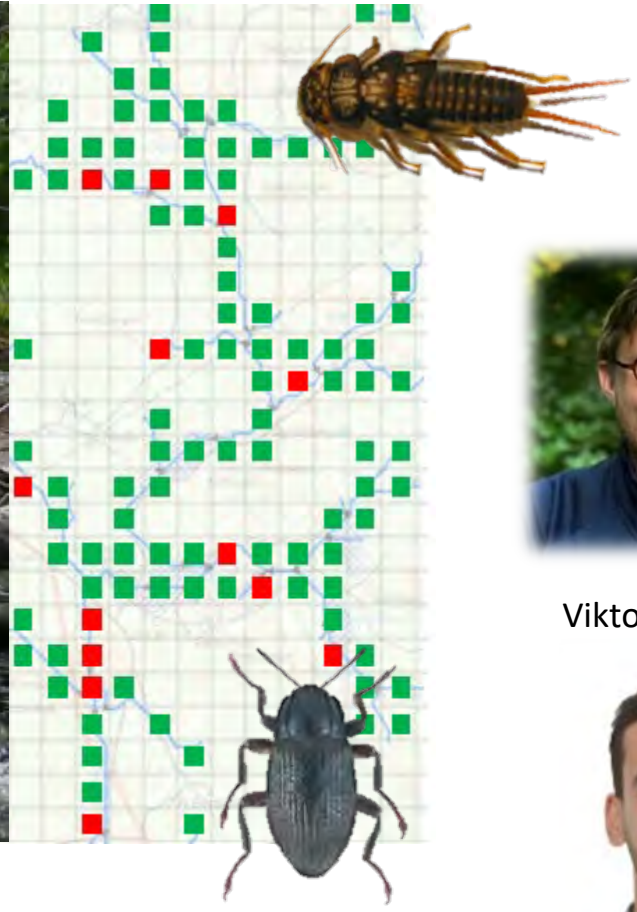


Viktor Nilsson

Rami Babas

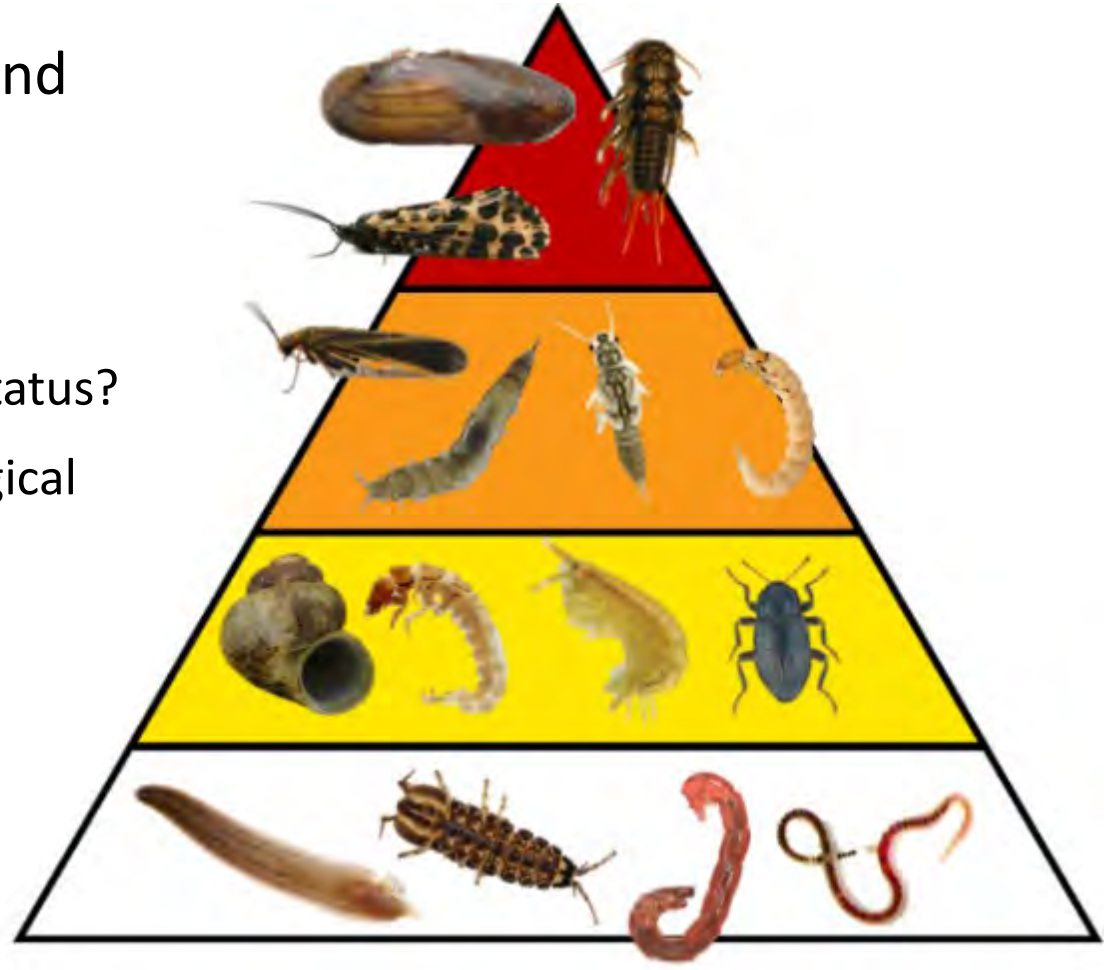
Benthic Macroinvertebrates as Biodiversity Indicators

Viktor Nilsson (Project leader)
Rami Babas (PhD student)

Evaluation: Measuring Ecological Performance

FAQ #9

- Restoration toolbox requires robust tools and indicators for ecological evaluation
- Key questions:
  - Did restoration measures improve ecological status?
  - Do our indicators reflect habitat quality, ecological function and biological values?



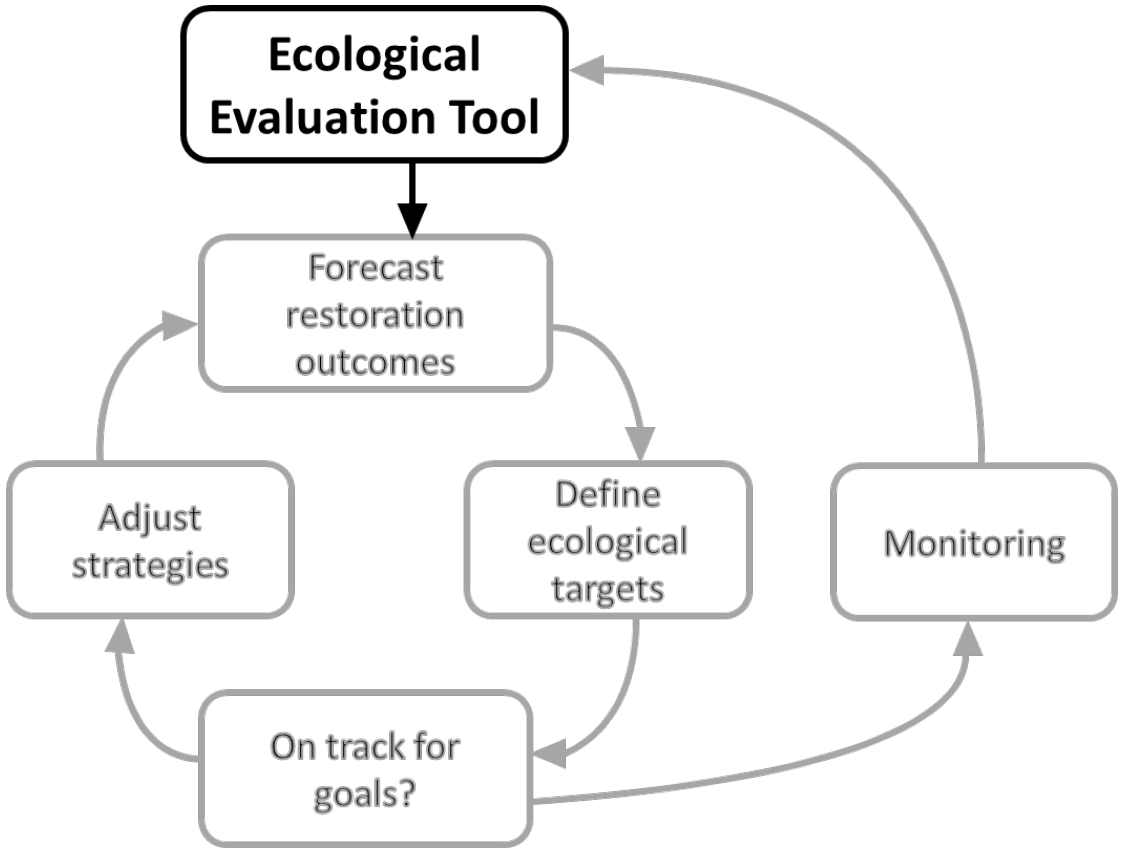
SVENSKT VATTENKRAFTCENTRUM

Benthic Macroinvertebrates as Ecological Performance Indicators

- Wealth of available data
- Relevance as indicators:
  - Sensitive: rapid response to stress
  - Limited mobility: integrate effects over time
    Species rich and ecologically diverse
- Functional relevance:
  - Drive nutrient cycling and energy transfer
  - Prey base for fish
- Policy relevance:
  - Core biological quality element under WFD
  - Long national monitoring time series

SVENSKT VATTENKRAFTCENTRUM

Building Evidence-Based Restoration tools



The SVC project will develop a tool to support:

- Comparing alternative restoration scenarios
- Identifying high-gain restoration sites
- Evidence-based quantification of ecological outcomes

Dynamic system:

→ Continuously updated with all available monitoring data

SVENSKT VATTENKRAFTCENTRUM

Freshwater monitoring & evaluation

- National monitoring programs
  - Fish
  - Benthic fauna
  - Hydrology
  - …
- EU Data Collection Framework (DCF)
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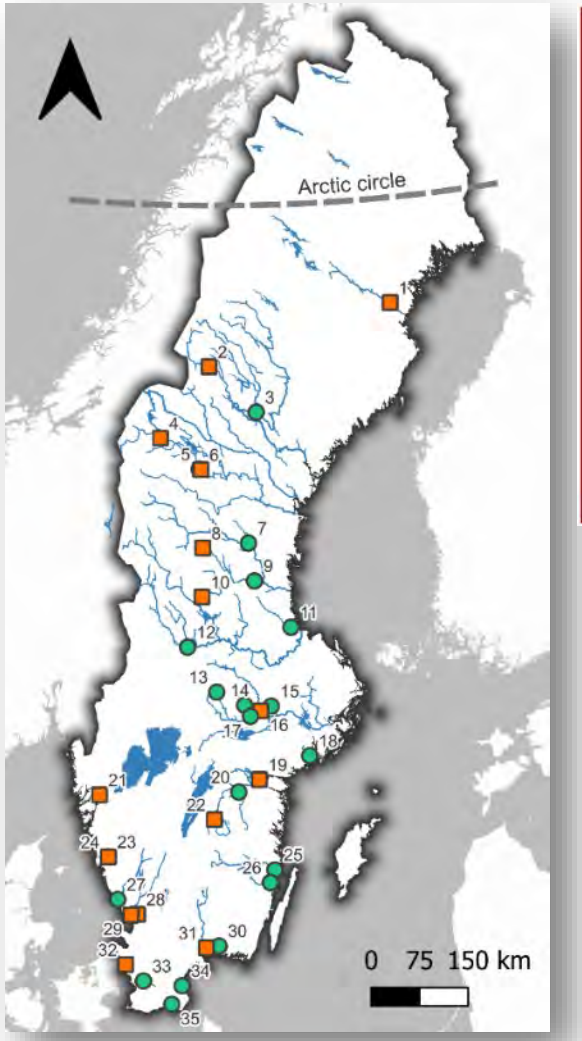

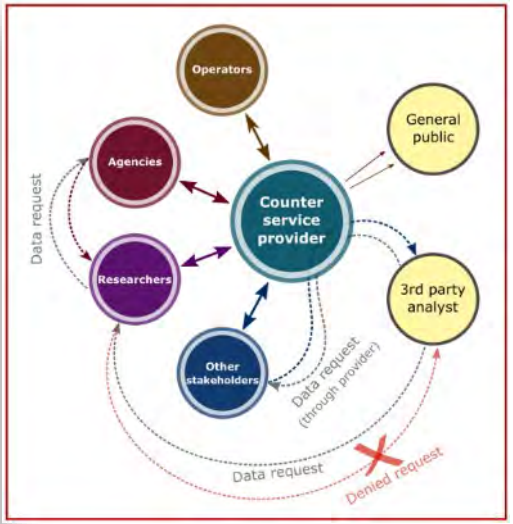

Fish counter data

FISK data.se

https://fiskdata.se/

https://fishstewards.org/

By unlocking the full potential of fish counter data, FISH STEWARDS enables better decision-making, more effective river rehabilitation, increased knowledge about our fish fauna, and long-term biodiversity protection.

FAQ #10

FORMAS

Freshwater monitoring & evaluation

- National monitoring programs
  - Fish
  - Benthic fauna
  - Hydrology
  - …
- EU Data Collection Framework (DCF)
- Self-monitoring by owners
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  - Swe: SVC, HåVa, Formas…
  - EU: MSCA, LIFE, Eurostars
- **NAP?**

Programmatic monitoring in regulated rivers
- SwAM assignment -

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Knowledge & Management of Aquatic Ecosystems

Journal fully supported by Office français de la biodiversité

REVIEW PAPER OPEN ACCESS

Balancing hydropower production and ecology – ecological impacts, mitigation measures, and programmatic monitoring

Daniel Nyqvist[1,*], Olle Calles[2], Peter Carlson[3], Kerstin Holmgren[1], Birgitta Malm-Renöfält[4], Åsa Widén[5], Jakob Bergengren[6] and Joacim Näslund[1]

[1] Institute of Freshwater Research, Department of Aquatic Resources, Swedish University of Agricultural Sciences, Drottningholm, Sweden
[2] River Ecology and Management Research Group RivEM, Karlstad University, Karlstad, Sweden
[3] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
[4] Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden
[5] Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden
[6] Tekniska verken i Linköping AB, Linköping, Sweden

Received: 3 July 2025 / Accepted: 26 August 2025

Abstract – Hydropower is a vital renewable energy source but has substantial ecological impacts on rivers, lakes, and surrounding ecosystems. It alters hydrogeomorphology, disrupts connectivity, and changes water physicochemical properties such as temperature and dissolved gas concentrations. Historically, the environmental impact has been of less concern compared to energy production, and there is an urgent need to adapt hydropower production to reduce impacts on aquatic ecosystems. While various mitigation measures exist, a systematic understanding of their efficiency is lacking. Here, we extensively review both the environmental effects of hydropower and the scientific base for mitigation measures. We then list key abiotic and biological candidates for systematic monitoring before outlining a programmatic monitoring approach to evaluate the efficiency of mitigation measures. This programmatic monitoring approach involves monitoring packages based on specific mitigation measures. A set of abiotic parameters and biological indicators are monitored with standardized methods and monitoring designs over the long-term and at several sites, covering different river types and hydropower configurations. The proposed program serves to inform ongoing and future remedial measures, expand our mechanistic understanding of the ecological effects, facilitate knowledge transfer, and allow for more reductionist monitoring approaches outside of the program.

Keywords: Environmental flow / fish passage / temperature effects / gas supersaturation / remedial measures / restoration

Nyqvist *et al.* (2025)

Toolbox take home message

Karlstads Universitet

RivEM

Svenskt Centrum för Hållbar Vattenkraft

LIFEConnects

Life

Improve Aquatic LIFE

Co-funded by the European Union

Energimyndigheten

FORMAS

Energiforsk

Länsstyrelserna

Havs och Vatten myndigheten

SLU

Lund University

Göteborgs Universitet

uniper

VATTENFALL

Statkraft

fortum

RIBES

NTNU

TiVA

Fiskevårdsteknik AB

Norconsult

KK-stiftelsen

Naturskyddsföreningen

Politecnico di Torino

NINA

Norwegian Institute for Nature Research

DHI

FALKENBERG

fishheart

eurostars

SportFiskarna

Sveriges Sportfiske- och Fiskevårdsförbund

SINTEF

HydroCen

SVC tools talk RivEM reference list

Addo,L., Hajiesmaeili, M., Piccolo, J.J. and Watz, J. (2025). Growth and mortality of sympatric Atlantic salmon and brown trout fry in fluctuating and stable flows. Ecology of Freshwater Fish. **32:** 282–290. https://doi.org/10.1111/eff.12685

Addo,L., Meneboo, L., Hajiesmaeili, M., Piccolo, J.J. and Watz, J. (2025). Drift Foraging by Allopatric and Sympatric Atlantic Salmon and Brown Trout Parr Under Rapid Flow Fluctuations. *River Research and Applications*. **41**: 1546–1557. https://doi.org/10.1002/rra.4464

Addo,L., Watz, J., Piccolo, J.J., Norrgård, J., Syjränen, J.T., Railsback, S.F. and Hajiesmaeili, M. (2026). Individual-based modeling of Atlantic salmon and brown trout outmigrants in a hydropeaking-regulated river: Effects of minimum baseflow and gravel augmentation on smolt production. *Global Ecology and Conservation*. **66:** e04111. https://doi.org/10.1016/j.gecco.2026.e04111

Björnås, K.L., Railsback, S.F., Calles, O. and Piccolo, J.J. (2021). Modeling Atlantic salmon (*Salmo salar*) and brown trout (*S. trutta*) population responses and interactions under increased minimum flow in a regulated river. *Ecological Engineering*. **16**: 106182. https://doi.org/10.1016/j.ecoleng.2021.106182

Eggers, F., Watz, J., Österling, M and Calles, O. (2026). Nature-like versus technical fishways: combining fish counter and electrofishing data to evaluate passage effectiveness at the community level. *Submitted.*

Hajiesmaeili, M., Addo,L., Watz, J., Railsback, S.F., and Piccolo, J.J. (2022). Individual-based modelling of hydropeaking effects on brown trout and Atlantic salmon in a regulated river. *River Research and Applications*. **39**: 522-537. https://doi.org/10.1002/rra.4037

Hajiesmaeili, M., Addo,L., Watz, J., Norrgård, J., Railsback, S.F., Syjränen, J.T., Blixt, M. and Piccolo, J.J. (2024). Sustaining high-value salmonid populations in regulated rivers: Insights from individual-based modelling of brown trout and Atlantic salmon. *Global Ecology and Conservation*. **51:** e02887. https://doi.org/10.1016/j.gecco.2024.e02887

Harbicht, A.B., Nilsson, P.A., Österling, M. and Calles, O. (2021). Environmental and anthropogenic correlates of migratory speeds among Atlantic salmon smolts. River Research & Applications. **37**: 358-372. https://doi.org/10.1002/rra.3760

Nyqvist, D., Calles, O., Carlson, P., Holmgren, K., Malm-Renöfält, B., Widén, Å., Bergengren, J. and Näslund, J. (2025) Balancing hydropower production and ecology – ecological impacts, mitigation measures, and programmatic monitoring. *Knowledge & Management of Aquatic Ecosystems*. **426**: 24. https://doi.org/10.1051/kmae/2025018

Shry, S. (2026). Anadromy in Fragmented Rivers: Downstream Passage Challenges for Migrating Salmonids. Karlstad University, Faculty of Health, Science and Technology, Doctoral thesis. https://urn.kb.se/resolve?urn=urn:nbn:se:kau:diva-107916

Shry, S., Harbicht, A., Forsberg, H., Nilsson, A., Hellström, G., Österling, M., Calles, O. (2024). Challenges in downstream dam passage and the effect of dam removal on Atlantic salmon (*Salmo salar*) smolt migrations. Journal of Fish Biology. **106**: 1440–1451. https://doi.org/10.1111/jfb.15770

Watz, J., Bergman, E., Calles, O., Eckstein, R.L., Nilsson, P.A., Carlsson, N., Zagars, M and Gómez, M. (2025a) Changes in the size distribution of a freshwater fish after lake outlet dam removal: a pilot study. *Ecohydrology*. ***18e***:70072**.** https://doi.org/10.1002/eco.70072

Watz, J., Carlsson, N., Bergman, E., Nilsson, P.A. and Calles, O. (2025b) Conservation benefits of lake outlet dam removals: reduced mercury in an apex fish predator. *Aquatic Conservation: Marine and Freshwater Ecosystems*. **35**: e70248**.** https://doi.org/10.1002/aqc.70248