Ecohydraulic research within Centre for environmental design of renewable energy (CEDREN)

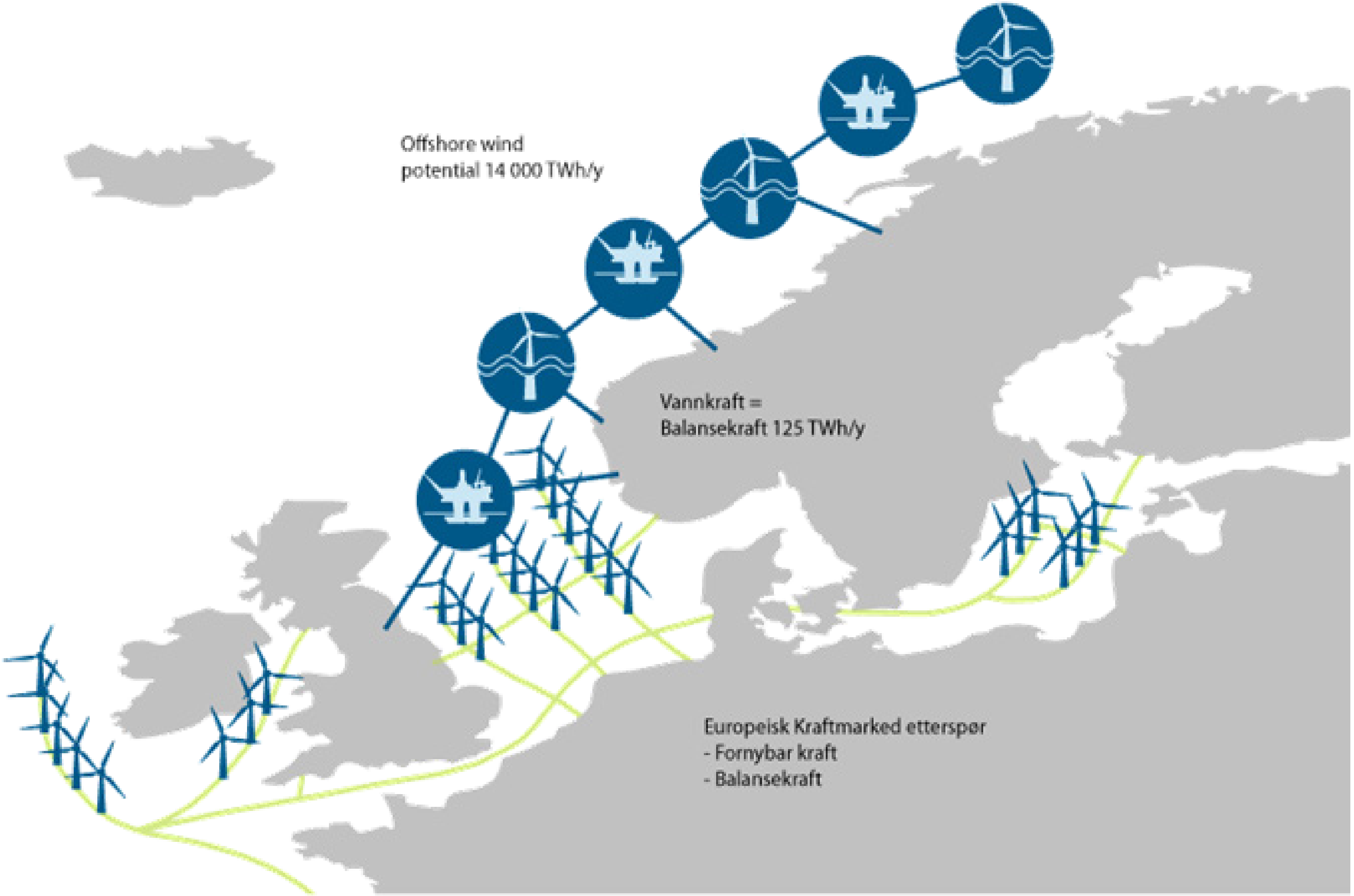
Atle Harby, CEDREN Director
SINTEF Energy Research
Norway

Centre for environmental design of renewable energy - CEDREN

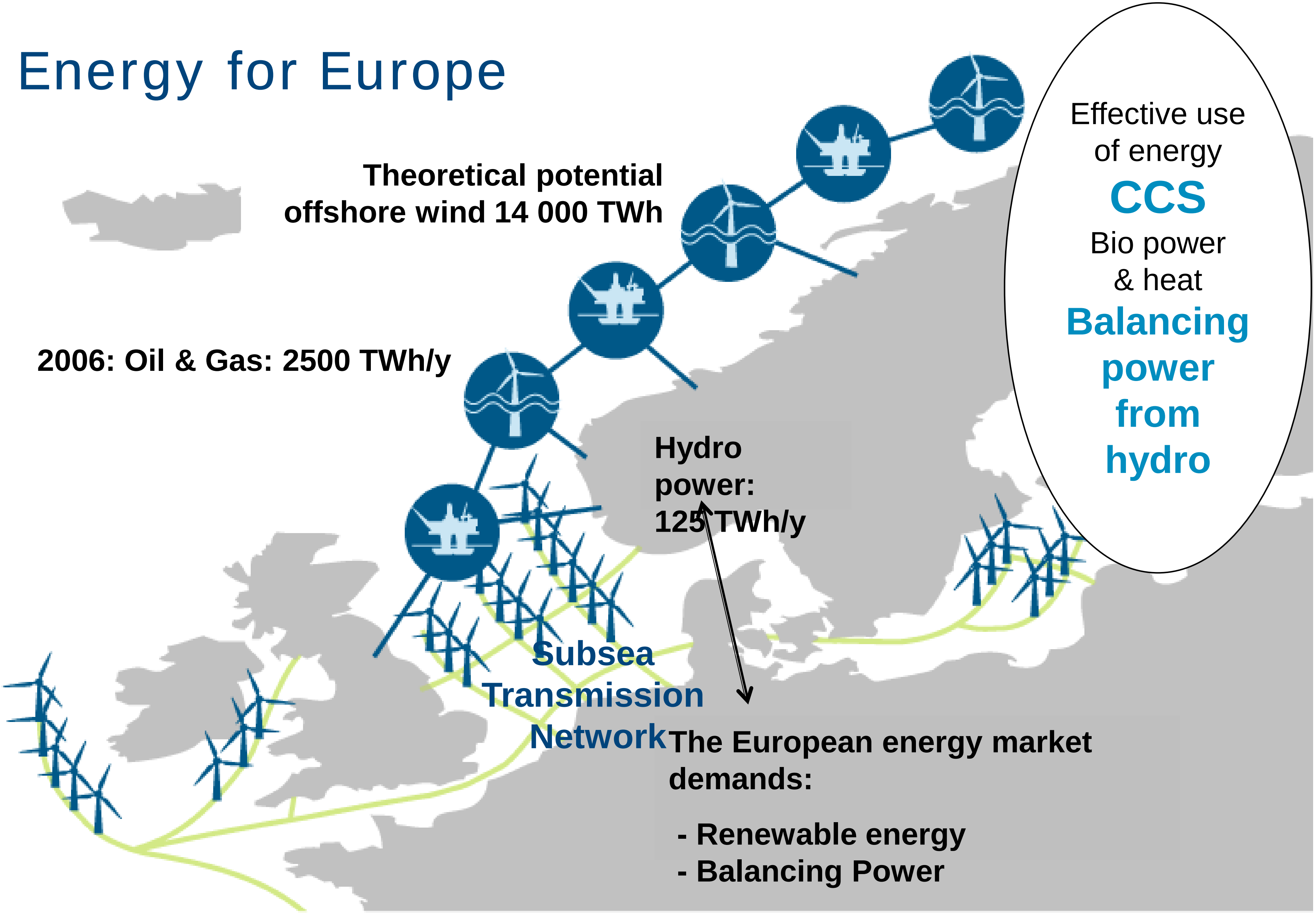
SINTEF
NTNU
100 skapende år
NINA
NATURHISTORISK MUSEUM
UNIVERSITETET I OSLO
NIVA
uni Research

Renewable energy respecting nature

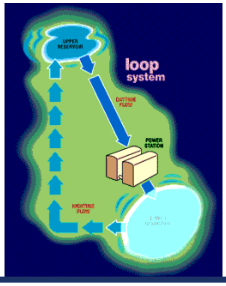
Energi21 and The Parliament
→ 8 new research centres on environmental-friendly energy



Energy for Europe



Hydropower technology for the future

Environmental design of hydropower



Impacts on birds and wildlife from wind turbines and power lines



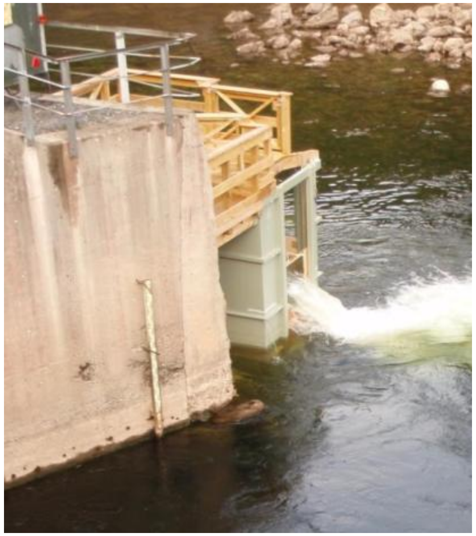
Reconciling environmental and energy policy concerns

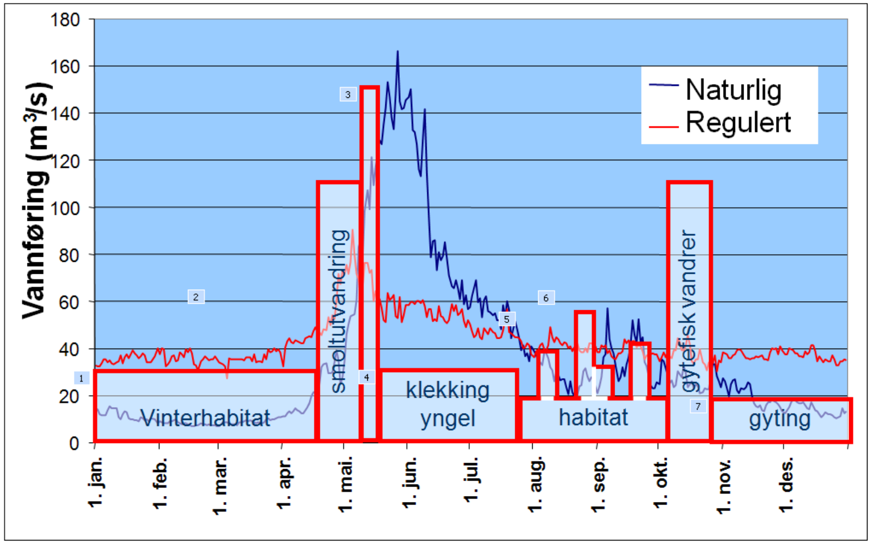
CEDREN will deliver

1. Knowledge about renewable and sustainable energy production

CEDREN will deliver

2. Innovation and new opportunities for renewable energy solutions





CEDREN will deliver

3. Outstanding dissemination and targeted communication of processes and results

VG Nett ▸ Nyheter ▸ Innenriks ▸ Artikkel

SINTEF slakter mastedebatt

Publisert 09.03.11 - 05:47, endret 09.03.11 - 05:59 (© NTB)

Regjeringen vinglet og lokalpolitikerne var utydelige. Konsekvensen av politikernes inkonsekvente oppførsel kan bli en strøm av nye konflikter, skriver SINTEF i en ny rapport.

MASTEDEBATT SLAKTES: I en ny rapport slakter SINTEF politikernes håndtering av mastedebatten. FOTO: ESPEN BRAATA

- Jeg tror ikke regjeringen skjønte sprengkraften i Hardangersaken. De ble tatt på sengen av mediestormen og turde ikke stå fast ved energipolitikken sin når saken eksploderte, sier forskningsleder Audun Ruud ved SINTEF Energi til Bergens Tidende.

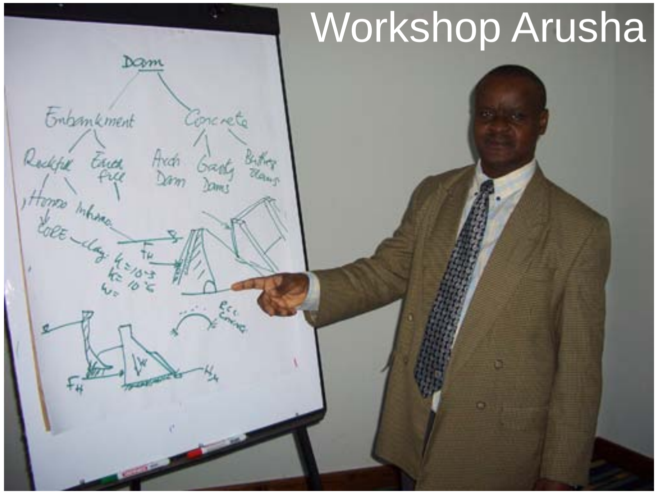
VG Nett følger
Olje og energi
Les også:
Tre av ti uten mening om oljeboring i nord
Flertallet for sjøkabel forsvant etter ekspertrapporter

PhD and Post doc

International collaboration

- Research and education
- Authorities
- Seminars, workshops
- Together with Norwegian industry
- Case-studies


GHG issues at
Bakun dam, Malaysia



Workshop Arusha

Policy brief


End-user
meeting in India

Funding

The Research Council of Norway

agder energi

BKK

ECO

Eidsiva

EnergiNorge

HYDRO

ICH

Sira-Kvina kraftselskap

Statkraft

Statnett

TrønderEnergi

NVE

Hafslund

NTE

TROMS KRAFT

Associated research partners

SEI STOCKHOLM ENVIRONMENT INSTITUTE
BRIDGING SCIENCE AND POLICY SINCE 1989

GAME AND FISHERIES RESEARCH

BOKU

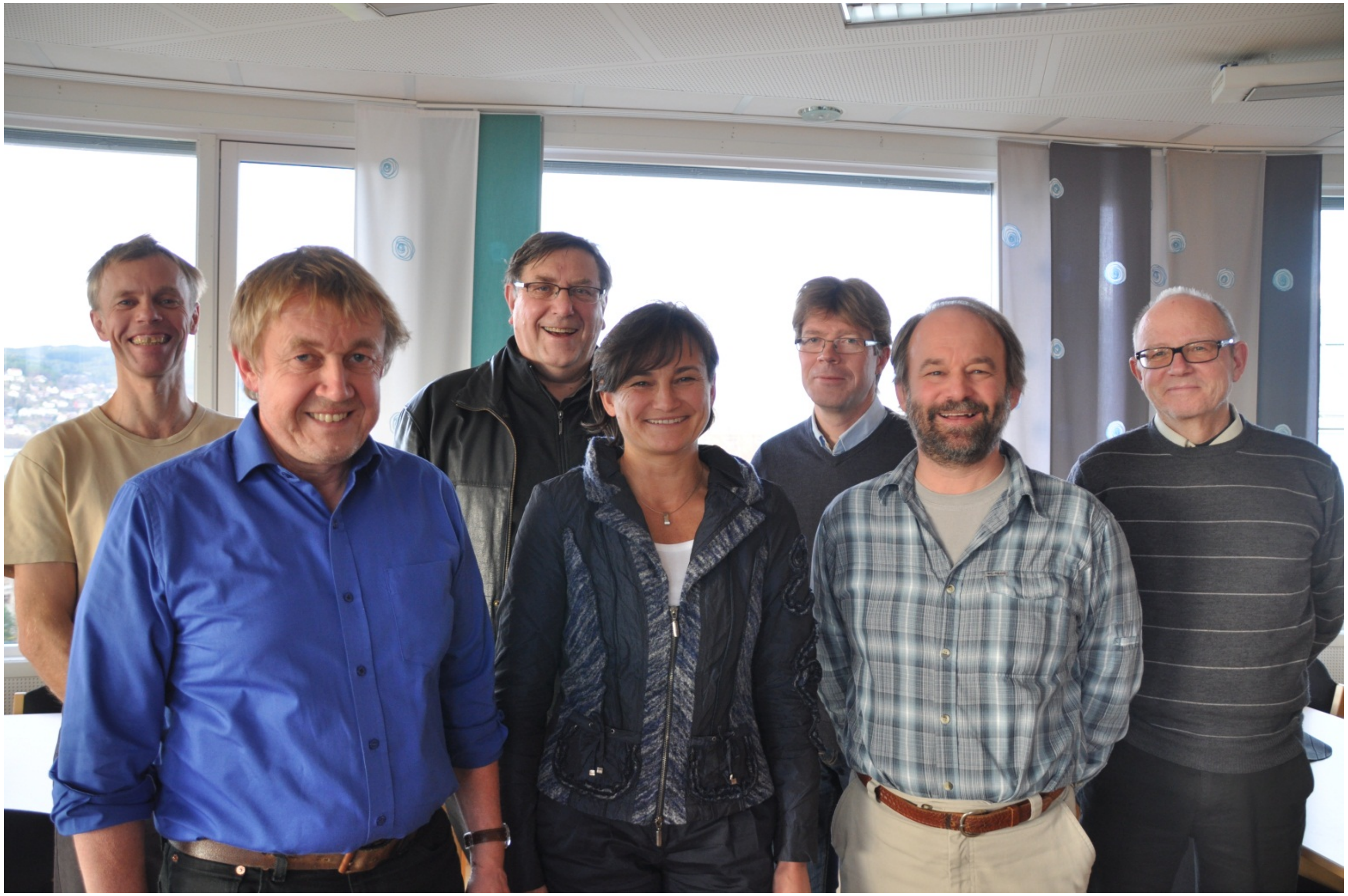
Universität Stuttgart

sje

HERIOT WATT UNIVERSITY

UNIVERSITY OF EXETER

Scientific Committee



Klaus Jorde
KJ Consult/SJE

Silke Wieprecht
Uni Stuttgart

Daniel Boisclair
Univ. Montreal

CEDREN key figures 2011

- Total costs: 64,6 Mill NOK
- 110 scientists and students working
  - SINTEF Energi 34
  - NINA 41
  - NTNU 14
  - LFI 5
  - NIVA 4
  - Uni Research 12
- 16 PhD og 4 post-doc


Helge Skoglund


Roel May


Maxim Teichert

Dams

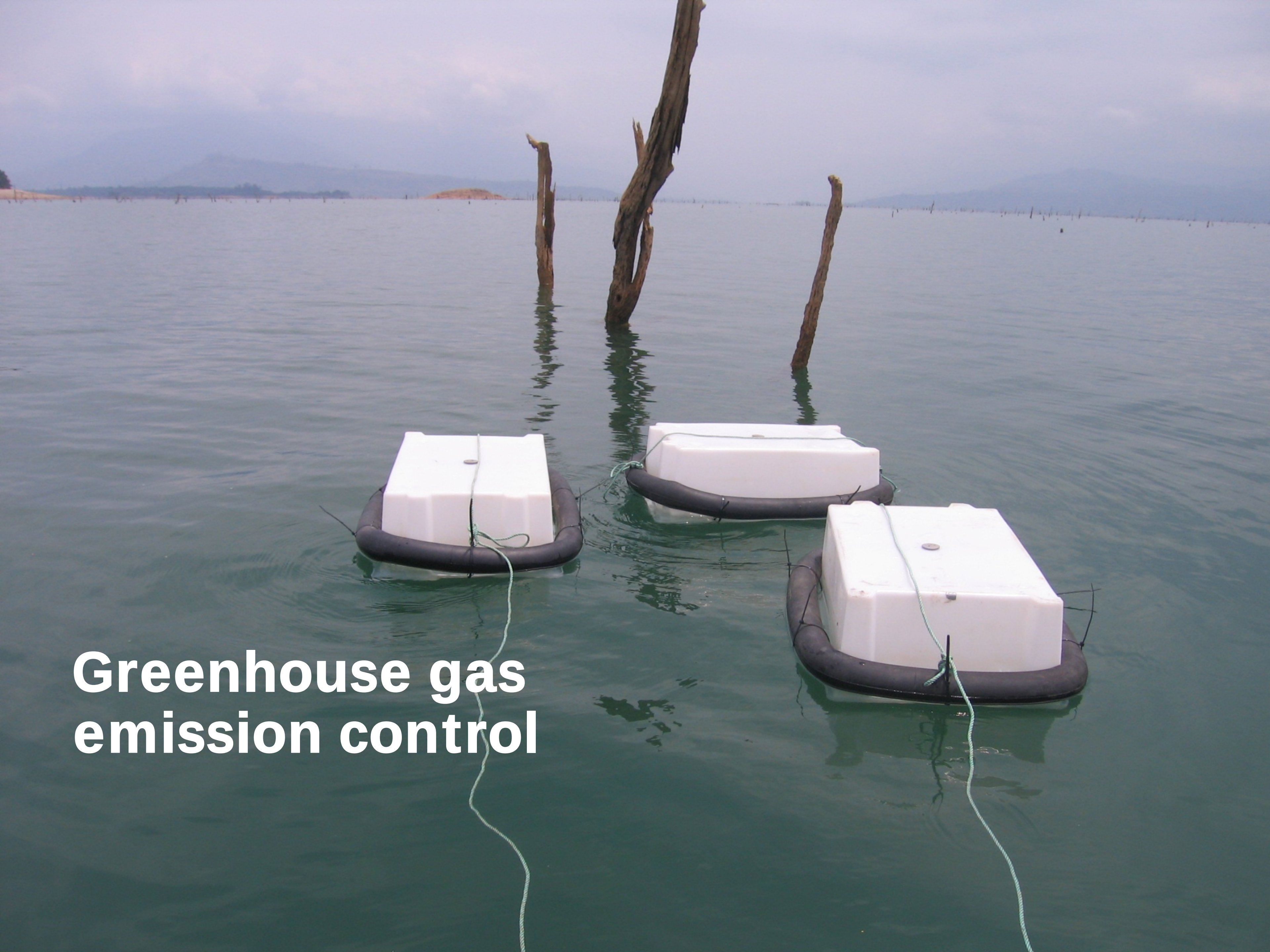
- Migration barrier
- Loss of connectivity
- Less access
- Loss of biodiversity


Degraded habitat in bypassed sections

Change in downstream flow regime

Landscape effect
Impacts on wildlife

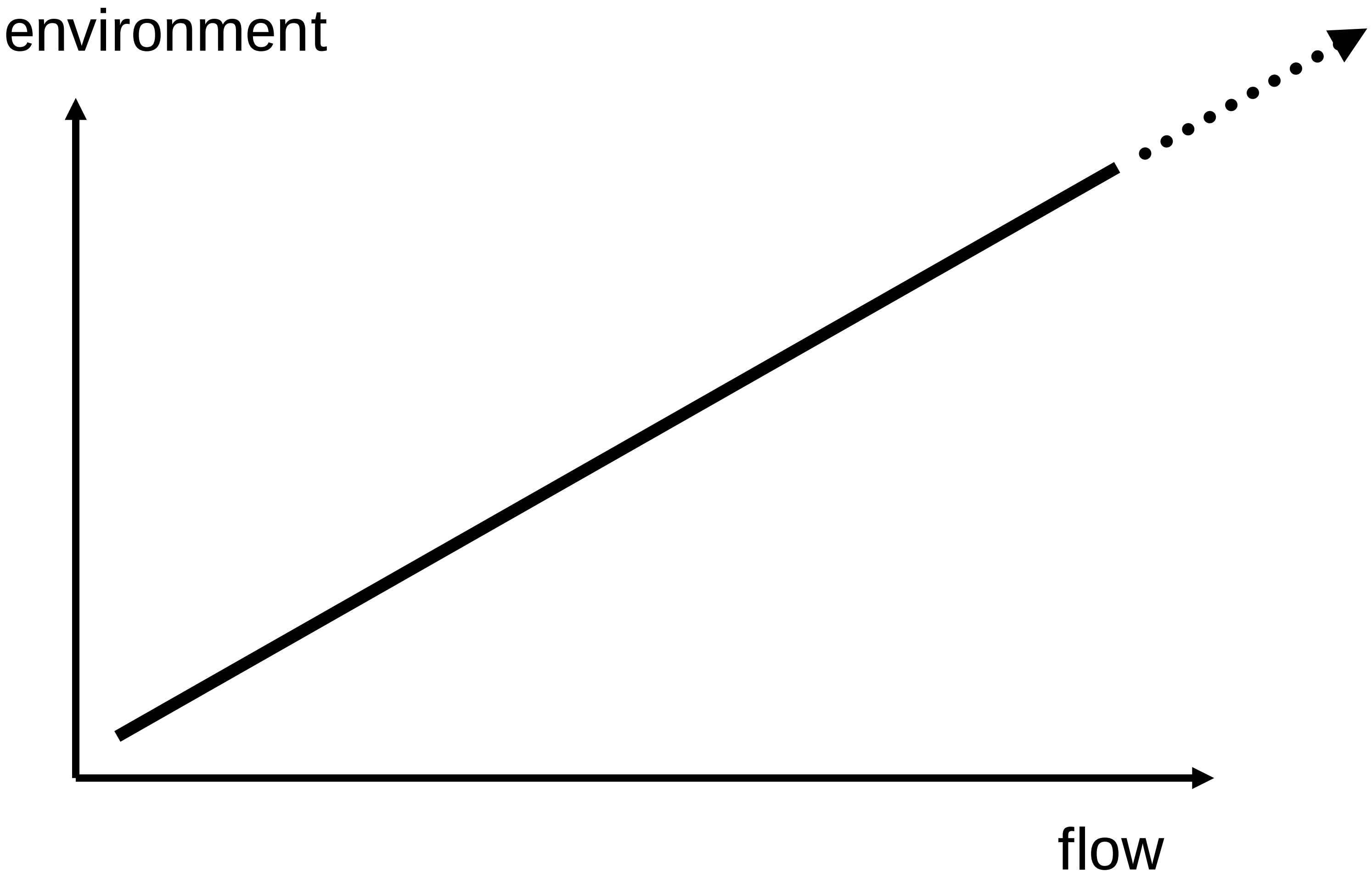
Foto: NINA


Greenhouse gas
emission control

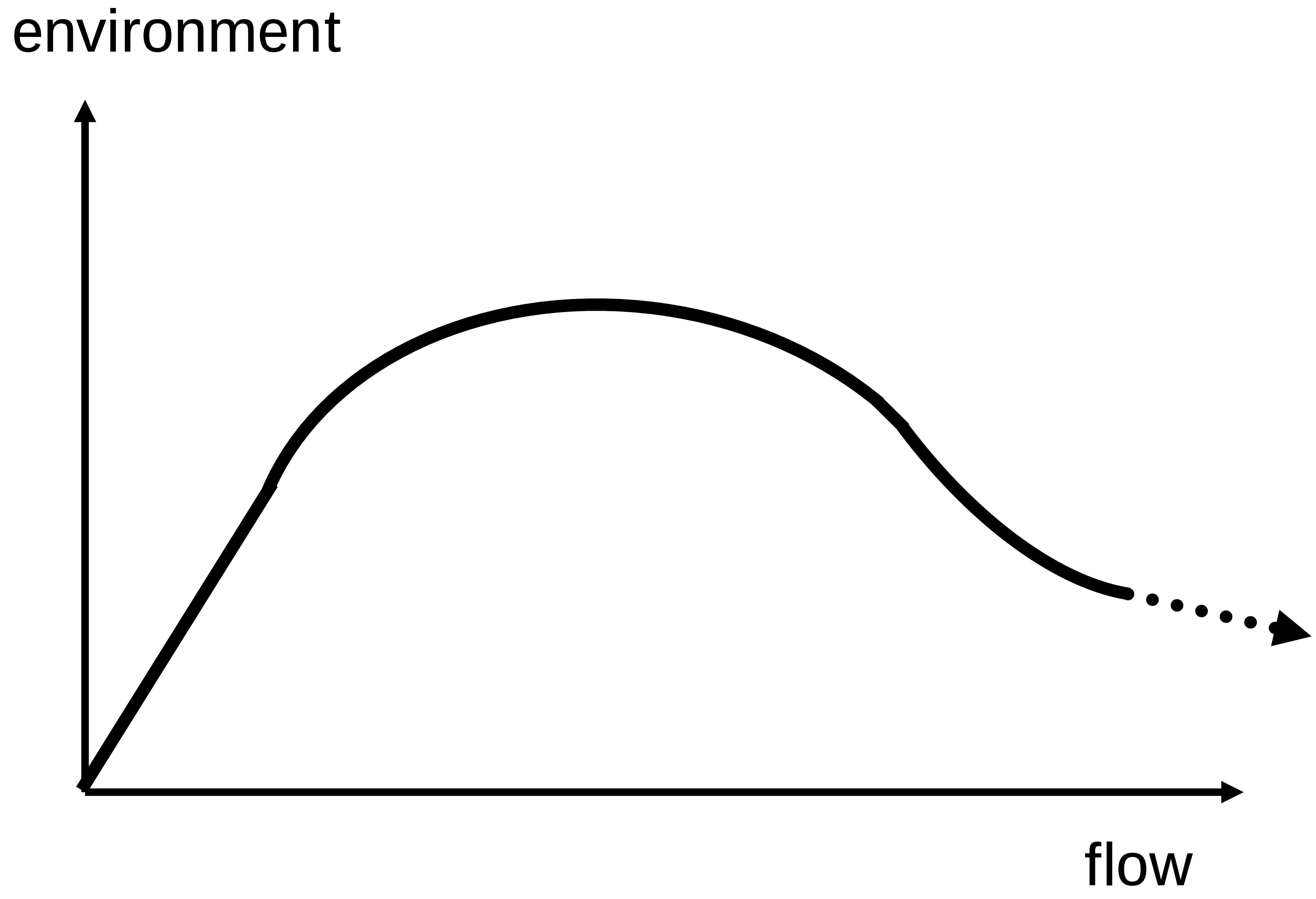
Resettlement

How to mitigate all this?

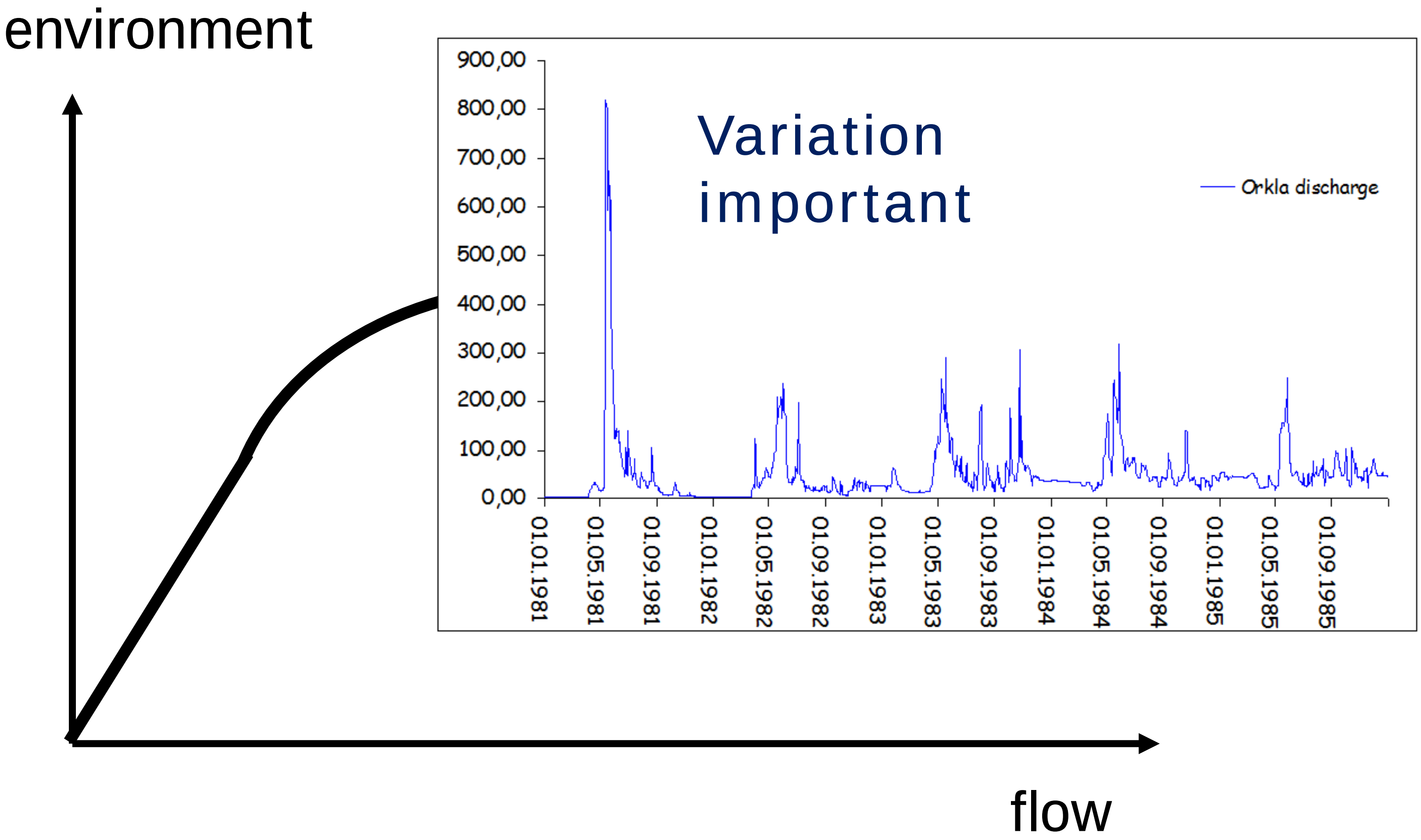
Flow and the environment



Flow and the environment



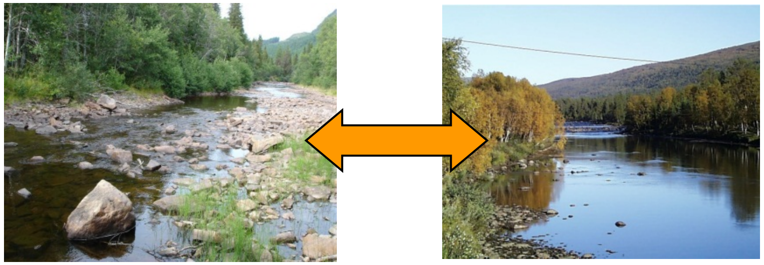
Flow and the environment



Alternatives

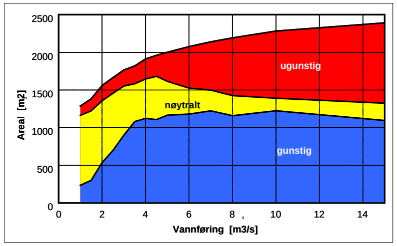


1. Investigate status



Compare to other rivers

Guess

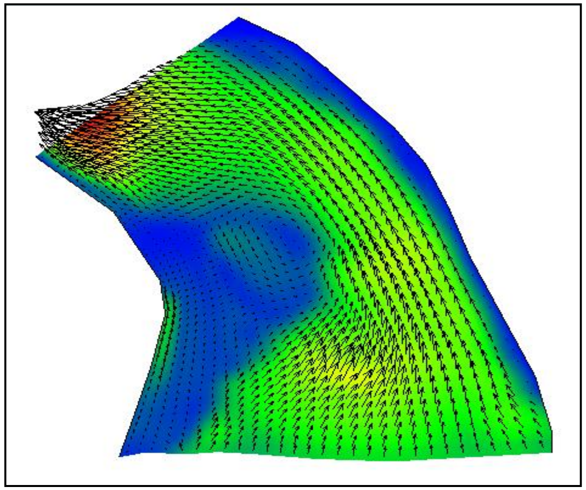


Model

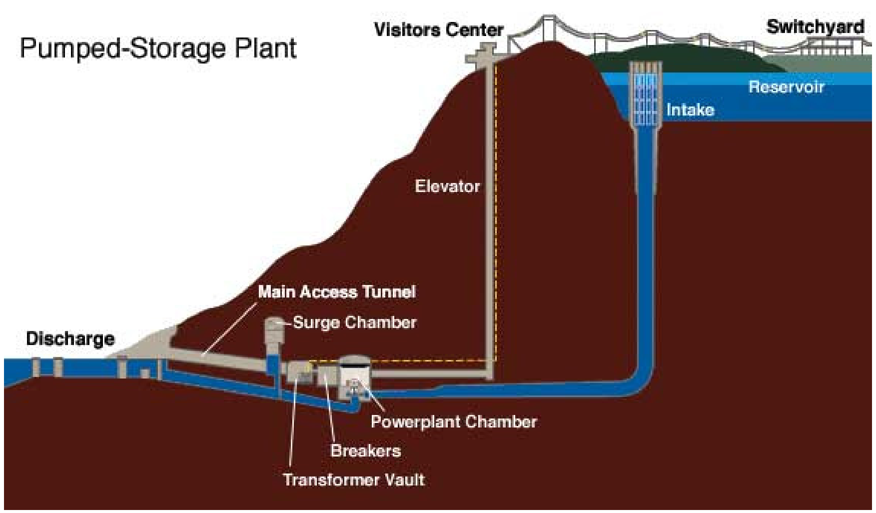
In *situ* study

Laboratory

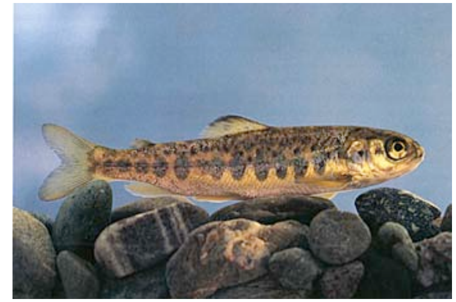
Model simulation



Demonstration

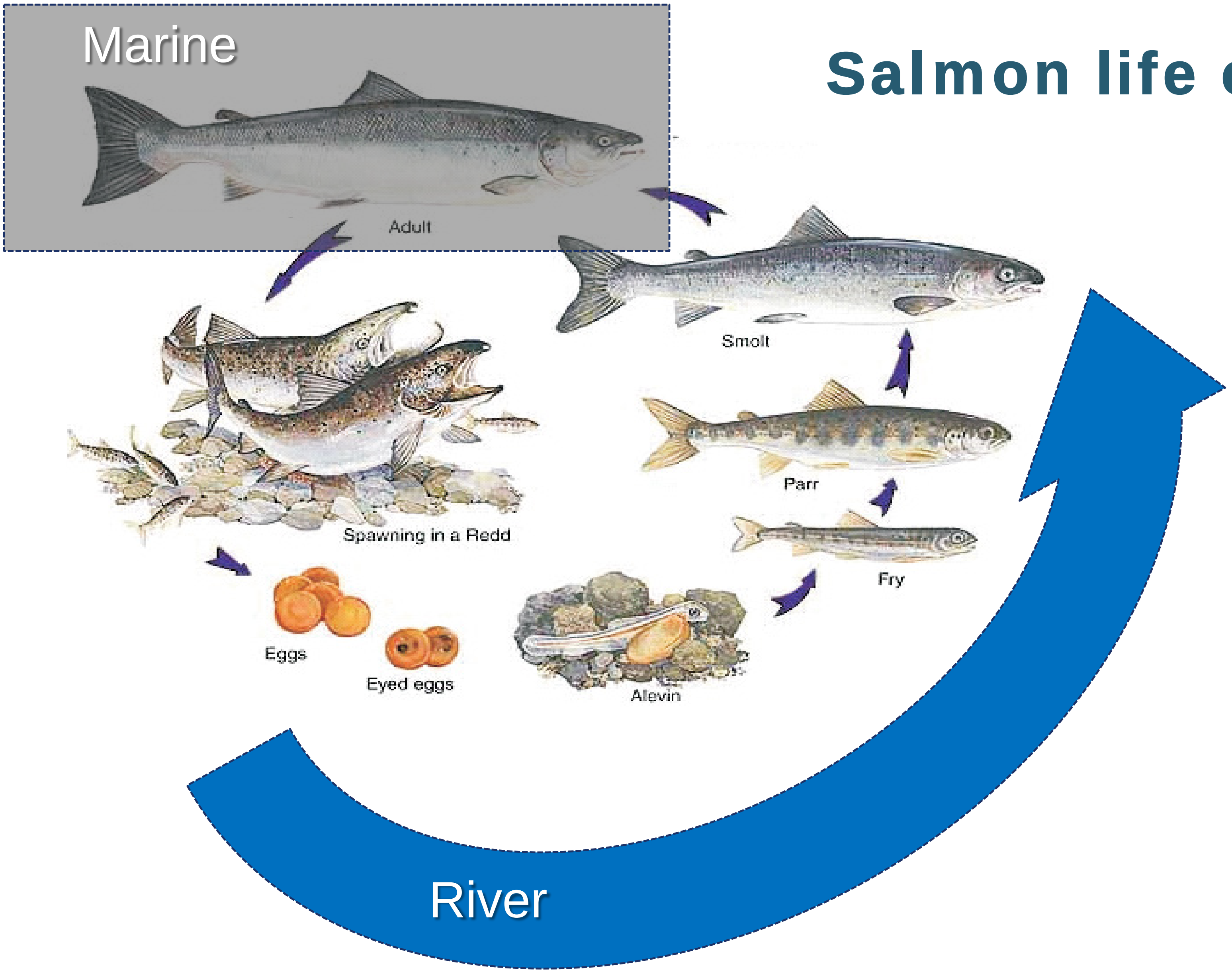


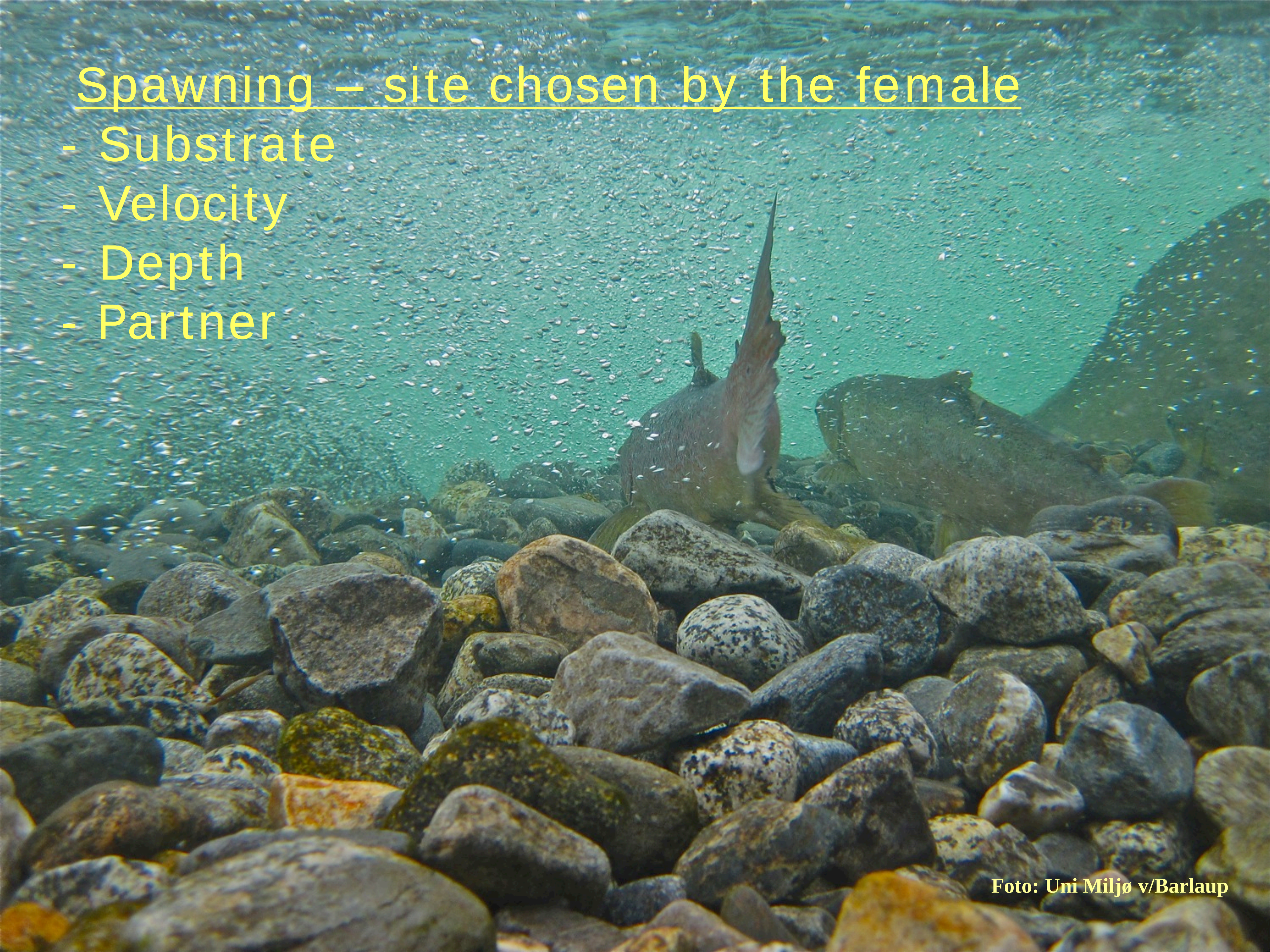
How much water is needed?

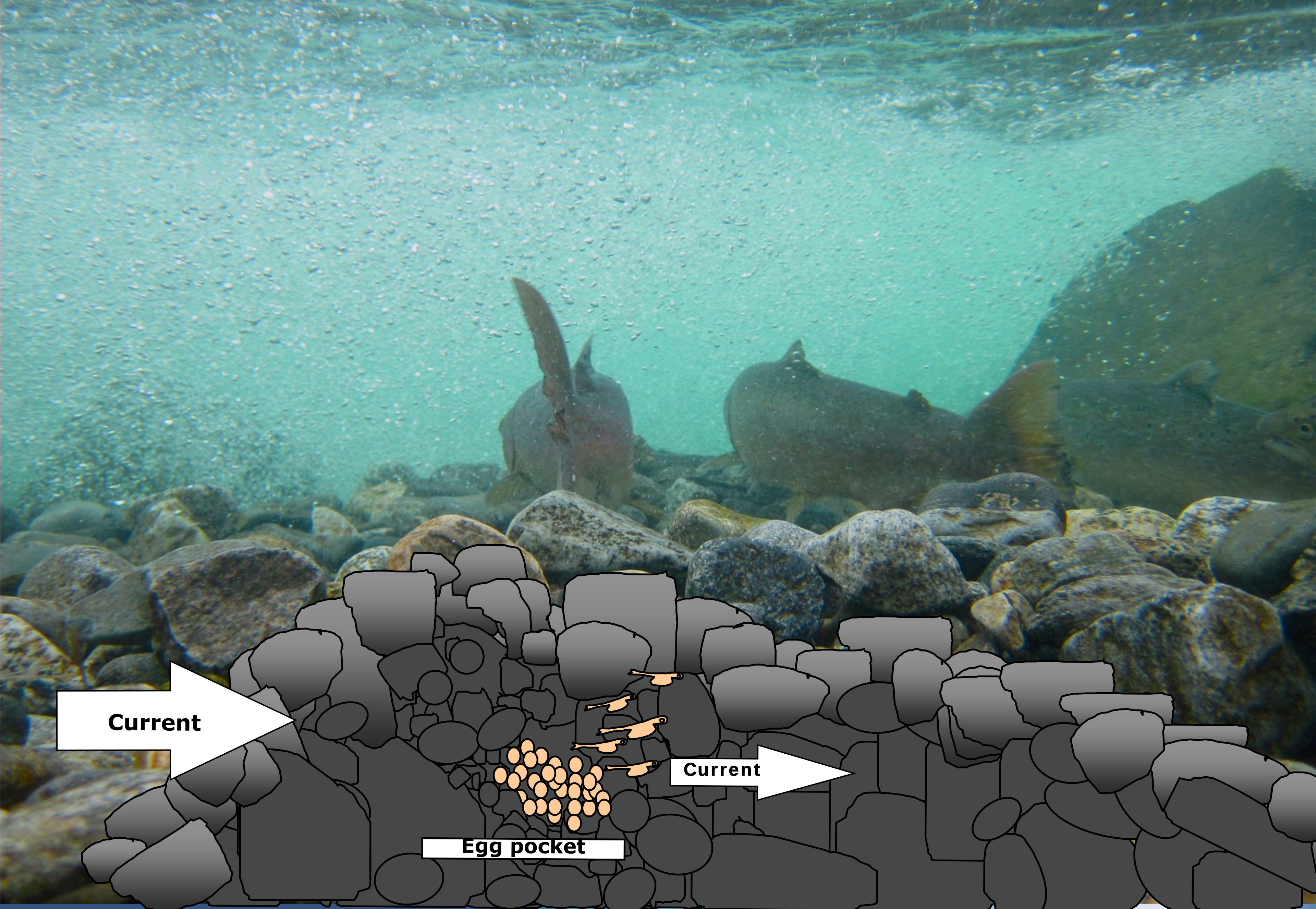


EnviDORR

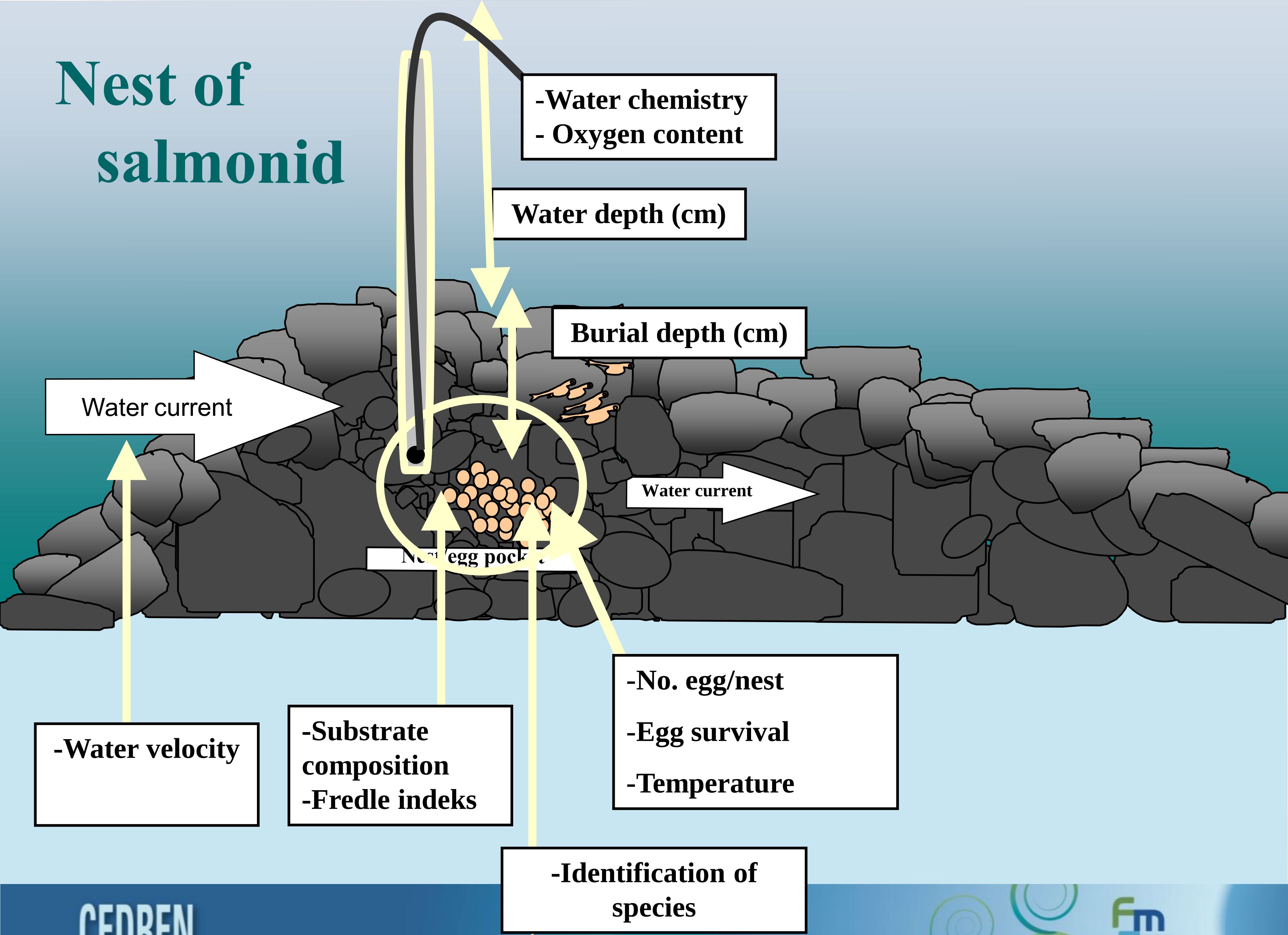
Salmon life cycle




Spawning – site chosen by the female
- Substrate
- Velocity
- Depth
- Partner
Foto: Uni Miljø v/Barlaup

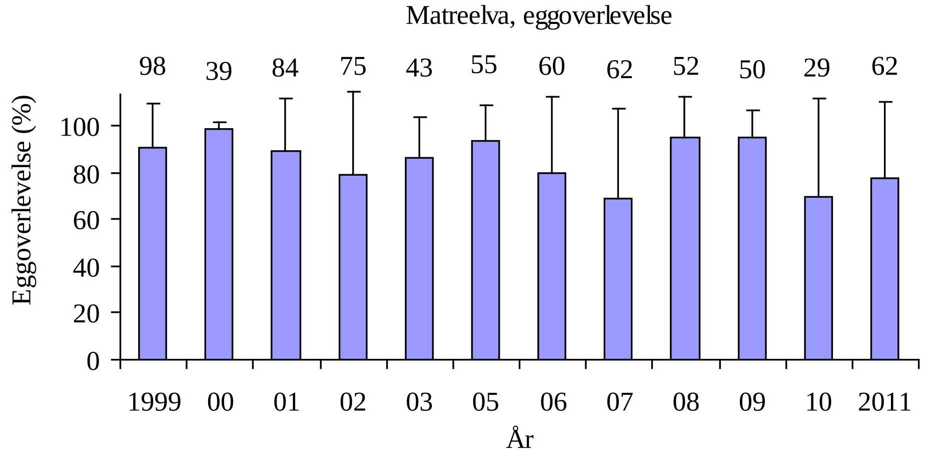

Current
Current
Egg pocket

Nest of salmonid



Spawning redd for Vosso salmon (110 cm):
- grain size > 64 mm.
- depth 25-30 cm

Foto: LFI v/Barlaup



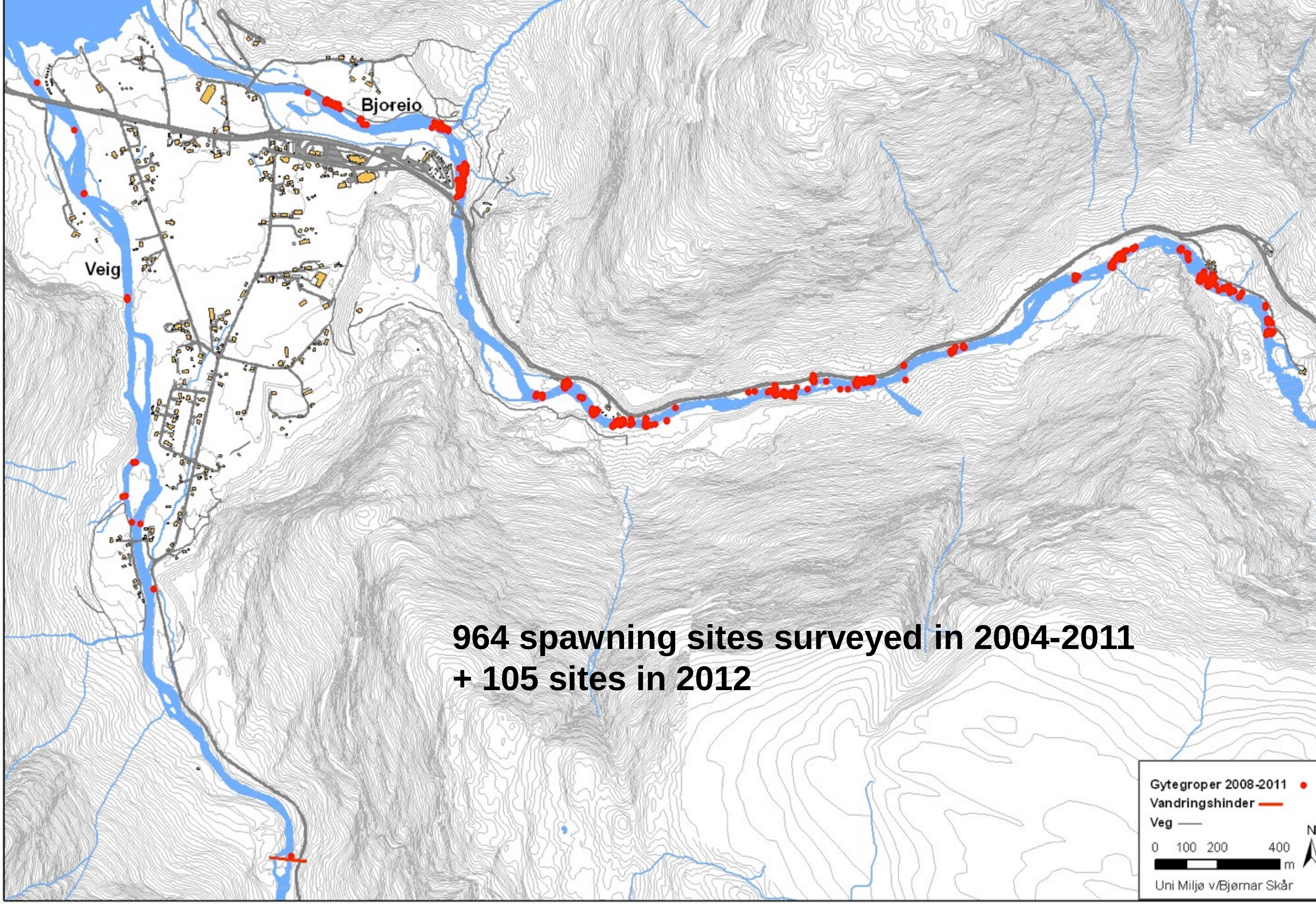
Normal egg survival > 80 %


Large spawning fields
Foto: LFI-Unifob v/Wiers

Small patches of spawning grounds

Small spawning site in Bjoreio

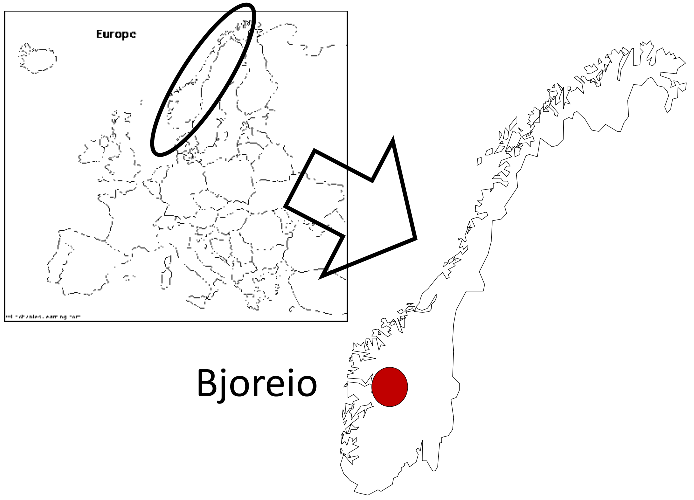
Foto: LFI-Unifob v/Barlaup



964 spawning sites surveyed in 2004-2011
+ 105 sites in 2012

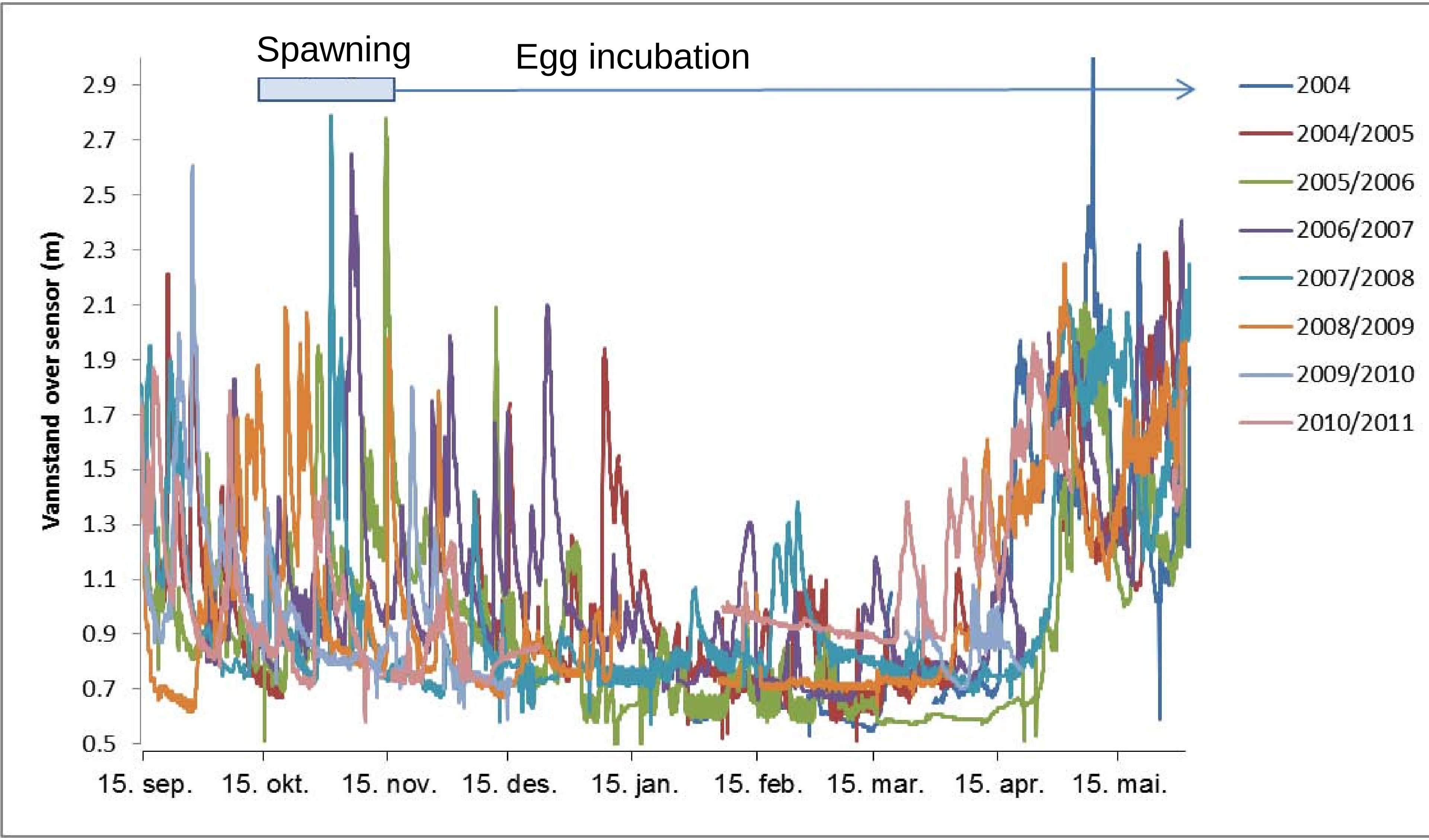
Vøringsfossen – one of Norway's highest rated tourist attractions

Bjoreio – water diverted for power production

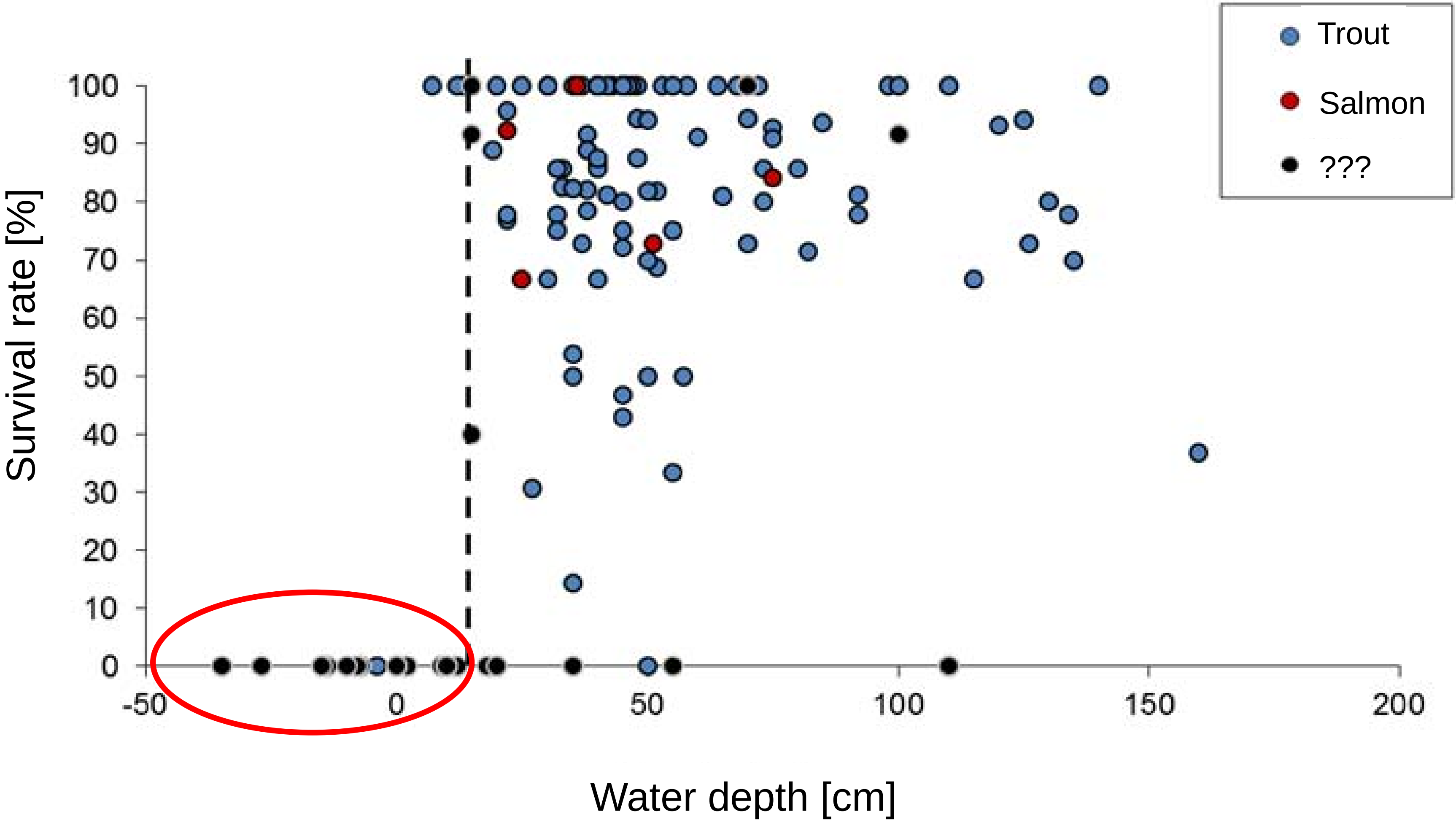


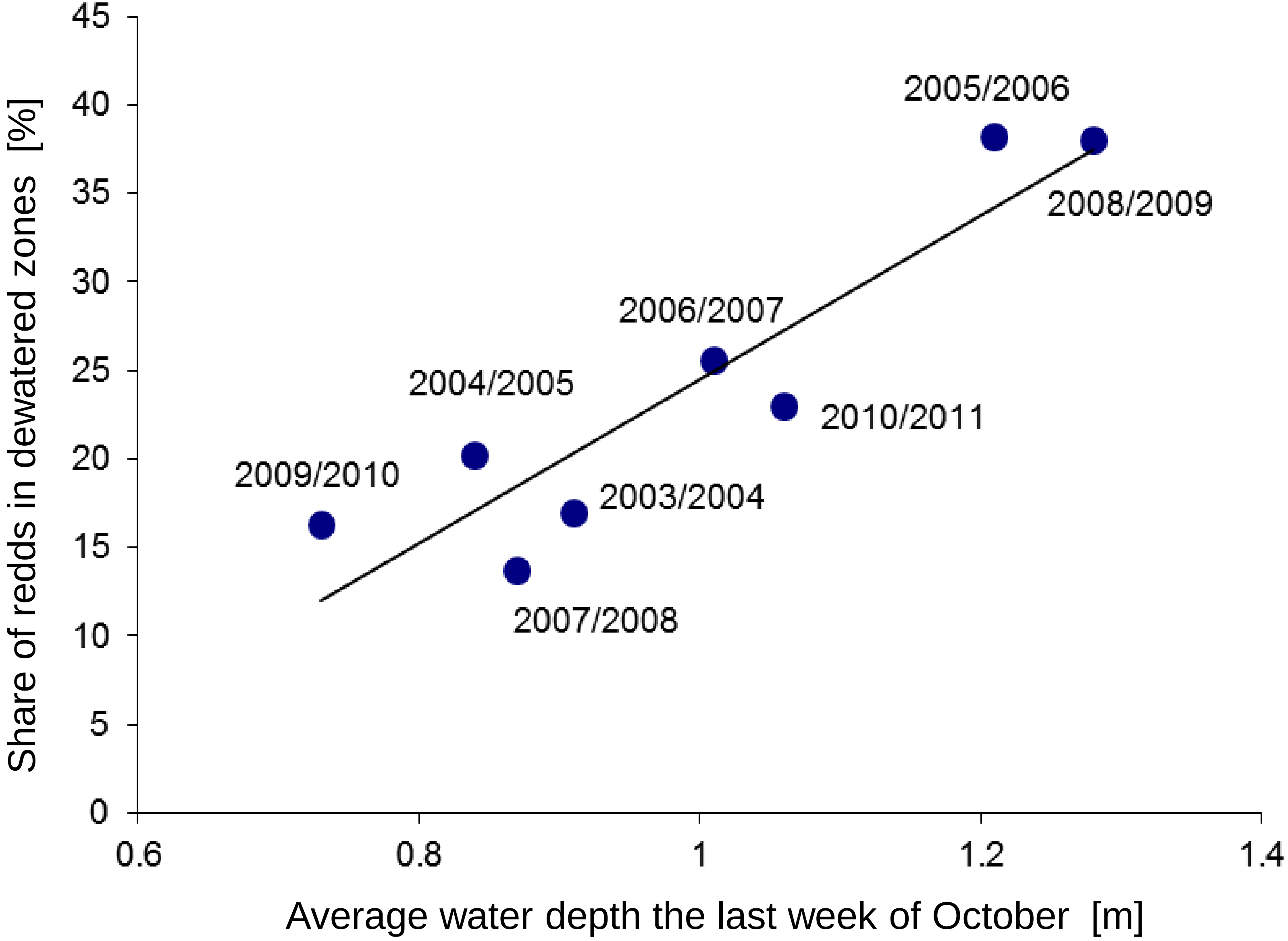
Flow at spawning time

During winter


Spawning
Egg incubation
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
Vannstand over sensor (m)
15. sep.
15. okt.
15. nov.
15. des.
15. jan.
15. feb.
15. mar.
15. apr.
15. mai.
2004
2004/2005
2005/2006
2006/2007
2007/2008
2008/2009
2009/2010
2010/2011

Egg survival and water depth 2004




45
40
35
30
25
20
15
10
5
0
Share of redds in dewatered zones [%]
2005/2006
2008/2009
2006/2007
2004/2005
2010/2011
2009/2010
2003/2004
2007/2008
0.6
0.8
1
1.2
1.4
Average water depth the last week of October [m]

Simple solution.....

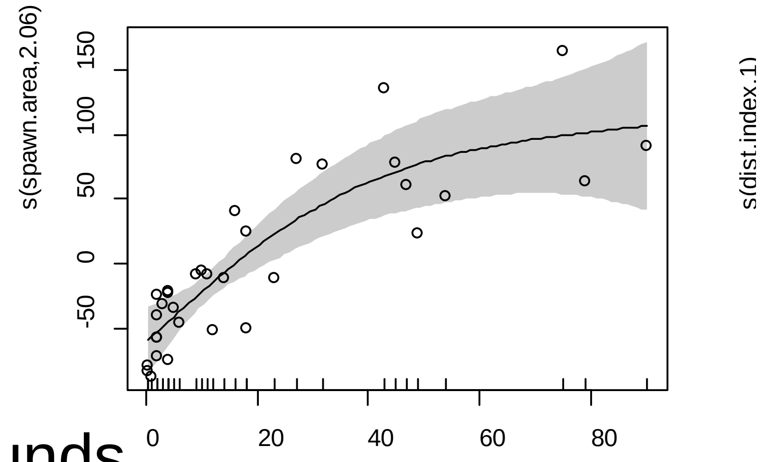
.....move some water released in summer to winter

How much spawning area is enough?

Quantifying the effect of spawning area on sea trout production

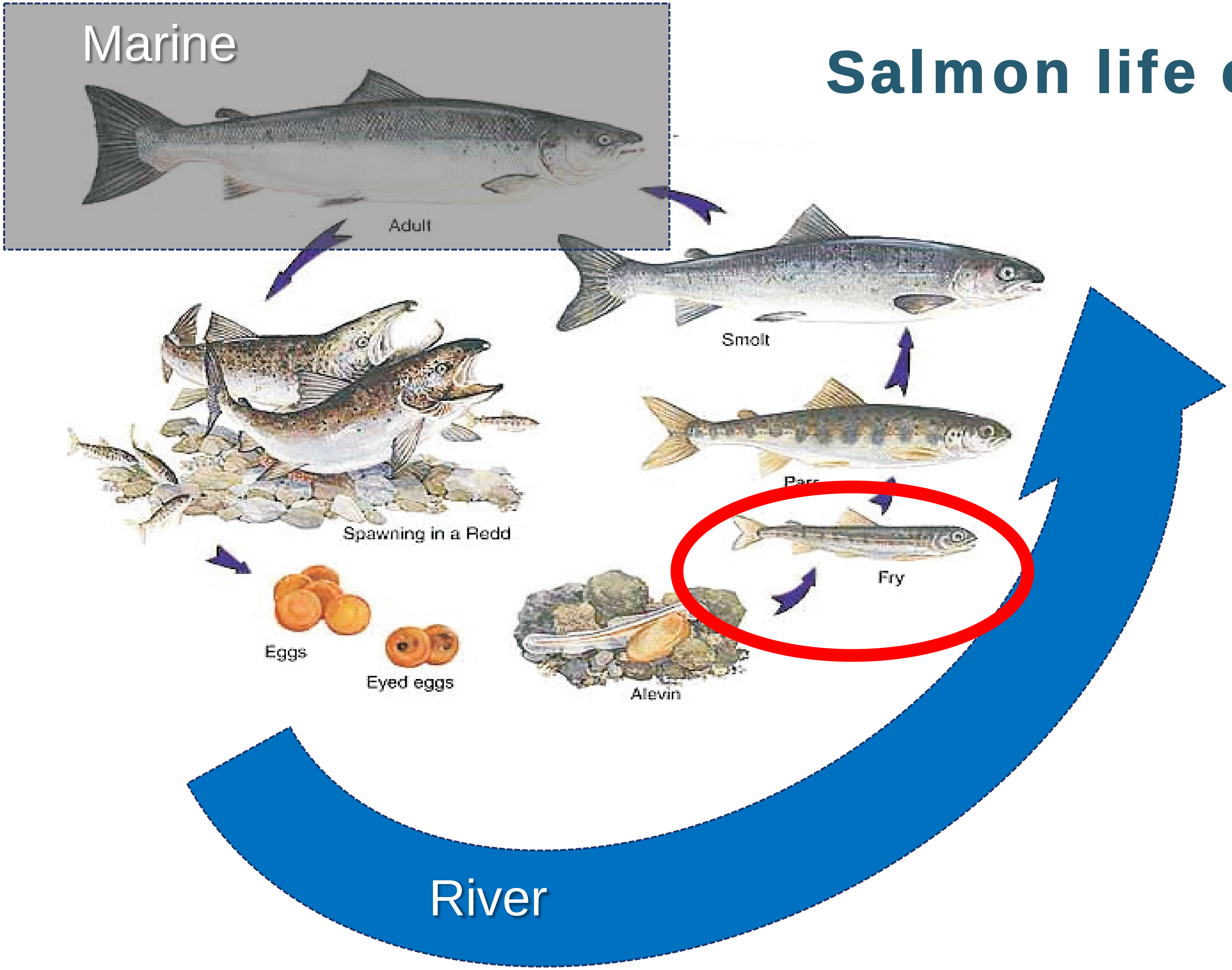
Strong correlations between river wide juvenile density

- and the percentage river area suitable for spawning
- and the distribution of spawning grounds

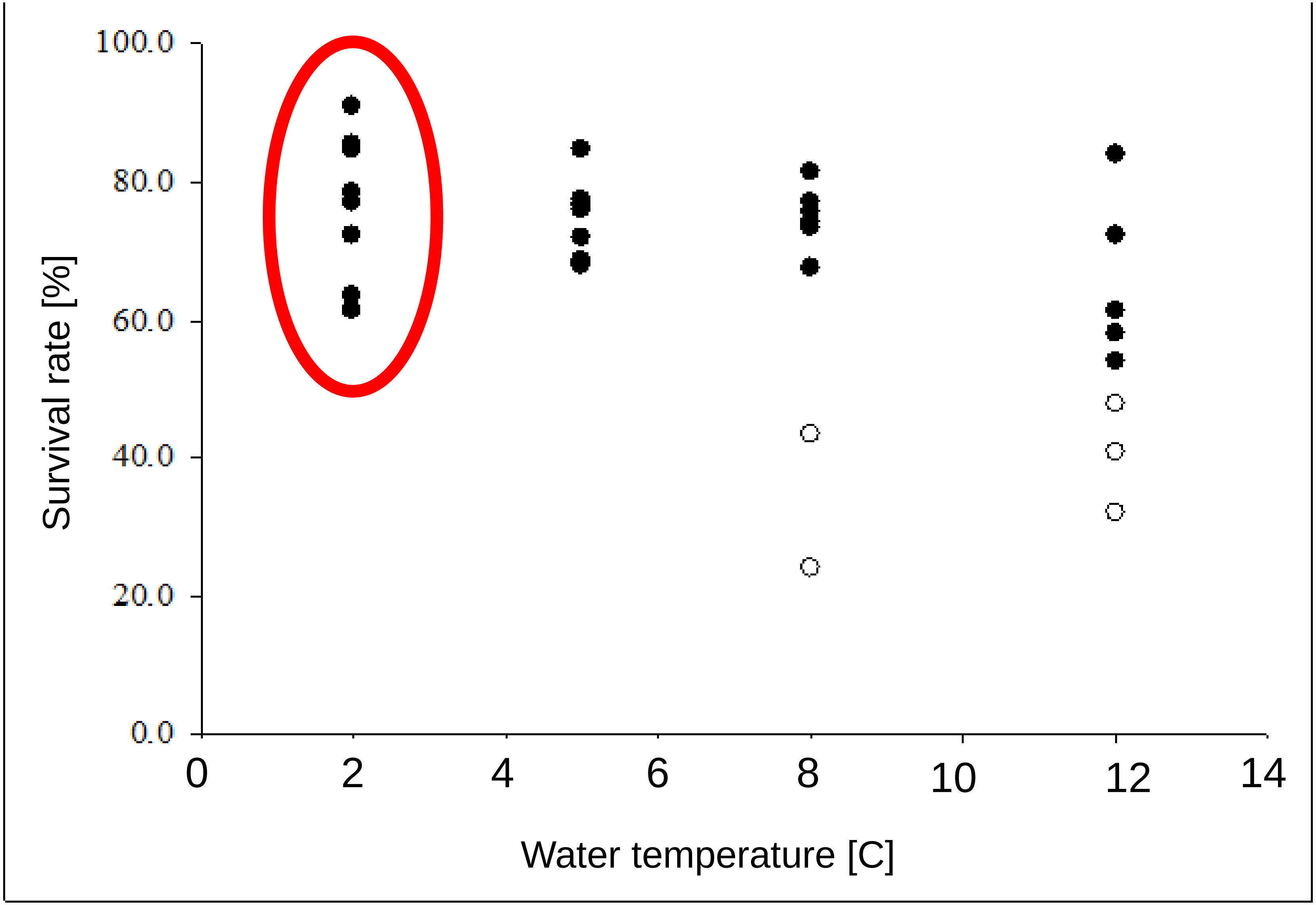


- Guidelines for river restoration and mitigation.
- **Presentation today, 17:00, A**

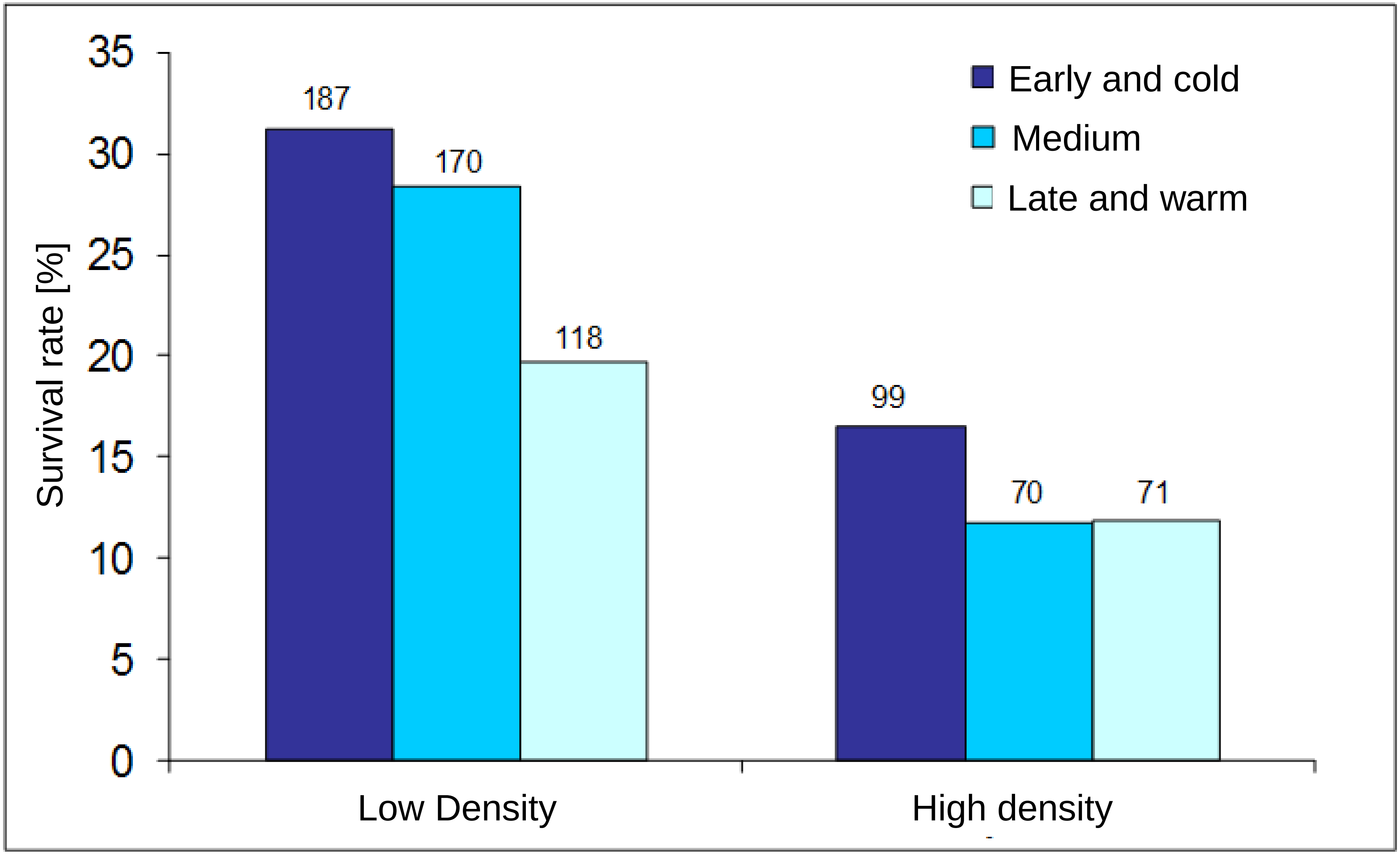
Salmon life cycle



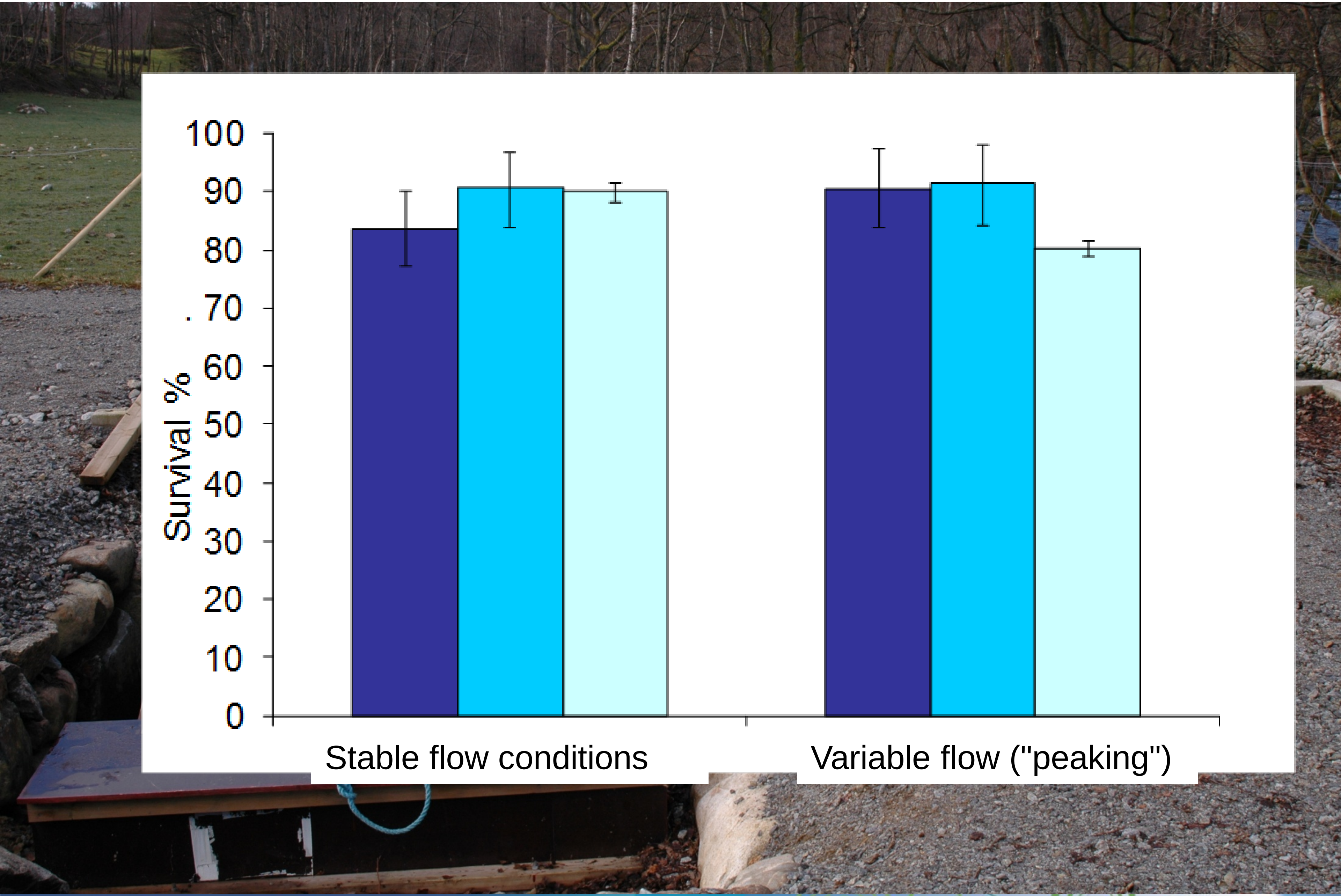
“temperatures at swim-up should be > 8 C ”



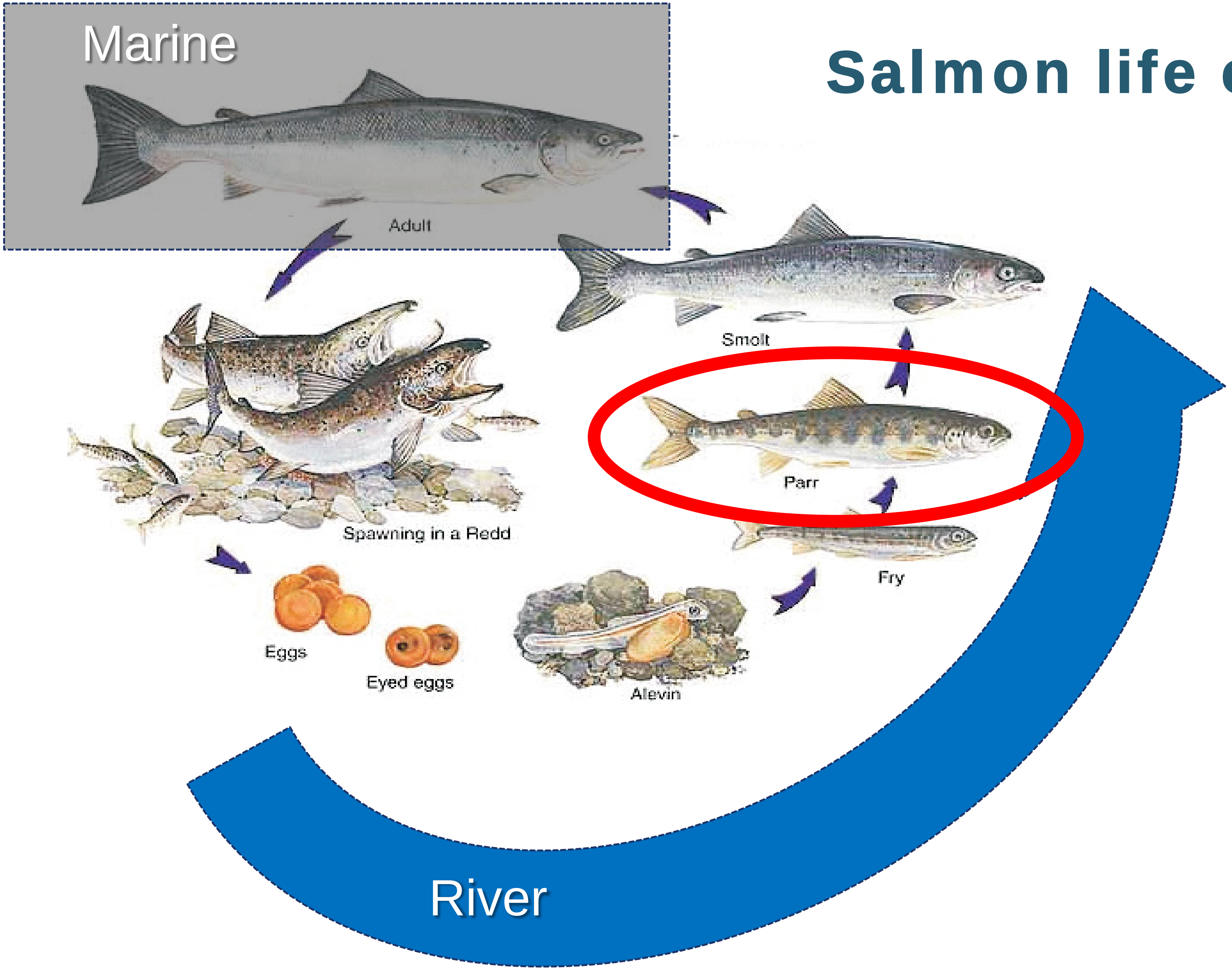
..and in a natural stream!



…and under peaking and stable conditions in semi-natural streams



Salmon life cycle



....focus on hydropeaking

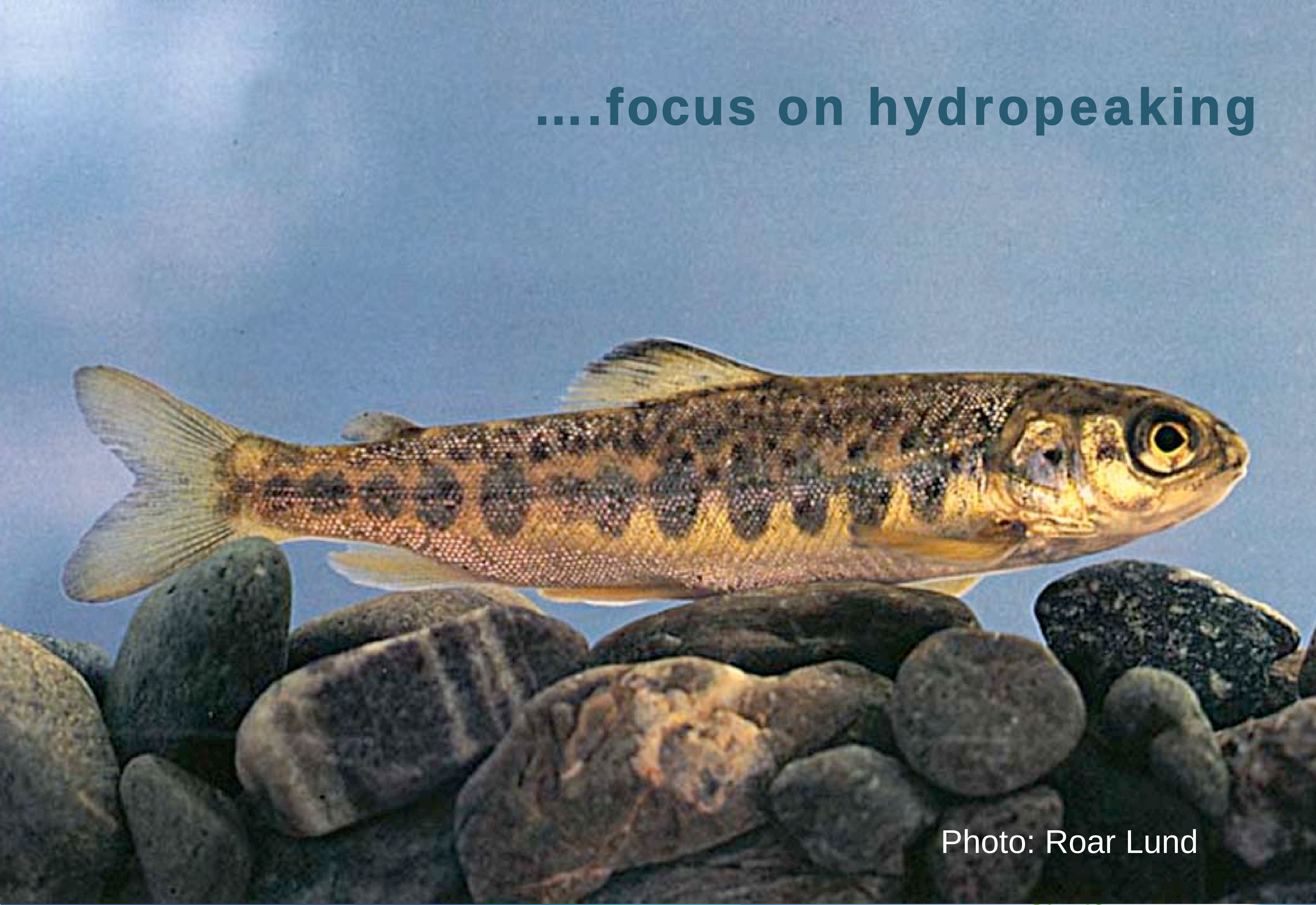
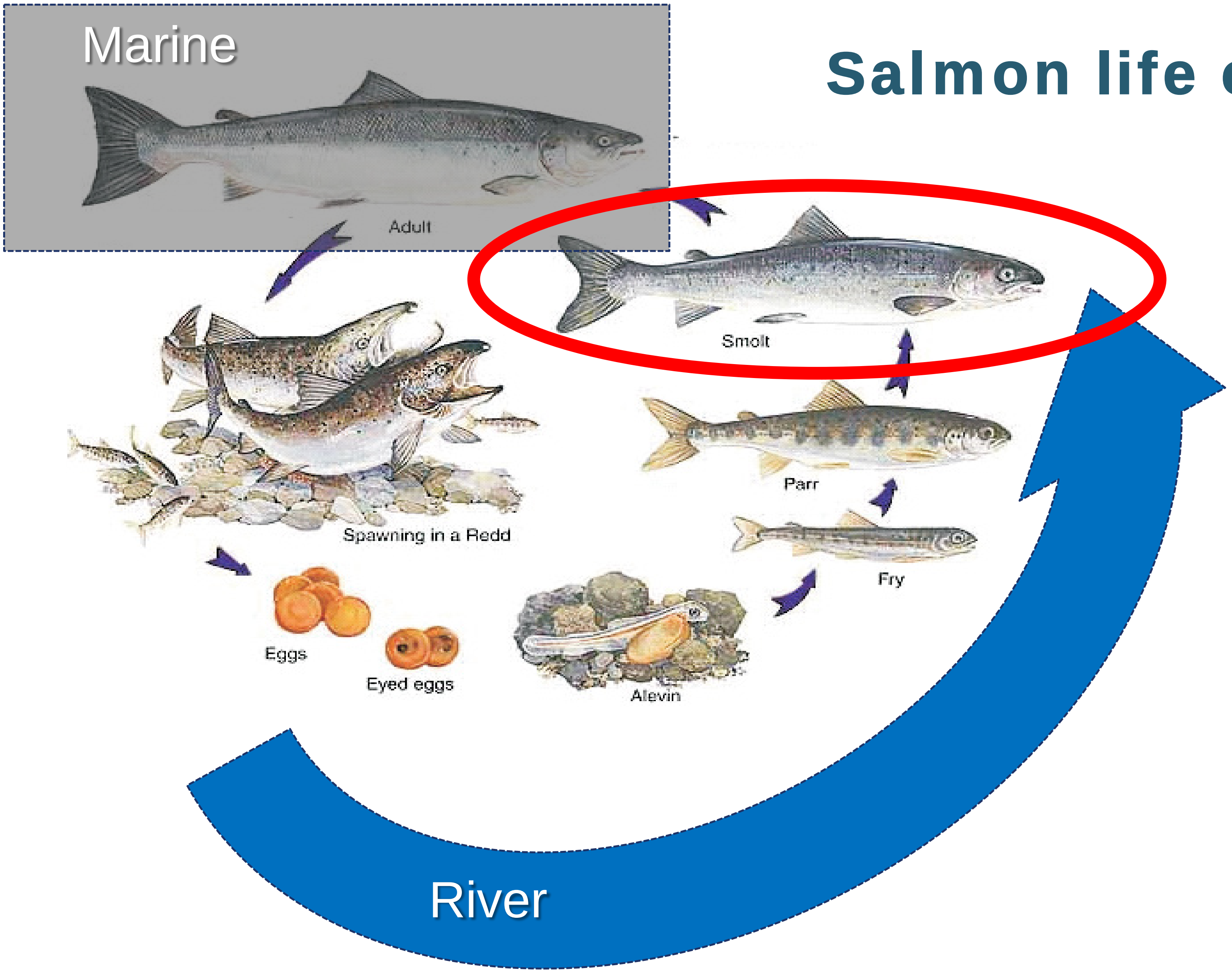
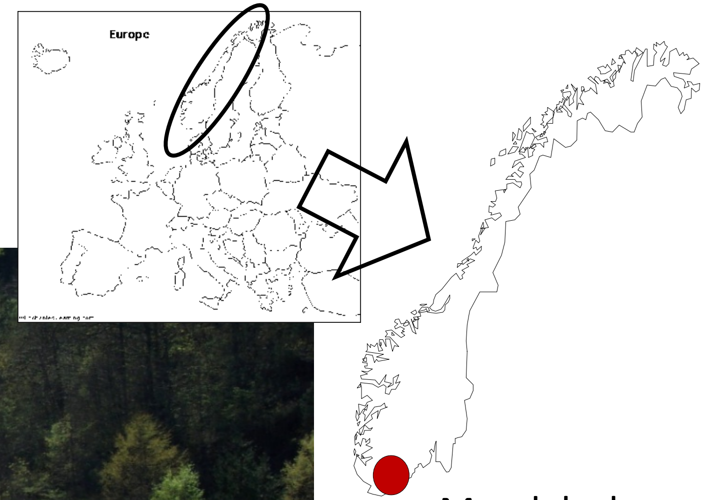


Photo: Roar Lund

Salmon life cycle



Smolt migration
River Mandal



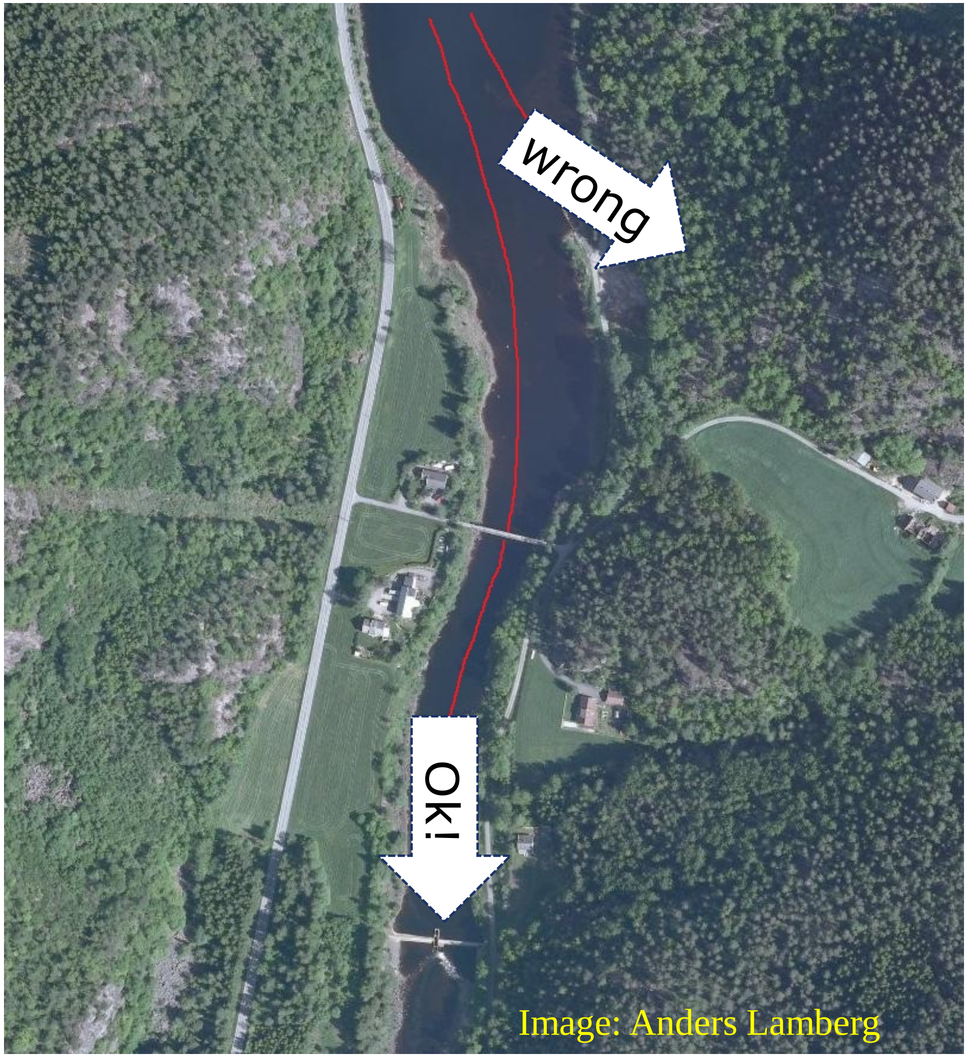
Torbjørn Forseth, Hans-Petter Fjeldstad, Ingebrigt Uglem
Knut Alfredsen & Thibault Boissy

Challenge:

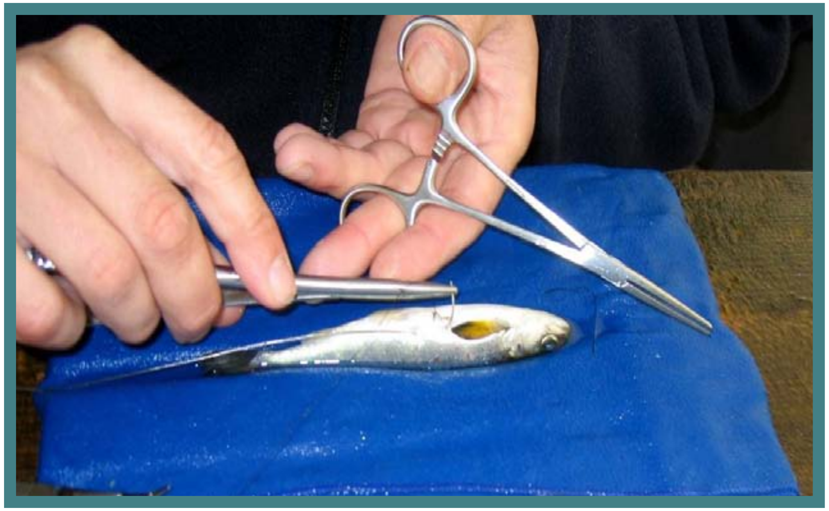
- Safe road:
  2003: 10%
  Goal: 90%

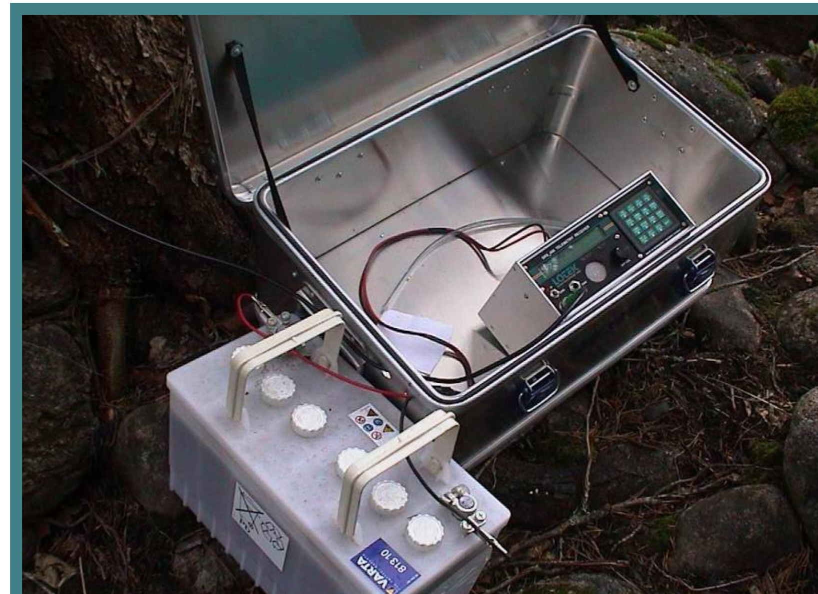
- Wrong route:

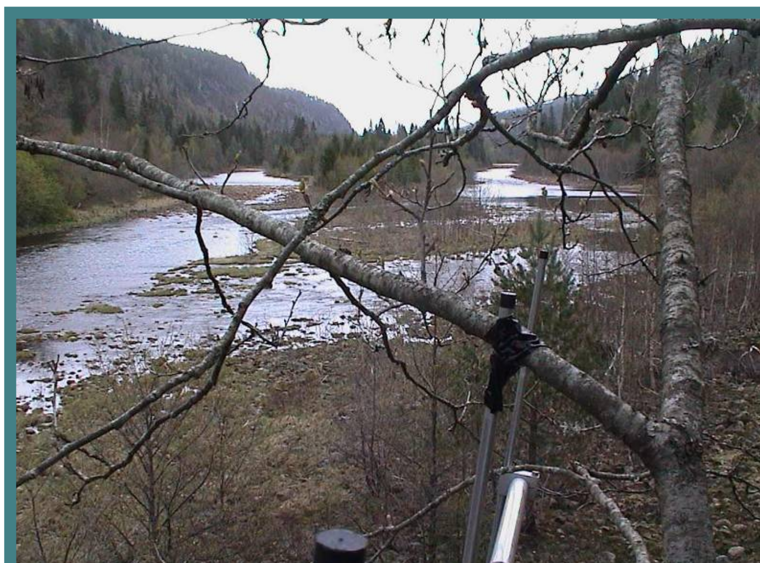
When do the smolts arrive and which route do they chose?



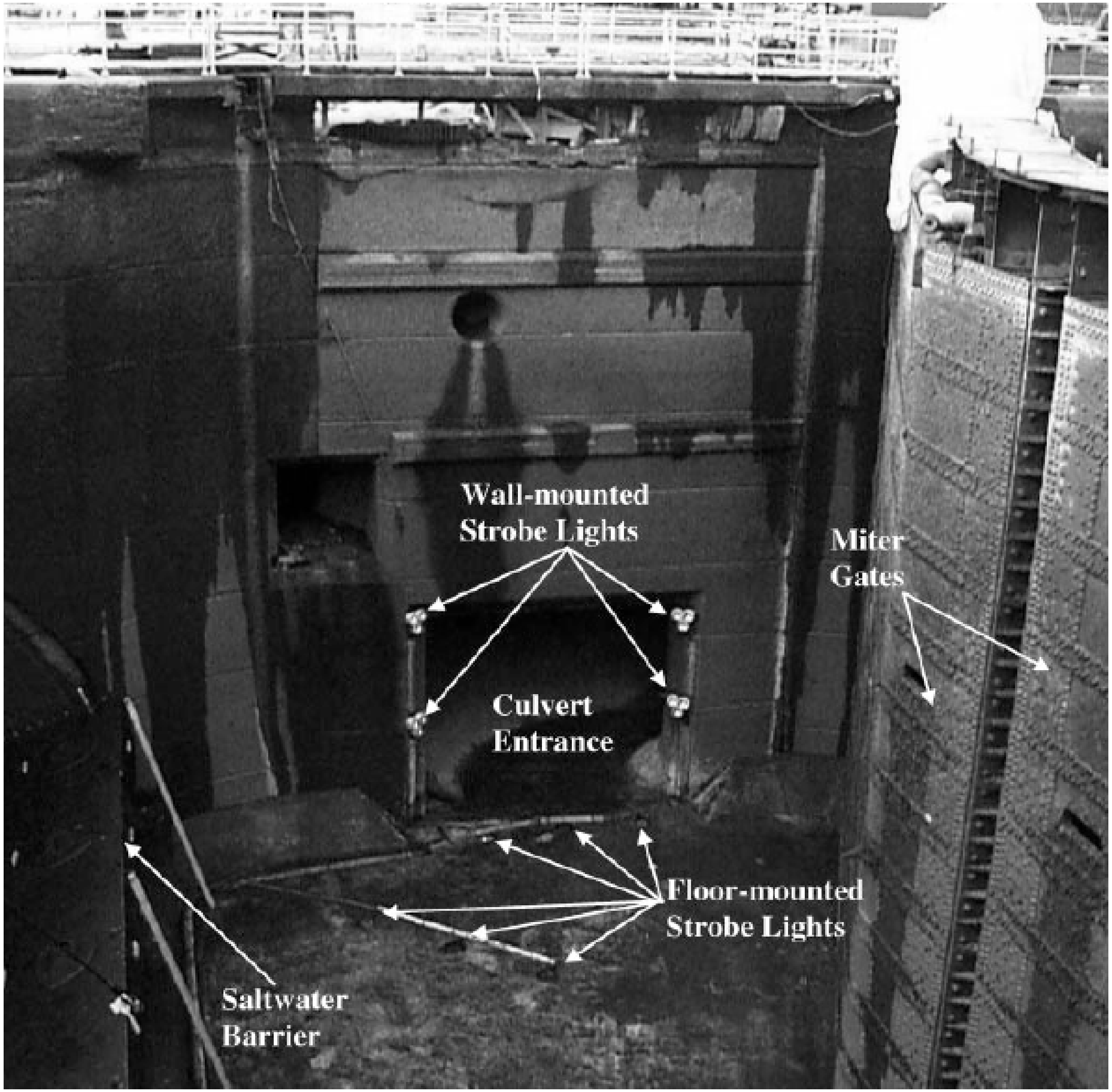
Telemetry: 250 smolts (2003, 2004 and 2008)





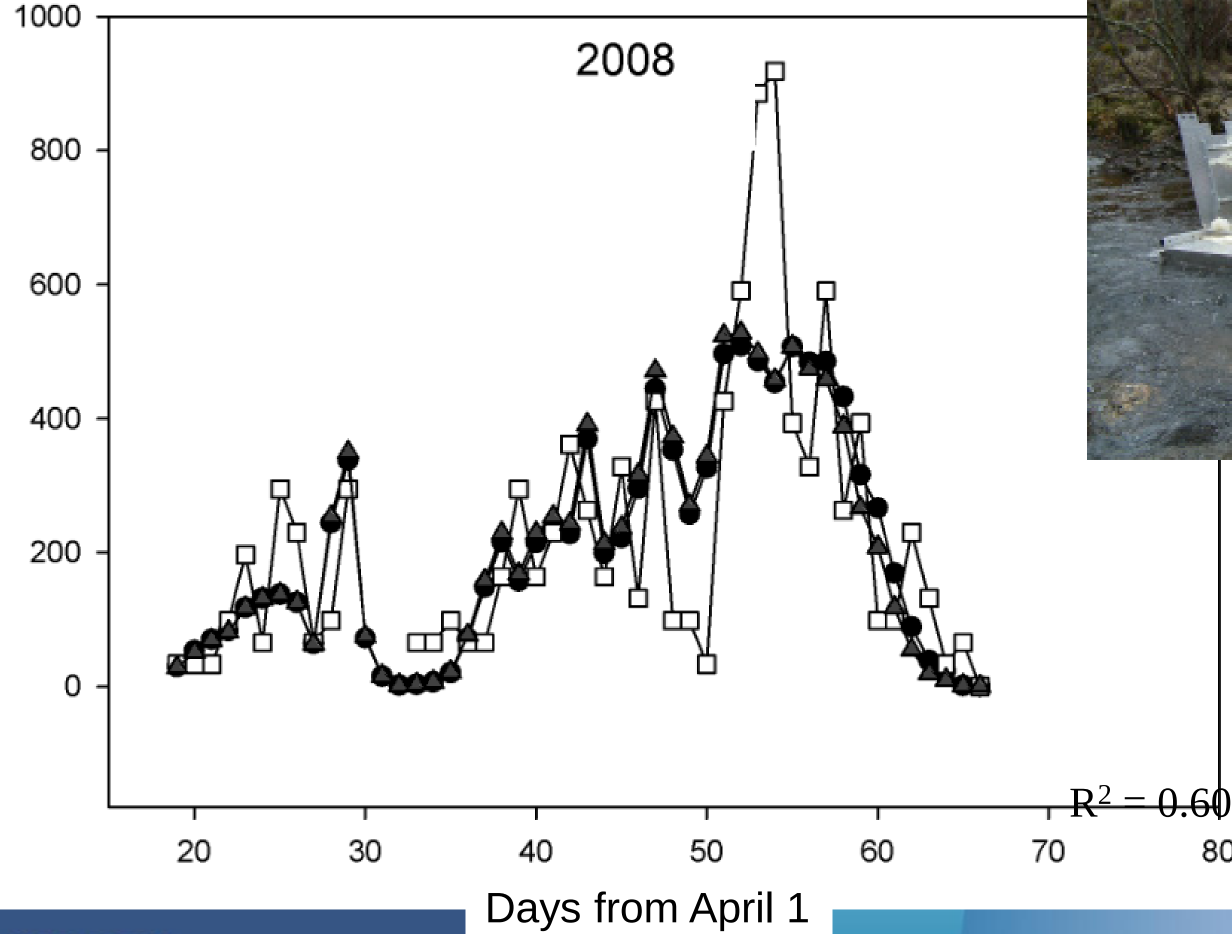


Impacts of strobe lights



Smolt timing model

$$\ln(Smolts) = \ln(MeanSmoltNumber) + Const + \beta_1 \times Tempsum + \beta_2 \times Temp + \beta_3 \times Tempdiff + \beta_4 \times Discharge + \beta_5 \times Dischargediff + \beta_6 \times \ln(Discharge) + \beta_7 \times \ln(Temp) + \beta_8 \times Days$$



□ Observed smolt catches

● / ▲ Model predictions

Fjeldstad et al., 2012

Predictions from route model

Likelihood for bypass migration

$$\log it(\pi) = \log\left(\frac{\pi}{1-\pi}\right) = \beta_1 \times Total + \beta_2 \times Share$$

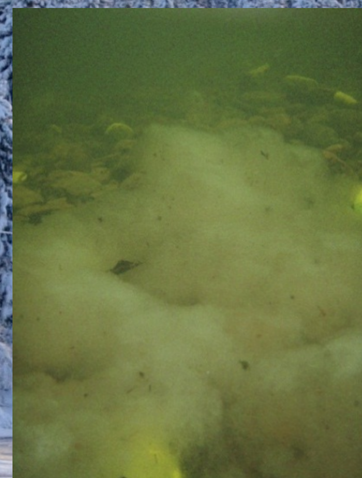
Proportion of total discharge in bypass (%)	Total discharge ($m^3\ s^{-1}$)											
	20	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
10	70	63	55	47	39	31	25	19	14	*11*	*8*	*6*
20	76	70	63	55	46	38	31	24	19	*14*	*11*	*8*
30	82	76	70	62	54	46	38	31	24	*19*	*14*	*11*
40	86	81	76	69	62	54	46	38	30	*24*	*18*	*14*
50	89	86	81	76	69	62	54	45	37	*30*	*24*	*18*
60	92	89	86	81	75	69	61	53	45	*37*	*30*	*23*
70	94	92	89	85	81	75	68	*61*	*53*	*45*	*37*	*29*
80	96	94	92	89	85	81	*75*	*68*	*61*	*53*	*44*	*36*

Fjeldstad et al., 2012

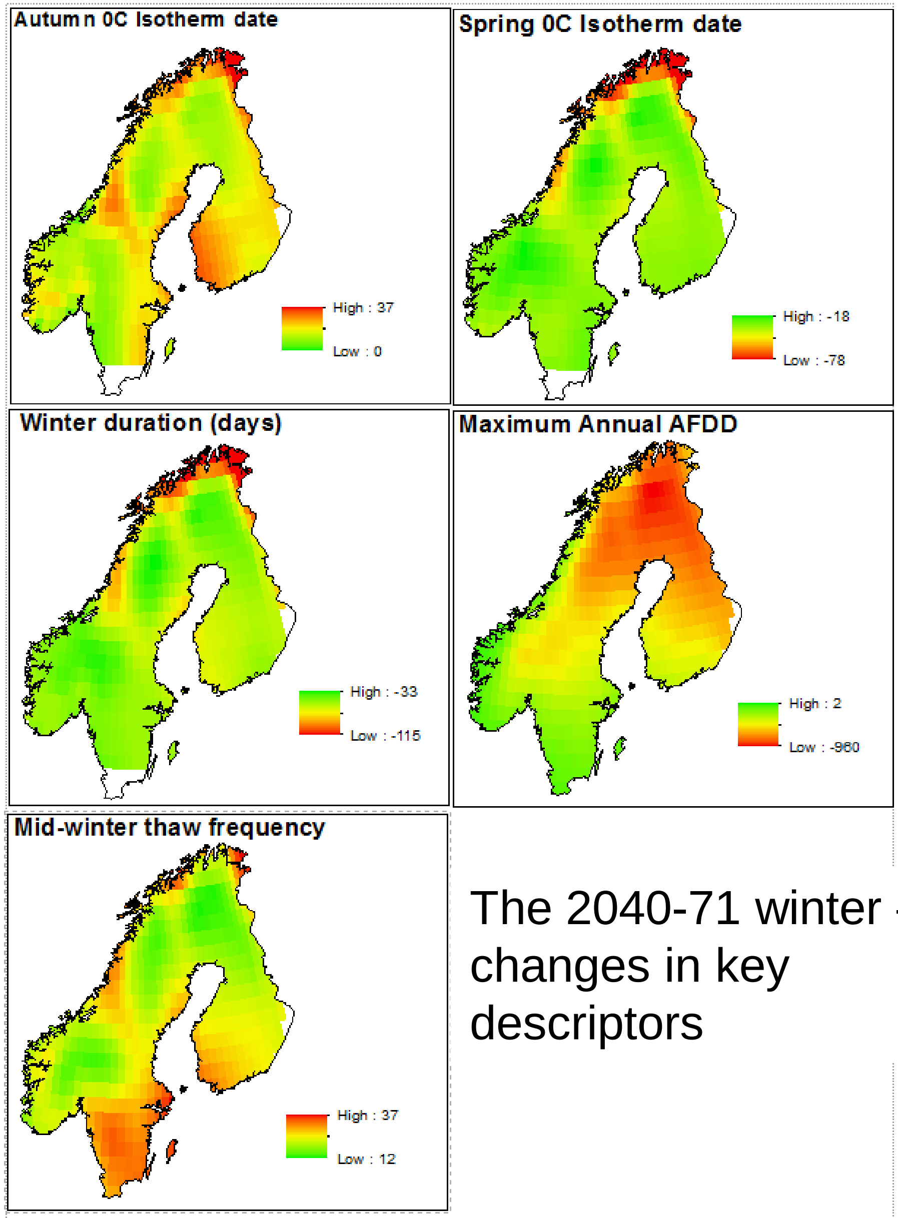

2008:
• 96 fish tagged
• 61 migrated out from lake Mannflåvatn (64 %)
39 fish – 64 %
22 fish – 36 %

How to predict what is happening here?

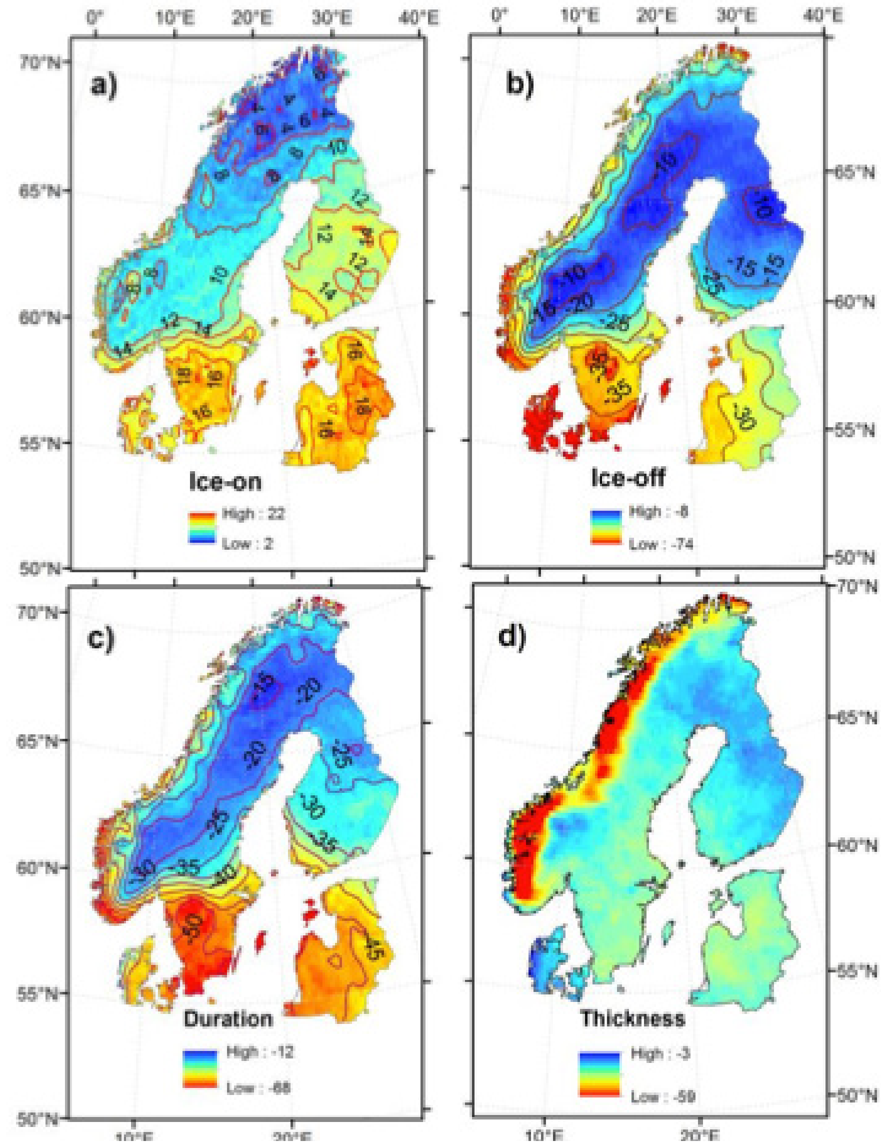
How to predict what is happening here?



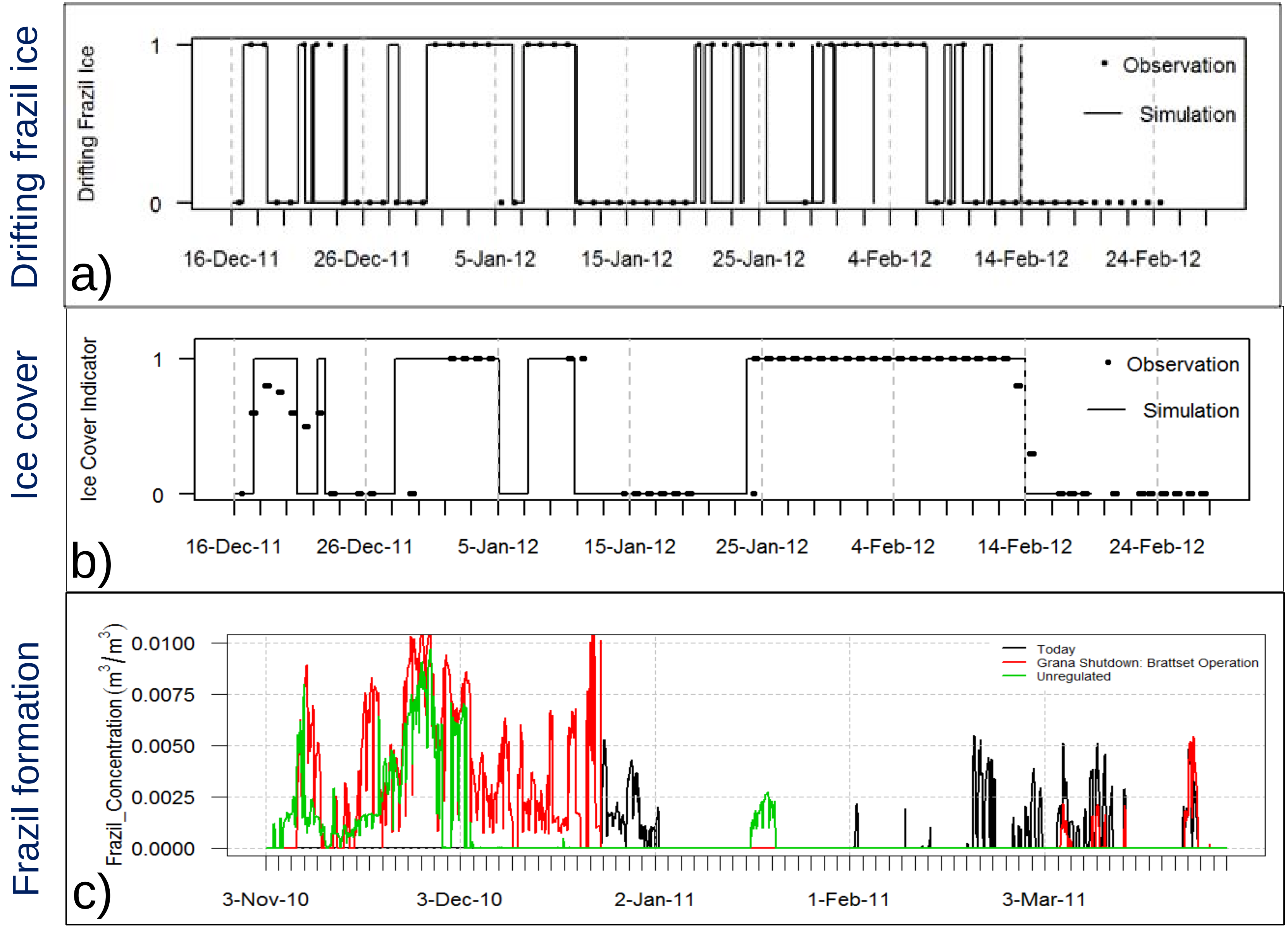
Climate change, ice, water temperature



The 2040-71 winter – changes in key descriptors



Changes in key lake ice parameters 1961-90 vs 2040-71 scenario

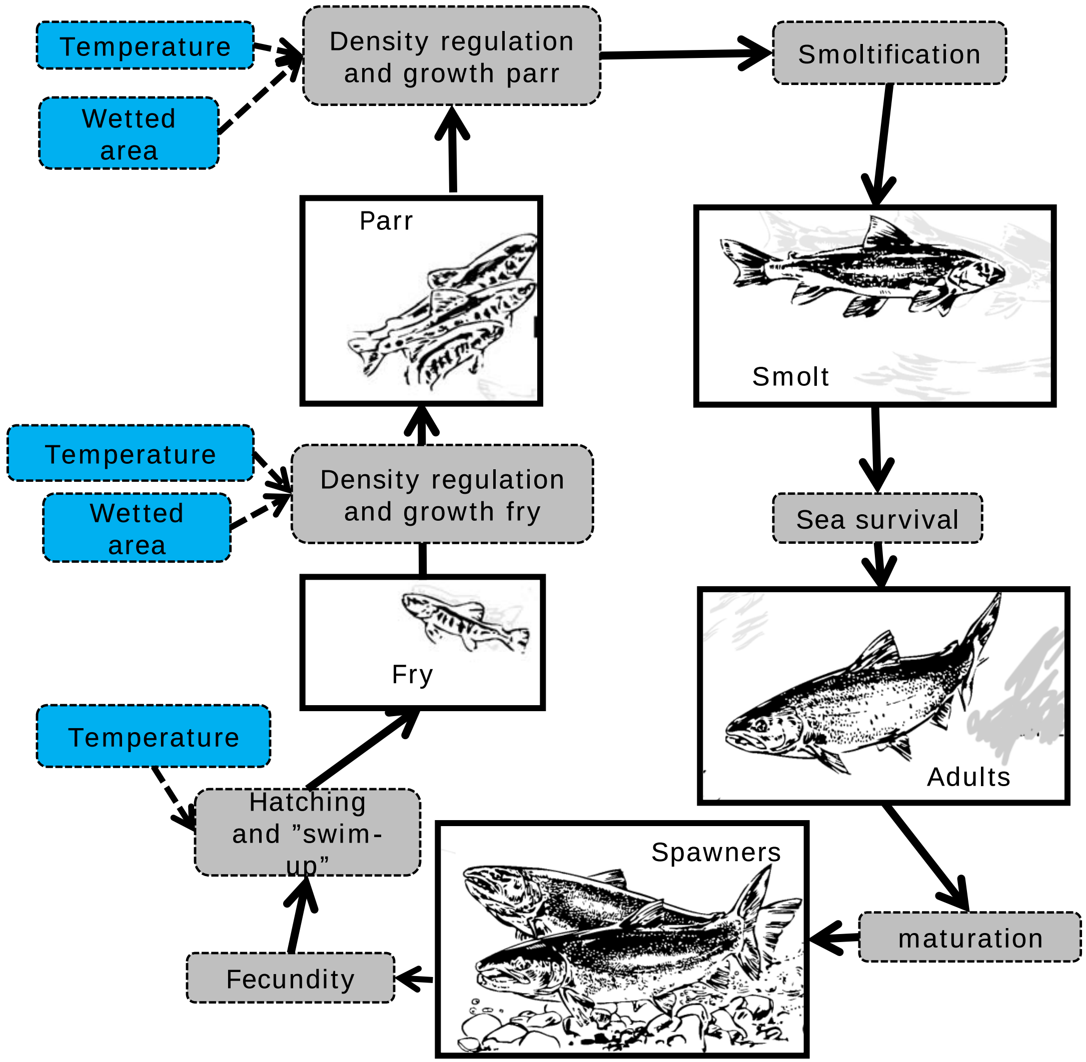


Model verification from *Timalsina et al. (in prep)*

IB-salmon

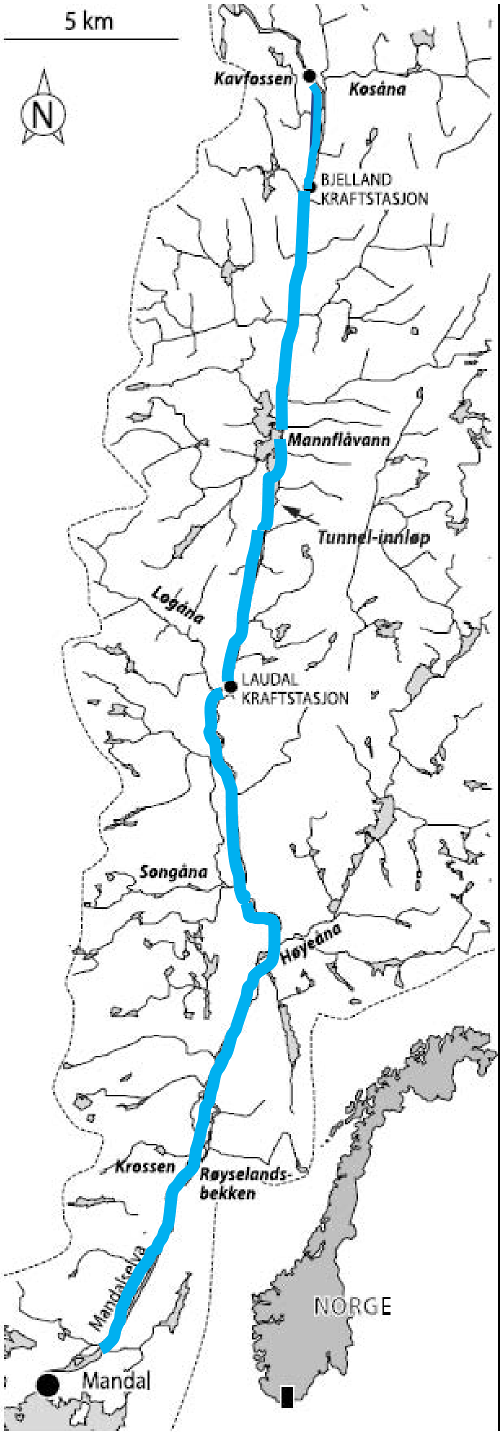
Abiotic input:
Water temperature
Wetted area per
section (discharge)

Biological input:
Egg deposition
(per section)
Habitat quality
(each year)

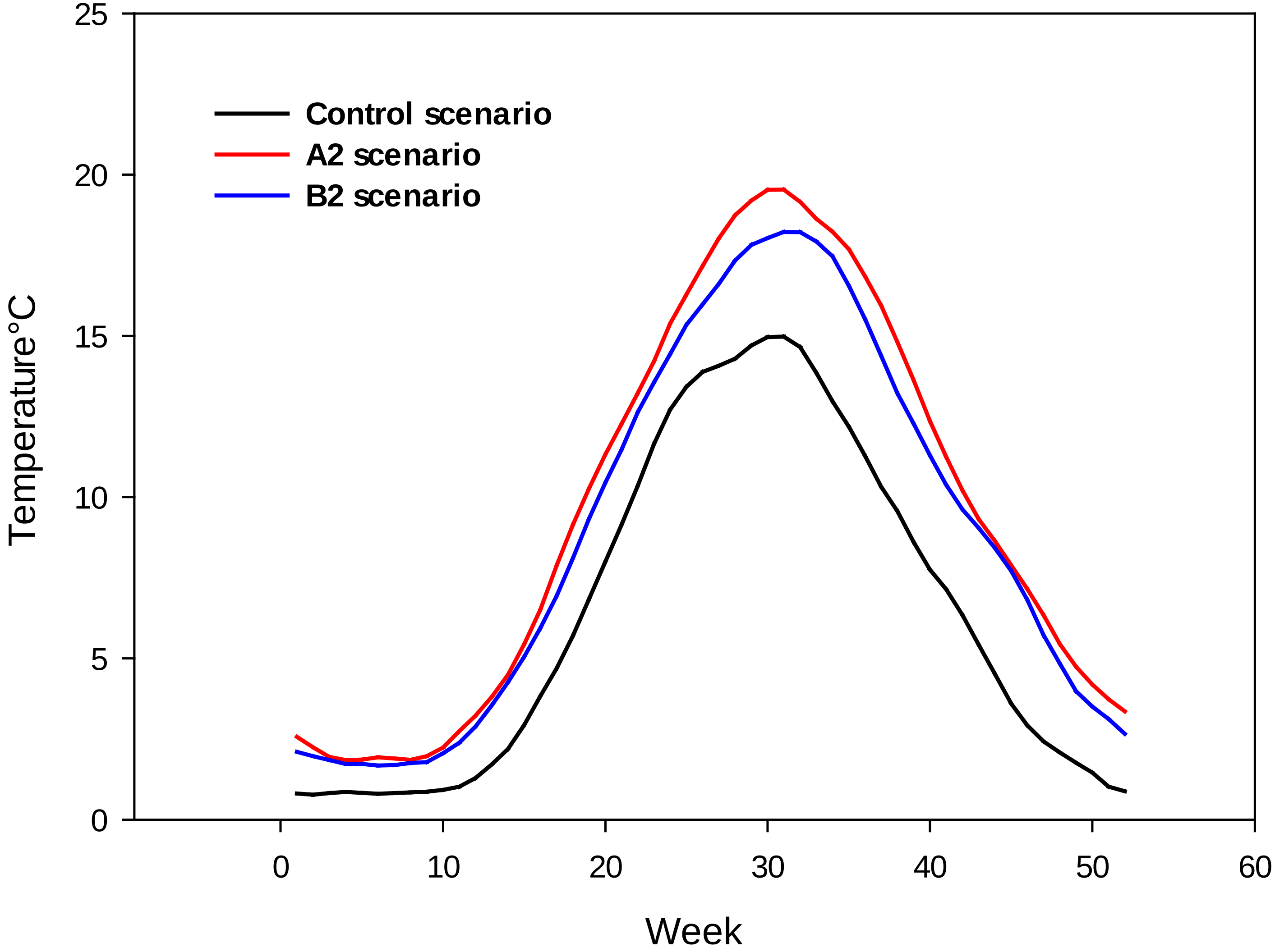


L. Sundt-Hansen, R. Hedger, O. Ugedal, O. Diserud, A. G. Finstad, T. Forseth, L. Tøfte & J. Sauterleute

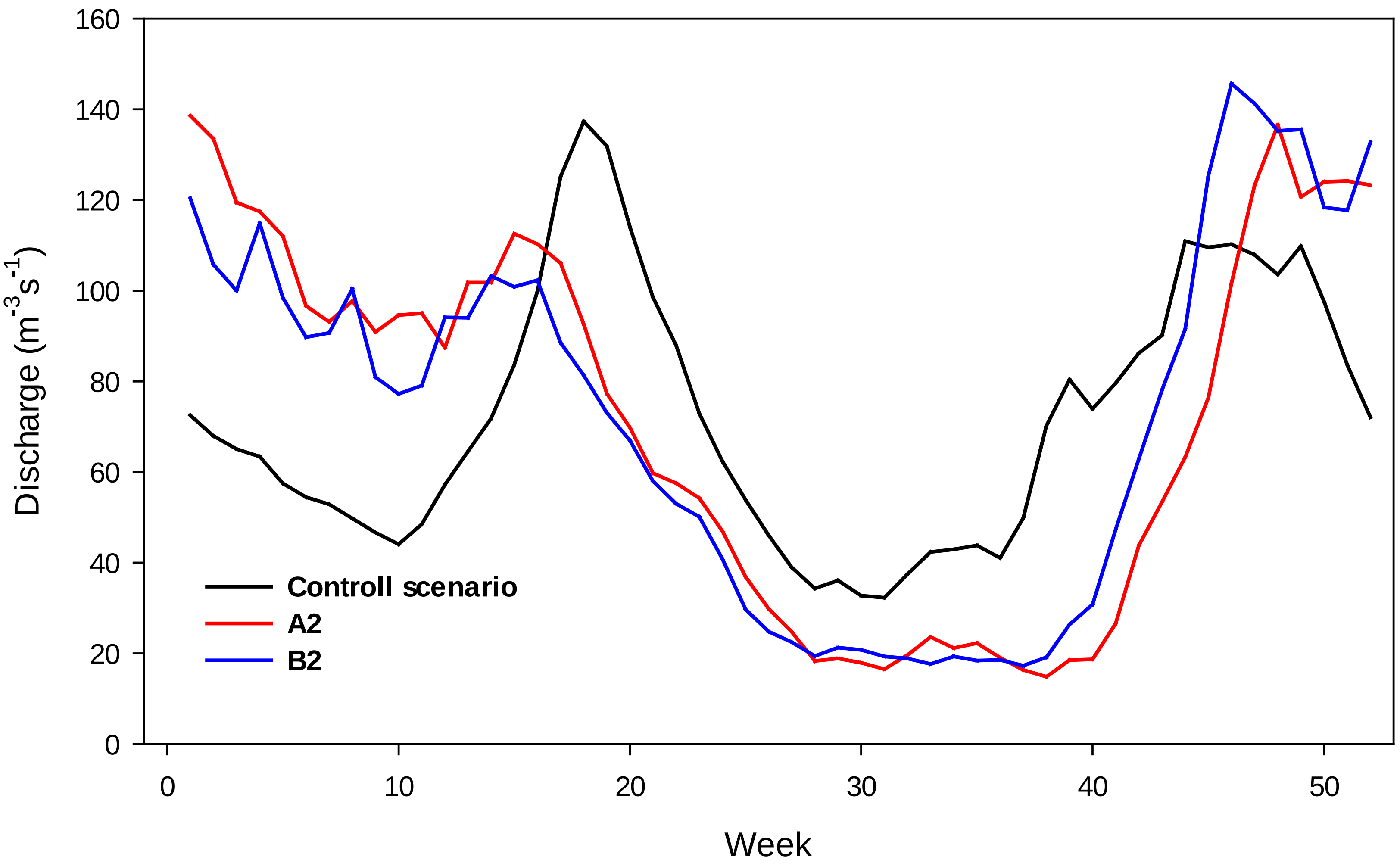
The Mandal River



Water temperature

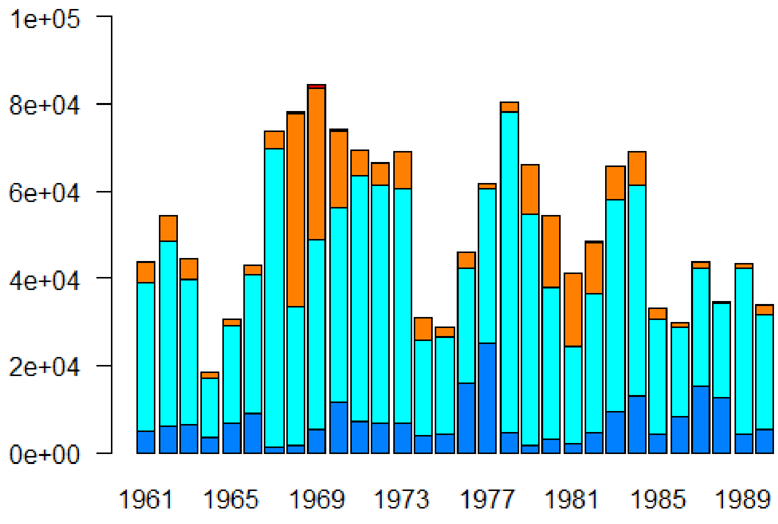


Flow

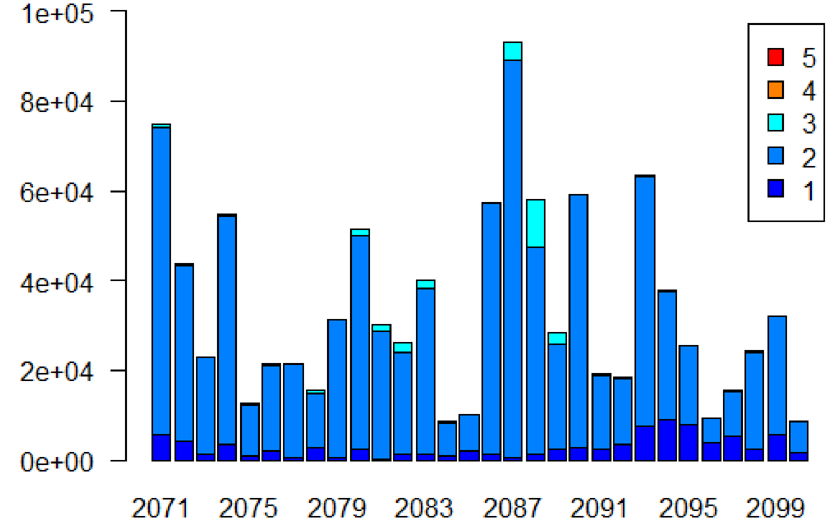


Discharge (m-3s-1)
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
Week
Controll scenario
A2
B2

Smolt age control

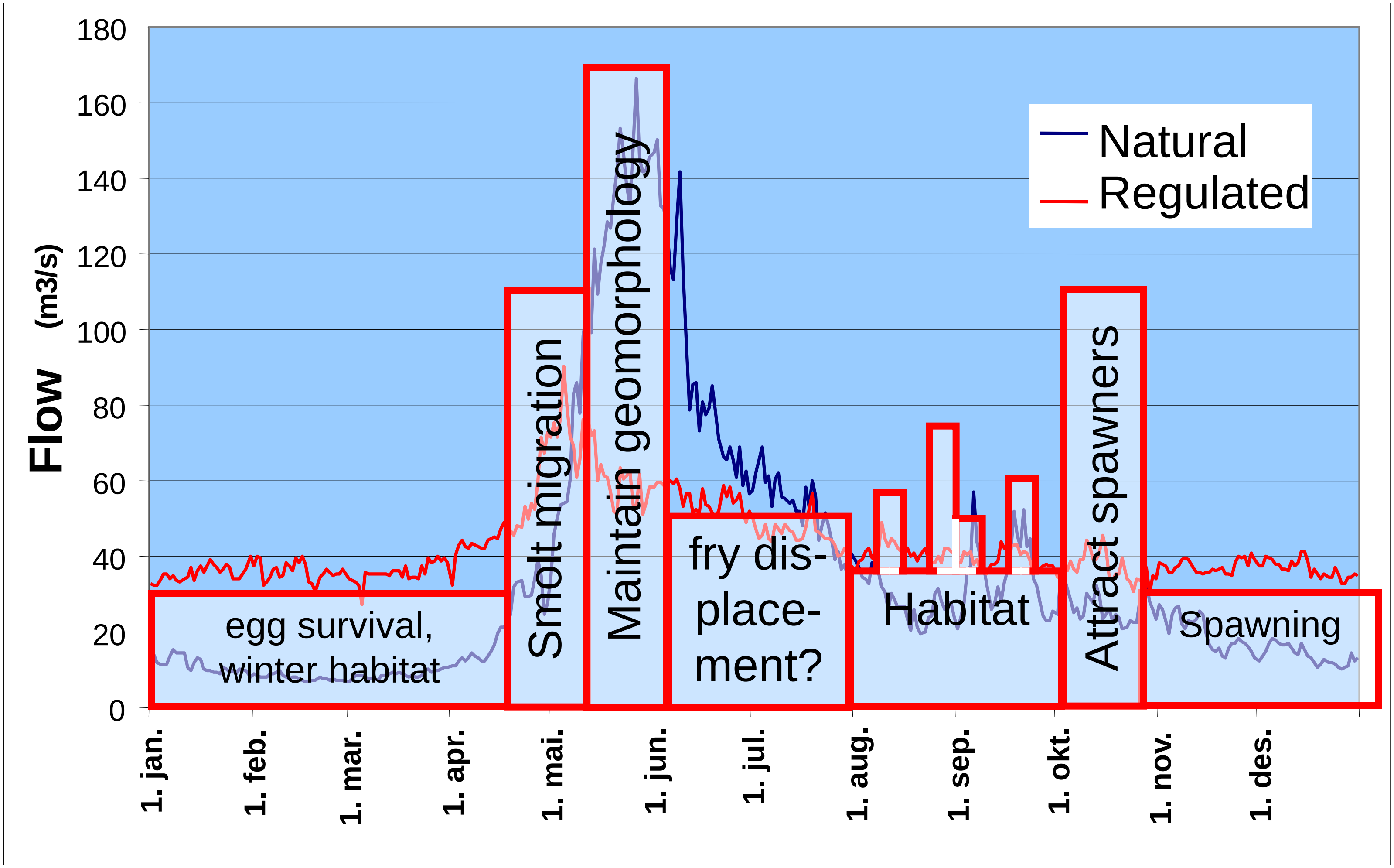


Smolt age scenario



- Salmon juveniles grow faster, smoltify younger
- Increased mortality in summers due to reduction in wetted area
- **Reduced recruitment and reduced production of salmon in future scenario**

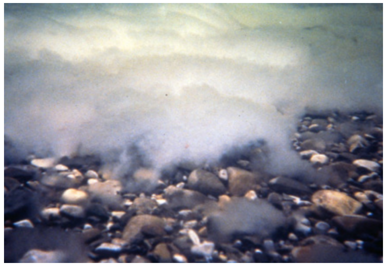
Seasonal requirements



Environmental impacts of rapid and frequent flow changes

Knowledge about how, when and where rapid variations in power production may be done with acceptable impacts on the ecosystem.

Physical processes



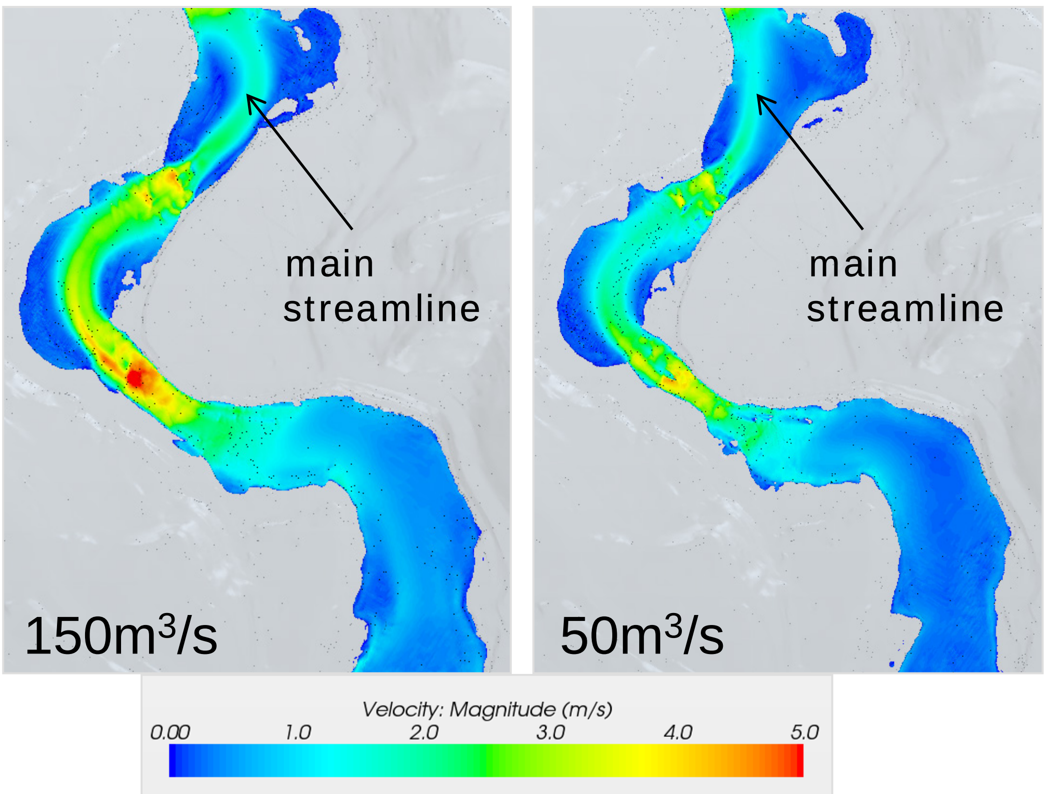
Biological processes

Mitigation

- Hydropower operation with rapid flow fluctuations
- Physical effects of highly unsteady flow
- Environmental effects of highly unsteady flow

Numerical approach

Example Nidelva River 4km upstream of Trondheim

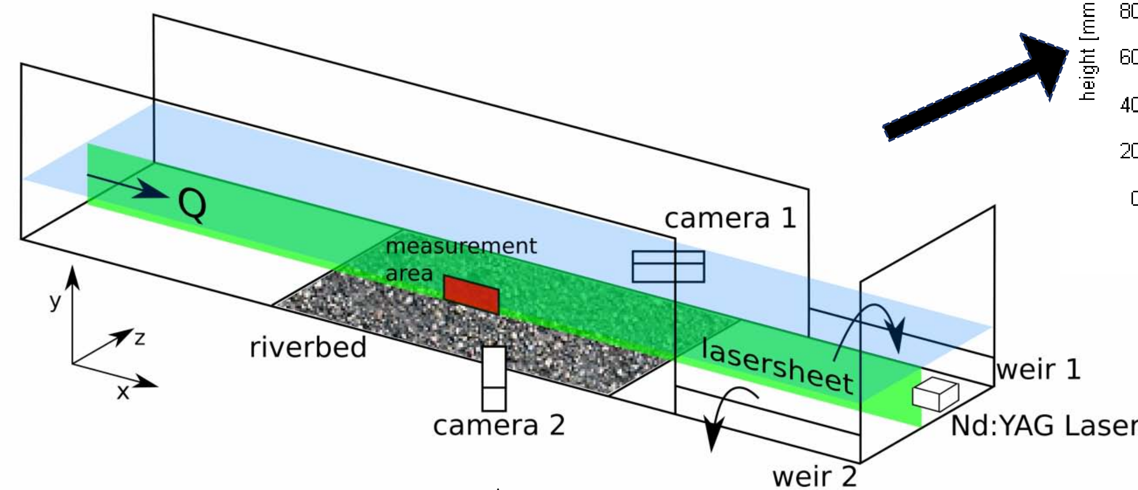


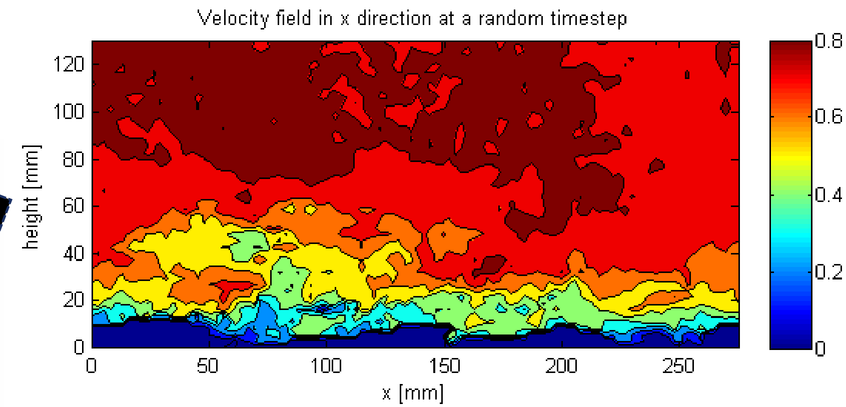
- Hydropower peaking scenario
- Inflow decreases from $150 m^3/s$ to $50 m^3/s$
- Simulation with Star CCM+ (7.600.000 cells)

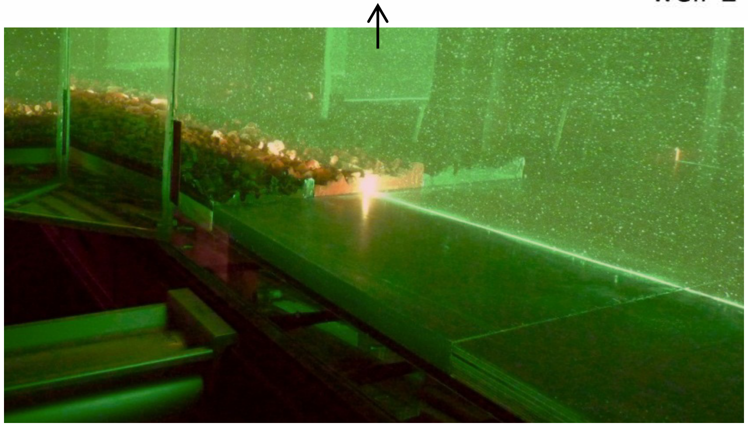
→ slowing down
→ wetted area decreasing
→ main streamline shifting sideways

Physical experiments

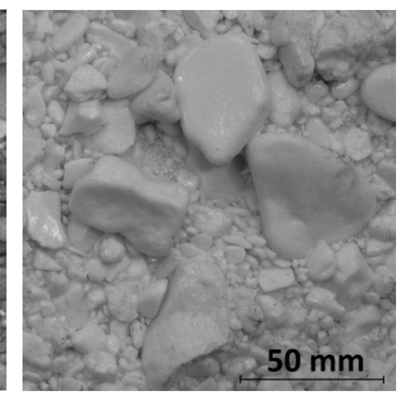
PIV – Particle Image Velocimetry
Artificial streambed
Highly unsteady discharge







Original

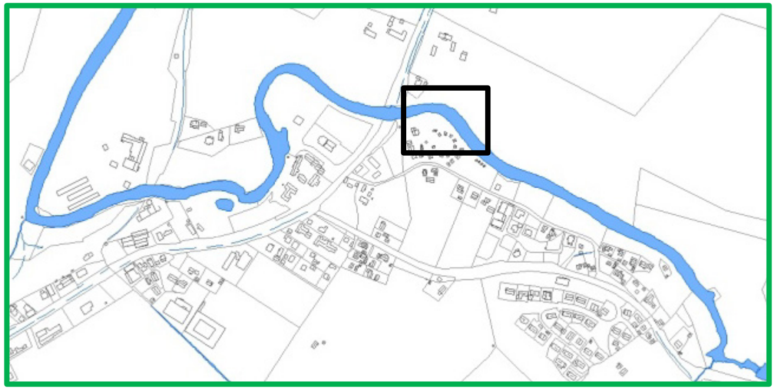


Artificial (plastic copy)

3D Hydraulic model simulation and results validation

Star CCM+:

- Commercial 3D code based on the Reynolds-averaged Navier-Stokes equations, k-epsilon turbulence model
- Free water surface calculation by "Volume of Fluid" Method



Discretization

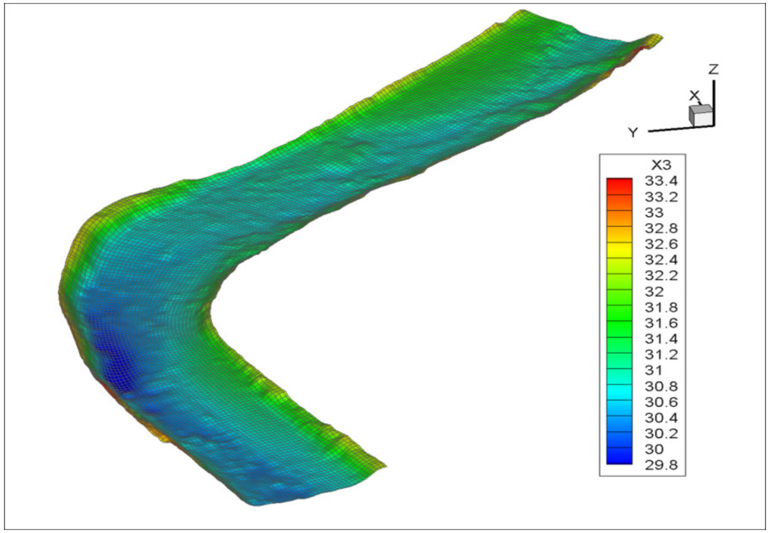
- 850 000 cells on rectangular mesh
- 0.35 x 0.35 x 0.175 m

Analysis

- Steady Flow at 2, 10, 16 and 20 m^3/s
- Unsteady Flow Analysis

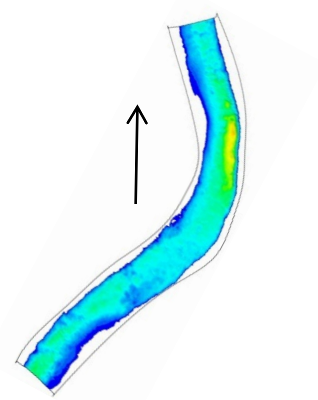
Verification

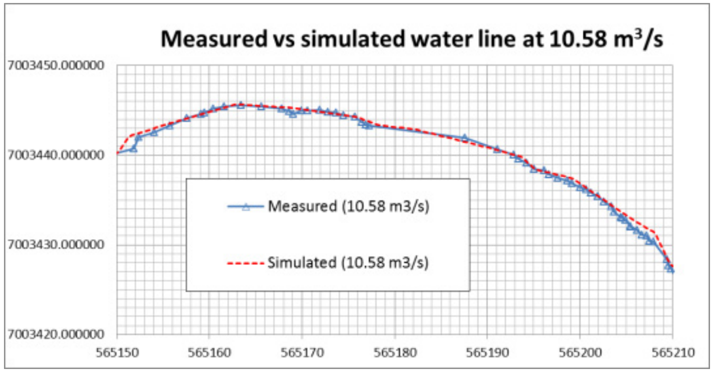
- Observed vs simulated velocity profiles and water lines

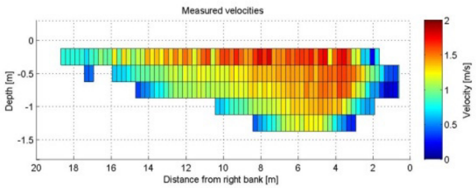


3D Hydraulic model simulation and results validation

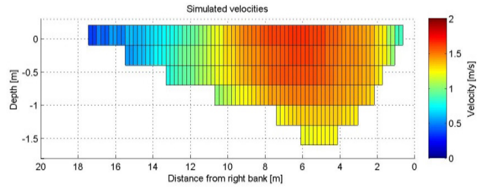
Steady simulationResults:



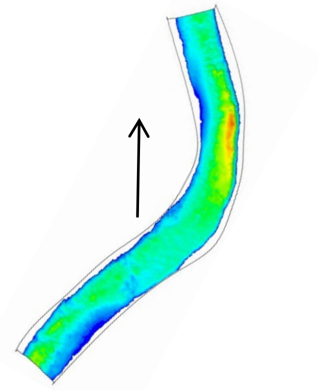


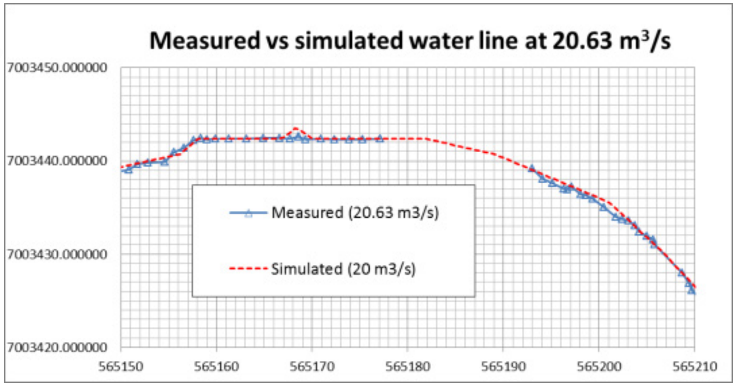


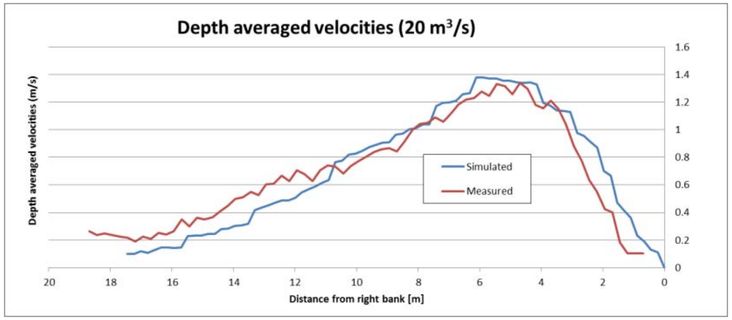
Measured

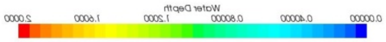


Simulated









3D Hydraulic model simulation and results validation

Unsteady Simulation Results:

Effects on bentic macro-invertebrates

Hydropeaking operation → Modification of the habitat

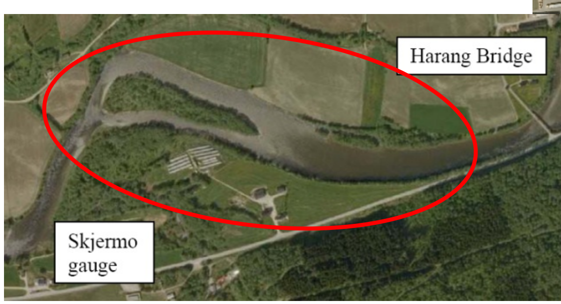
↓

Effect on
- biomass
- abundance
- behaviour
- life cycle

Qualifying and quantifying this impact to define locally adapted mitigation measures

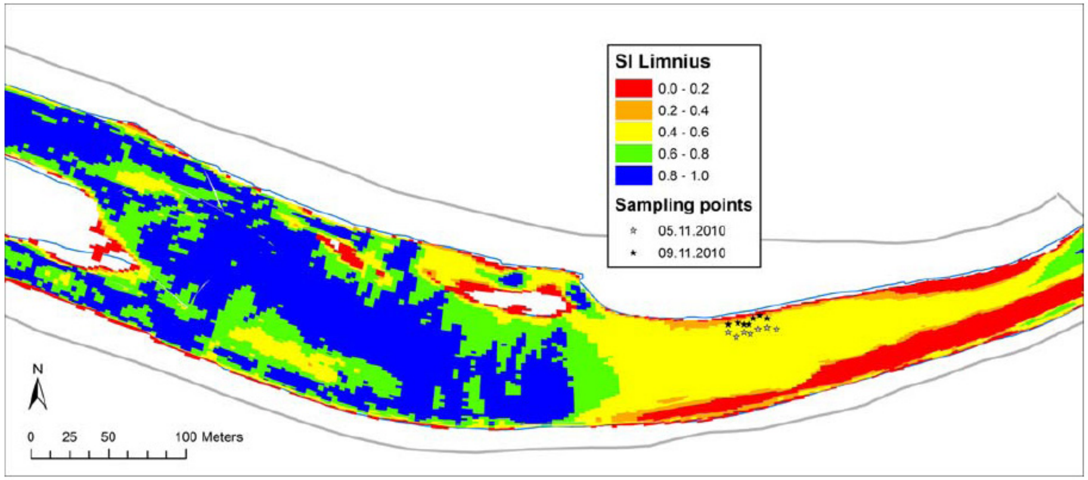
Modeling the suitability for benthic macro-invertebrates in Surna River

- One site upstream power plant
- One site downstream power plant (affected by hydropeaking)



Suitability for *Limnius spp*. at the site affected by hydropeaking

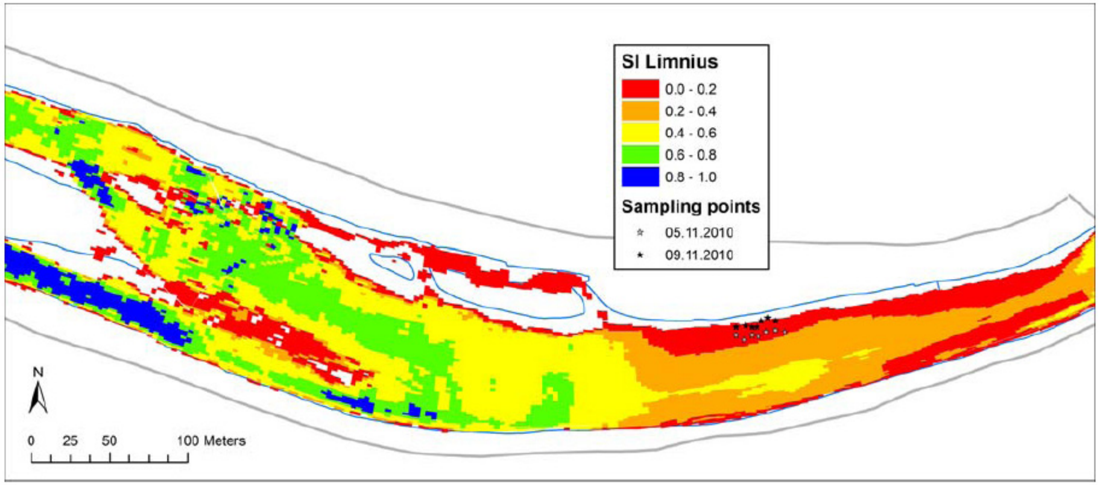
Q = 53 m^3/s



Included parameters:

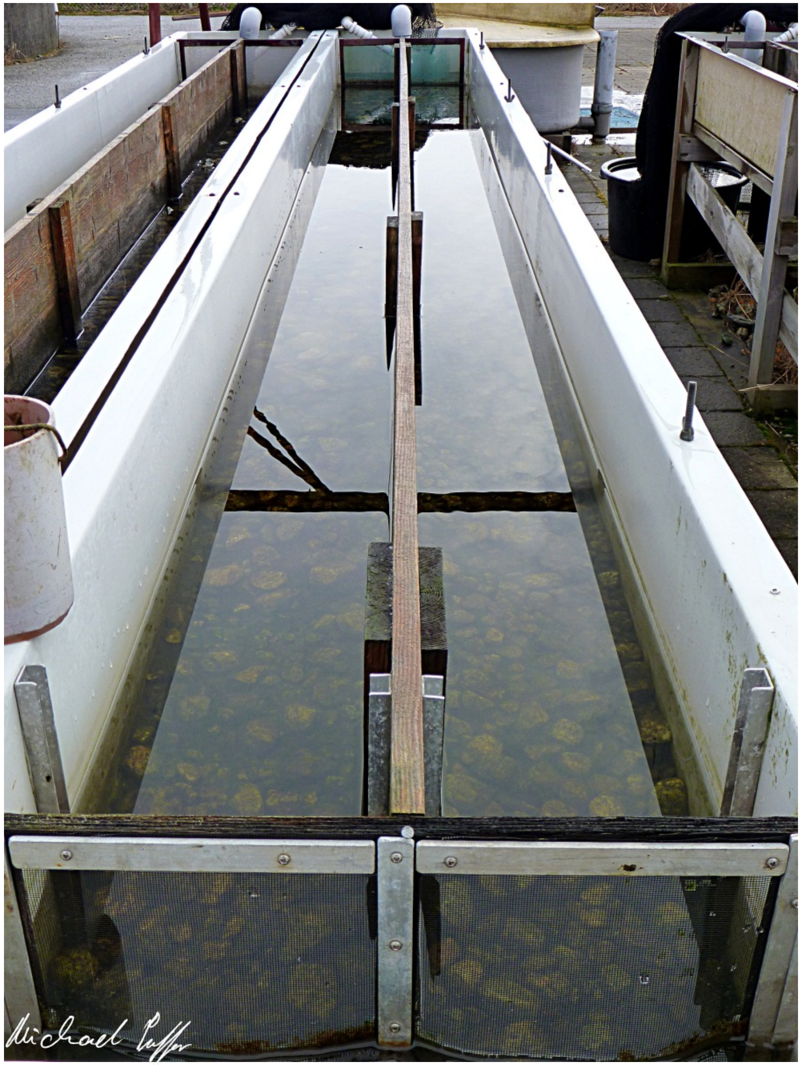
- Water depth
- Substrate type
- FST-number

Q = 15.4 m^3/s

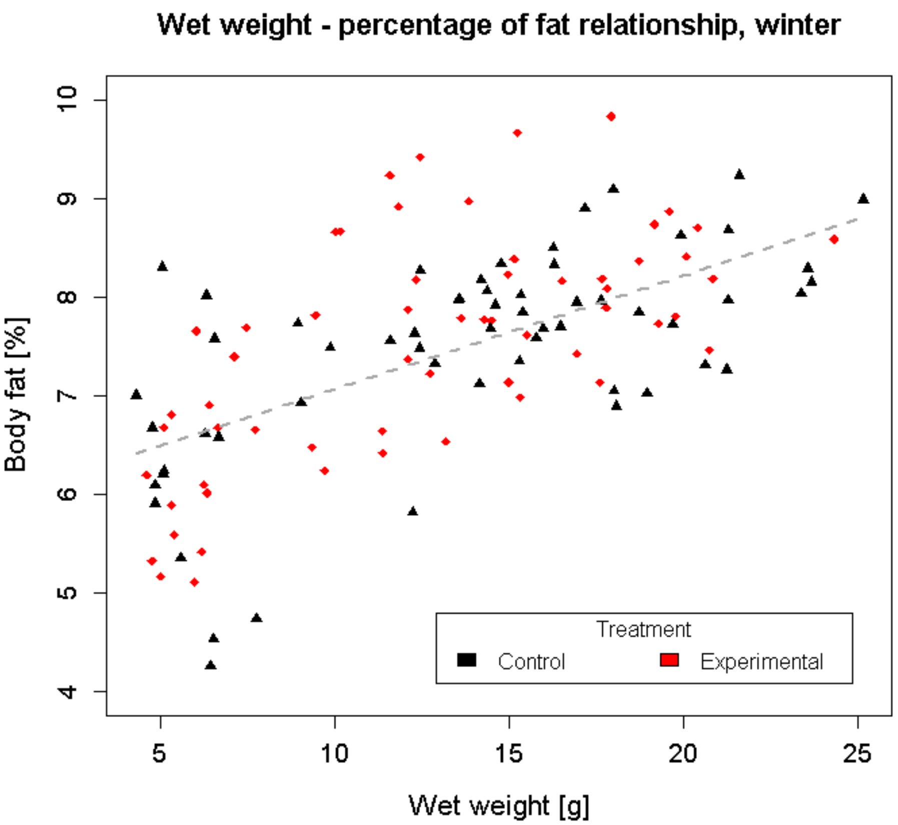


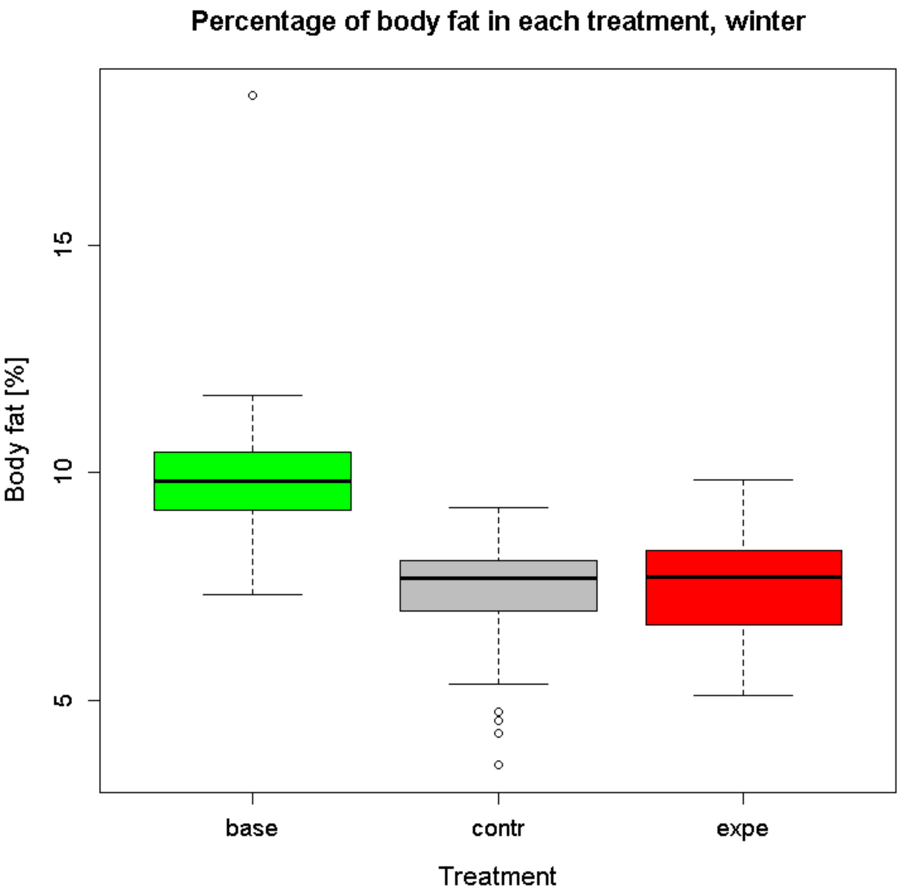
- Frequent drops in water level down to 15.4 m3/s
  → decrease in suitable habitat

Fish: Experimental setup in Ims



Results: Winter

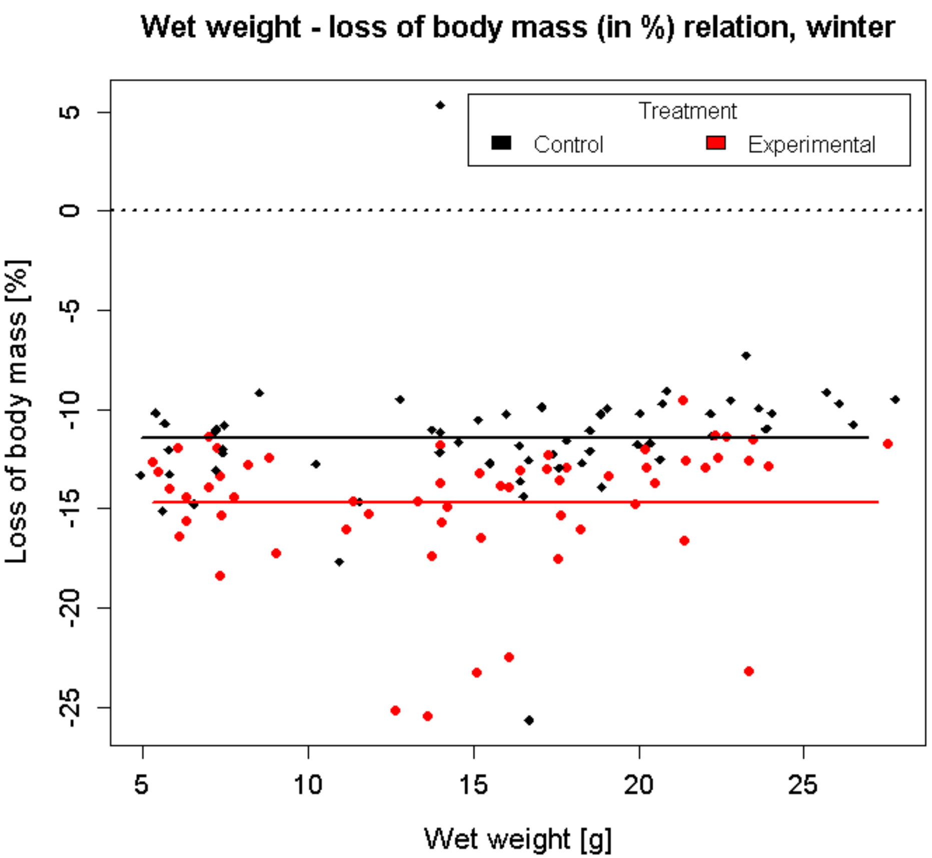


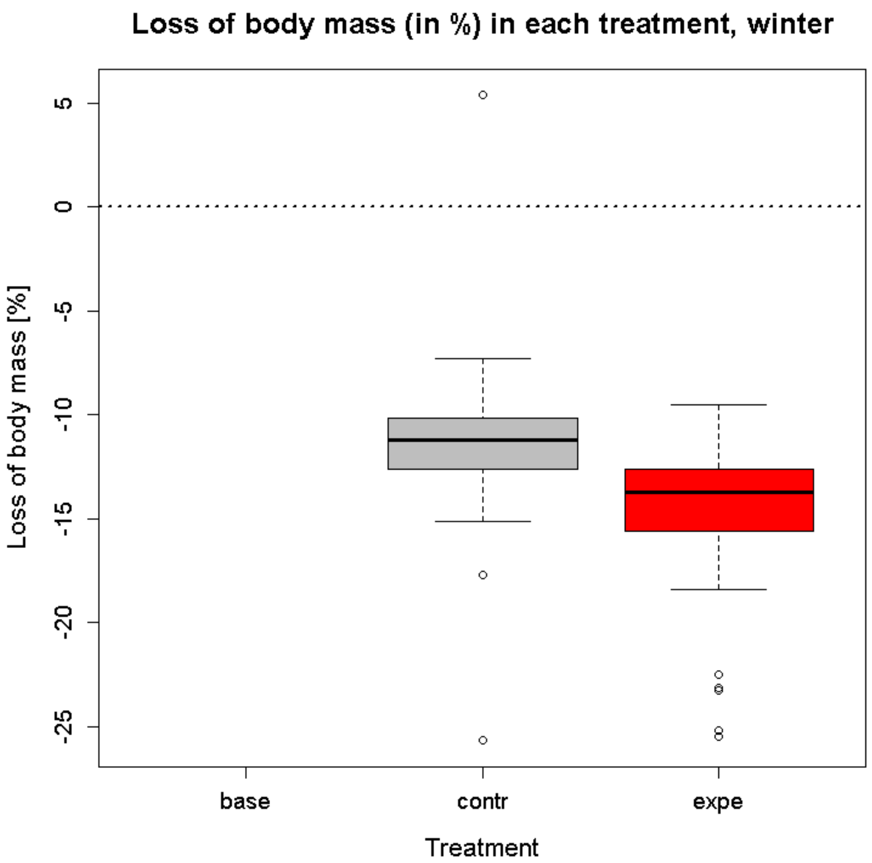


Flow fluctuations had no effect on body fat

Fish surviving stranding - experimental setup in Ims

Results: Winter

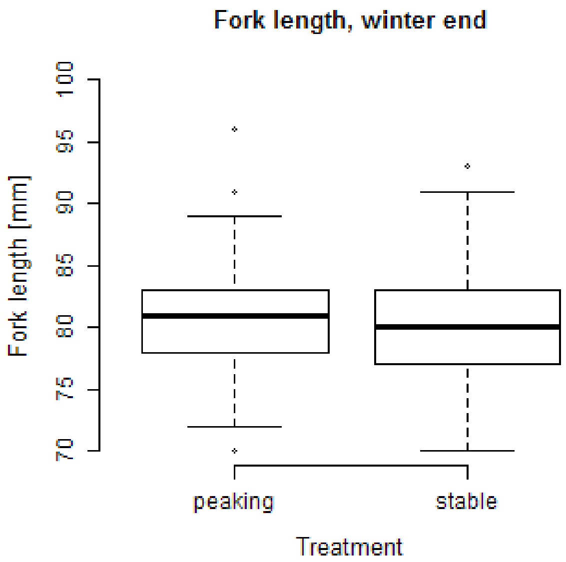


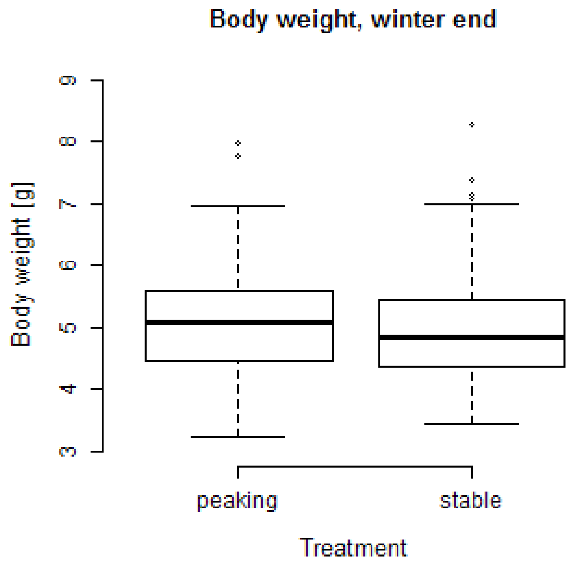


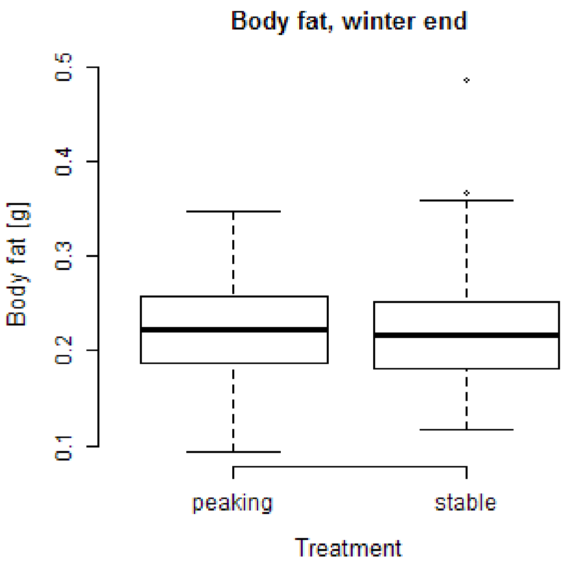
Survivers of stranding had significant less body mass

Growth of fish in peaking environment - experimental setup in Paltamo (Finland)

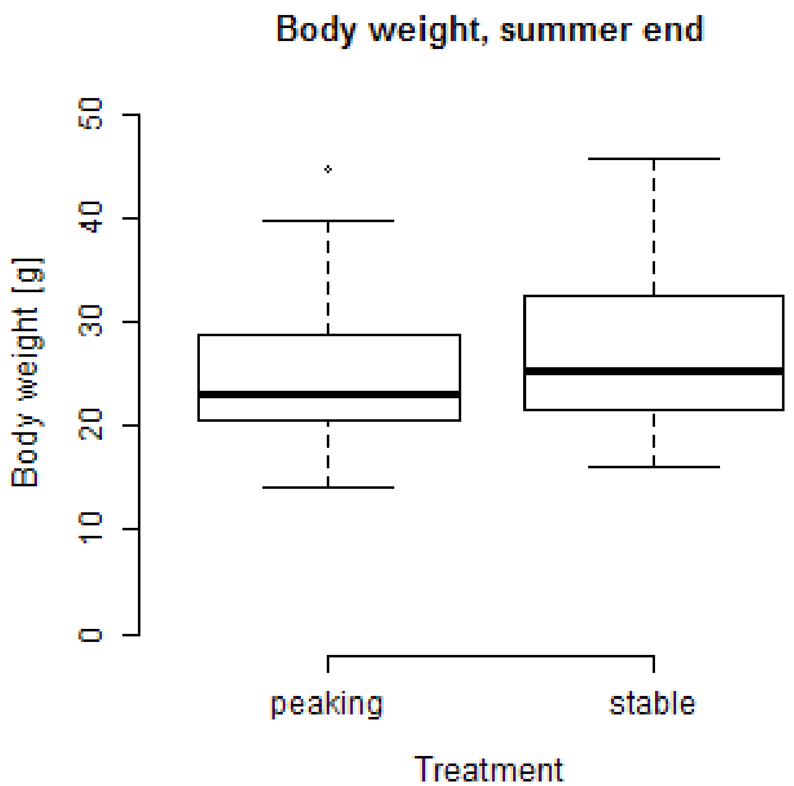
Results: Winter

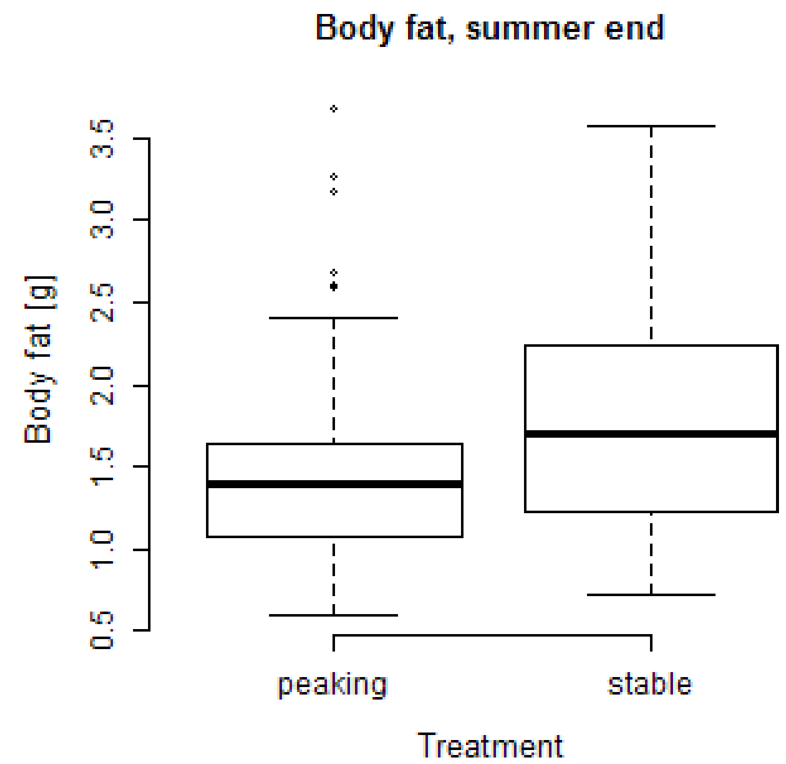






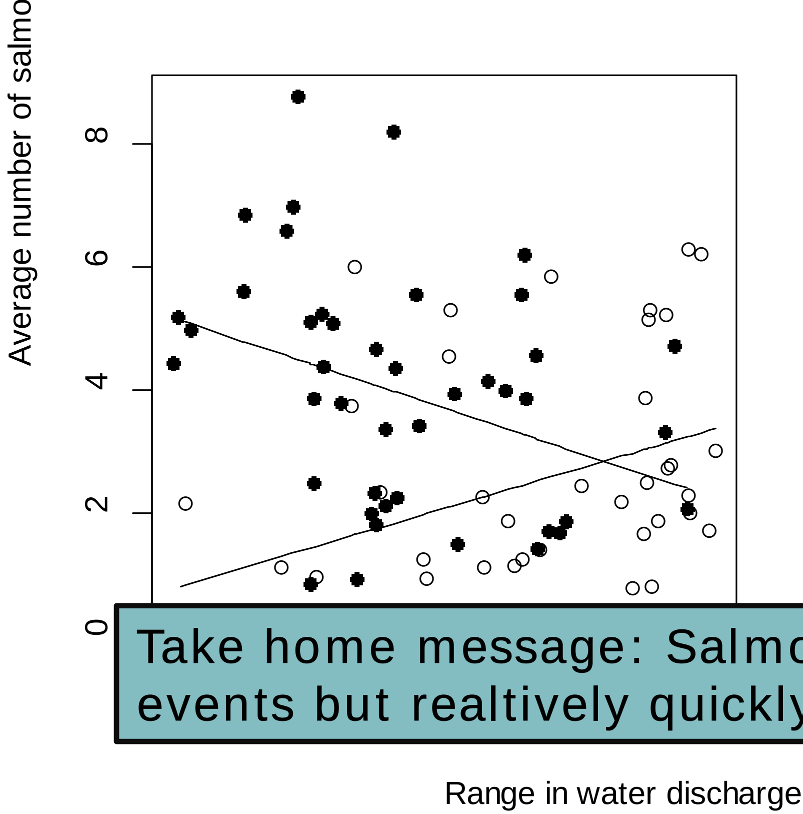
Results: Summer





Significant effects on:

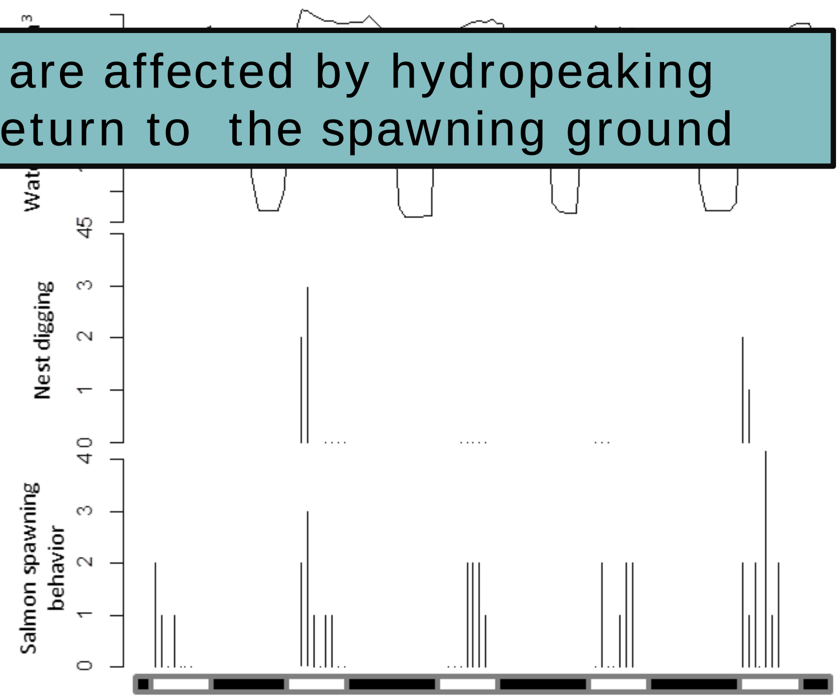
- body weight → control fish 2.56 g **(= 10.3%)** heavier;
- body fat → control fish have 0.25 g **(= 16.6%)** more body fat



Presence of salmon at the spawning ground affected by variability in water discharge

Take home message: Salmon are affected by hydropeaking events but realtively quickly return to the spawning ground

Nest digging within an hour after a typical hydropeaking event



Linking Population and Habitat Model

Effects of hydropeaking
on the Atlantic salmon
populations…

Engineers‘ view

Hydraulic Habitat Models

Biologists‘ view

Population Models

…on large temporal
and/or spatial scales

Linking Population and Habitat Model

Hydraulic Habitat Model

CASiMiR stranding

multivariate fuzzy hydraulic habitat

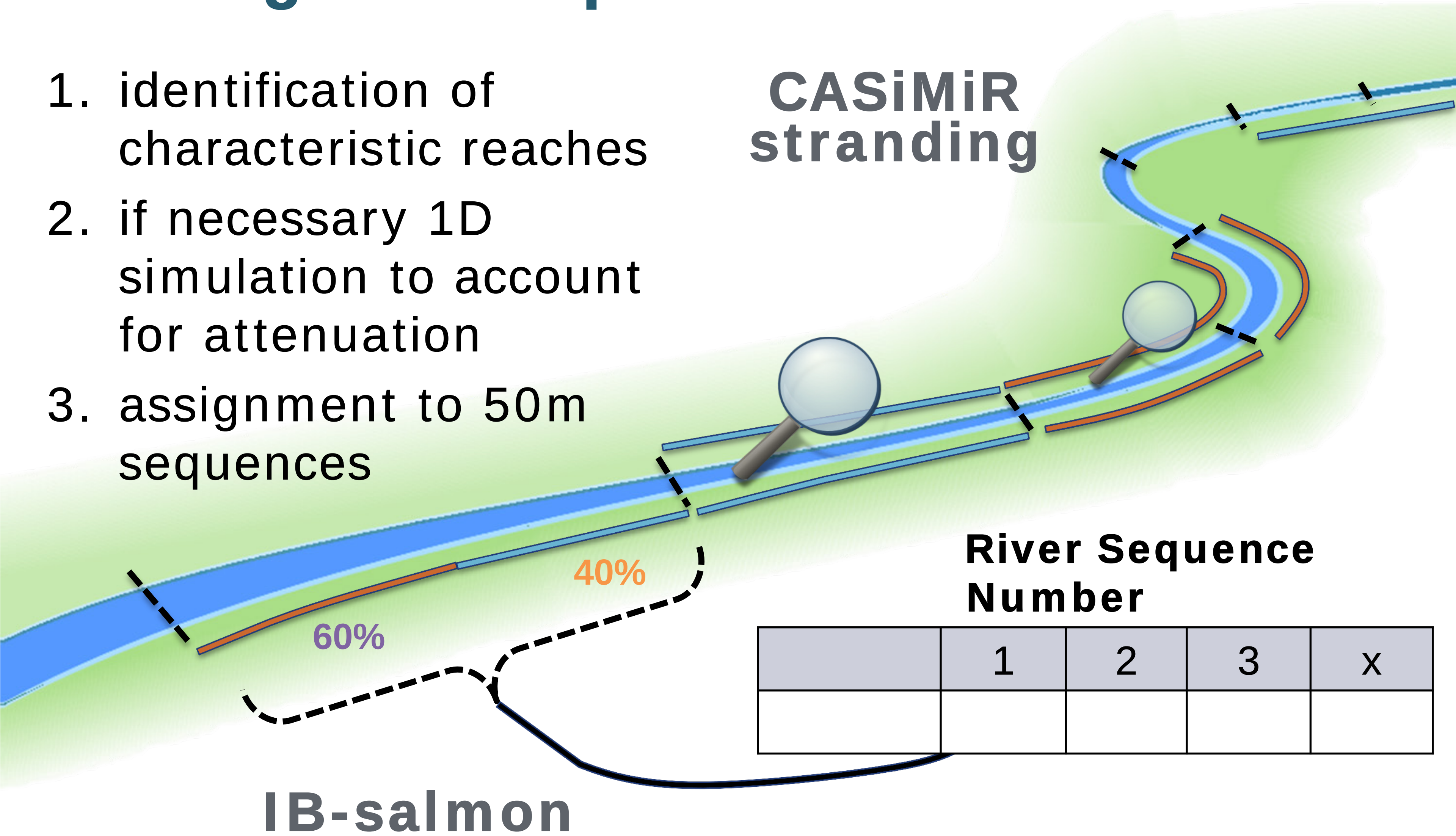
Population Model

IB-salmon

mechanistic ecological population dynamic

Linkage concept

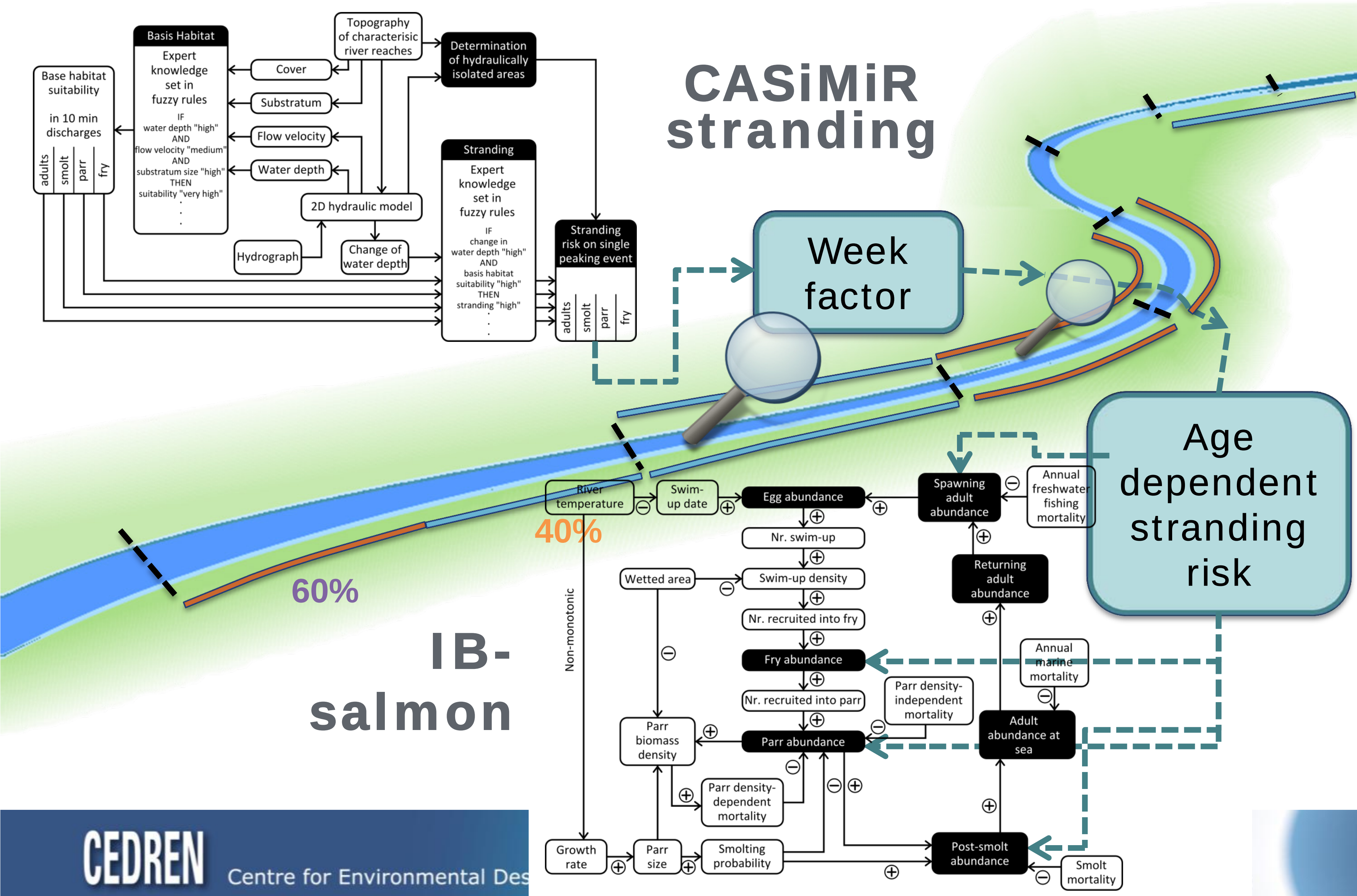
1. identification of characteristic reaches
2. if necessary 1D simulation to account for attenuation
3. assignment to 50m sequences



River Sequence Number

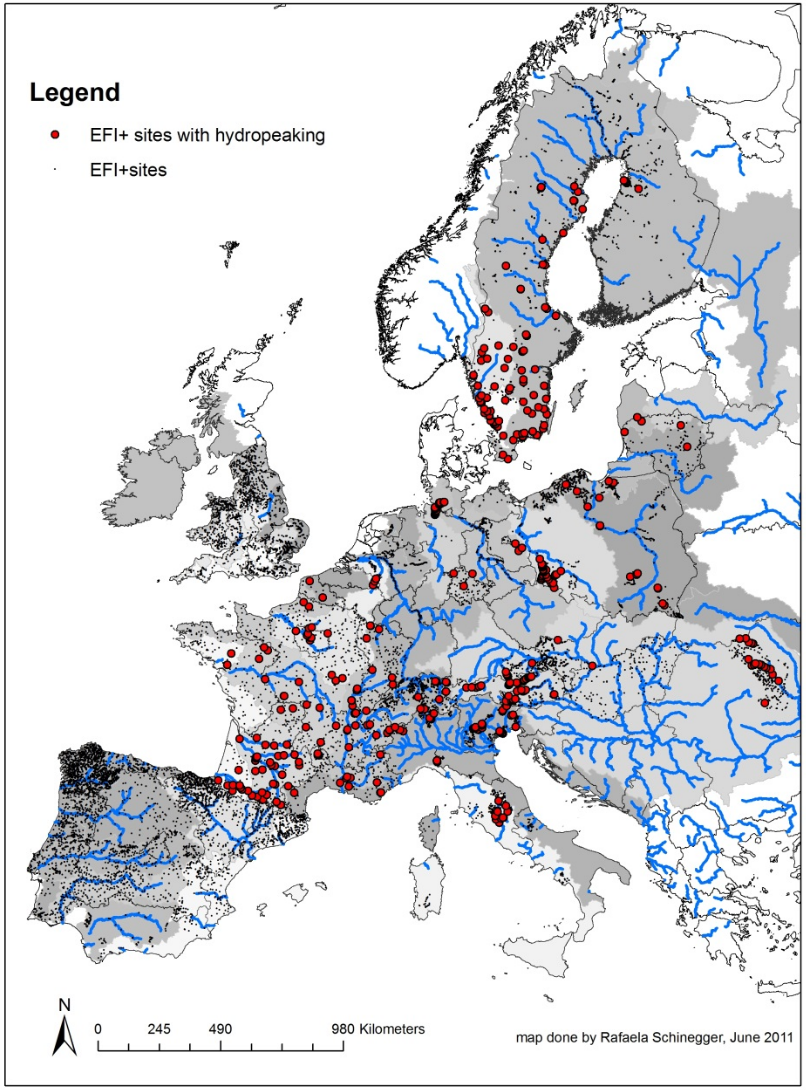
	1	2	3	x

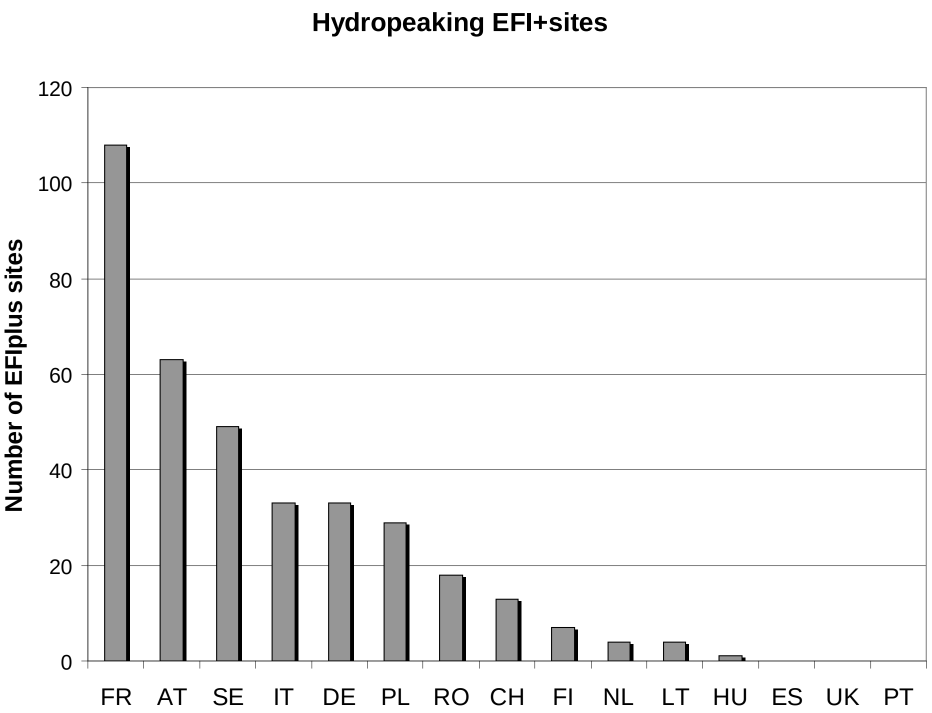
Linking Population and Habitat Model



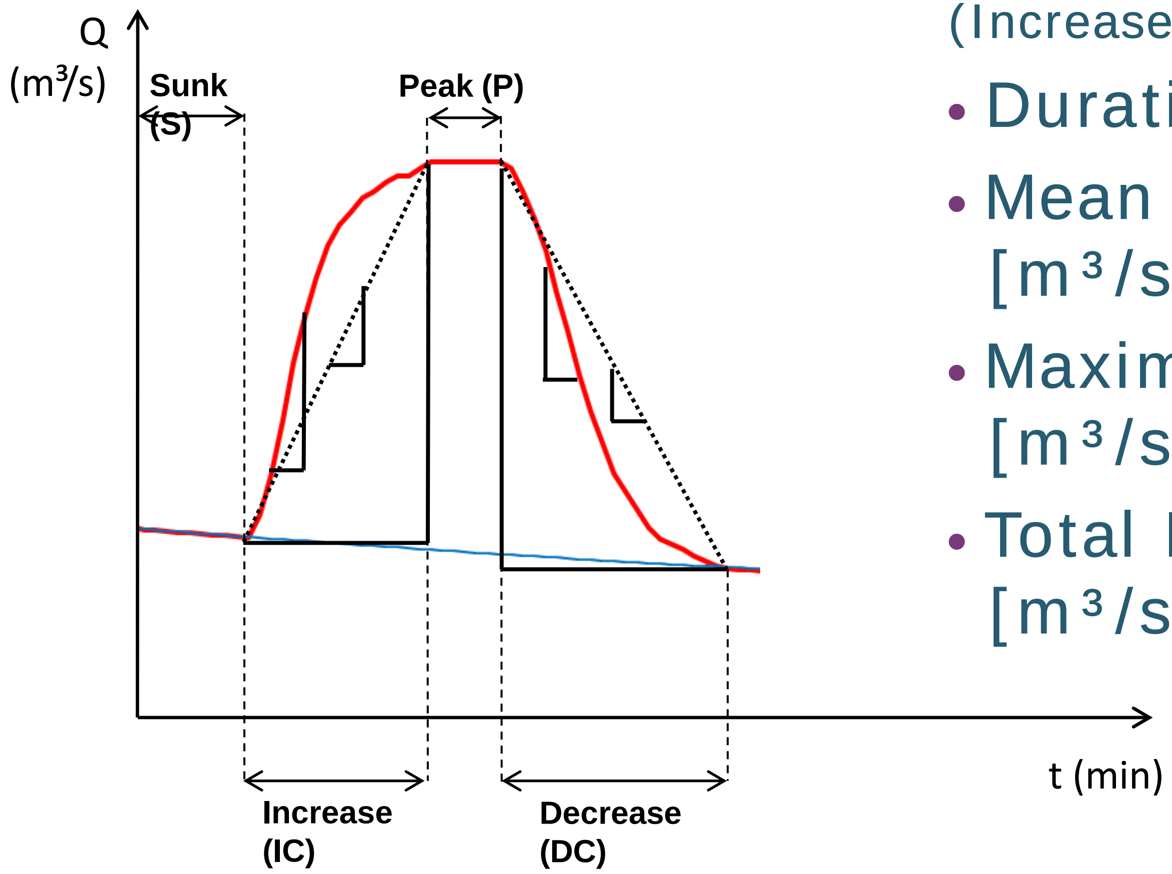
CEDREN Centre for Environmental Des

Hydropeaking in Europe





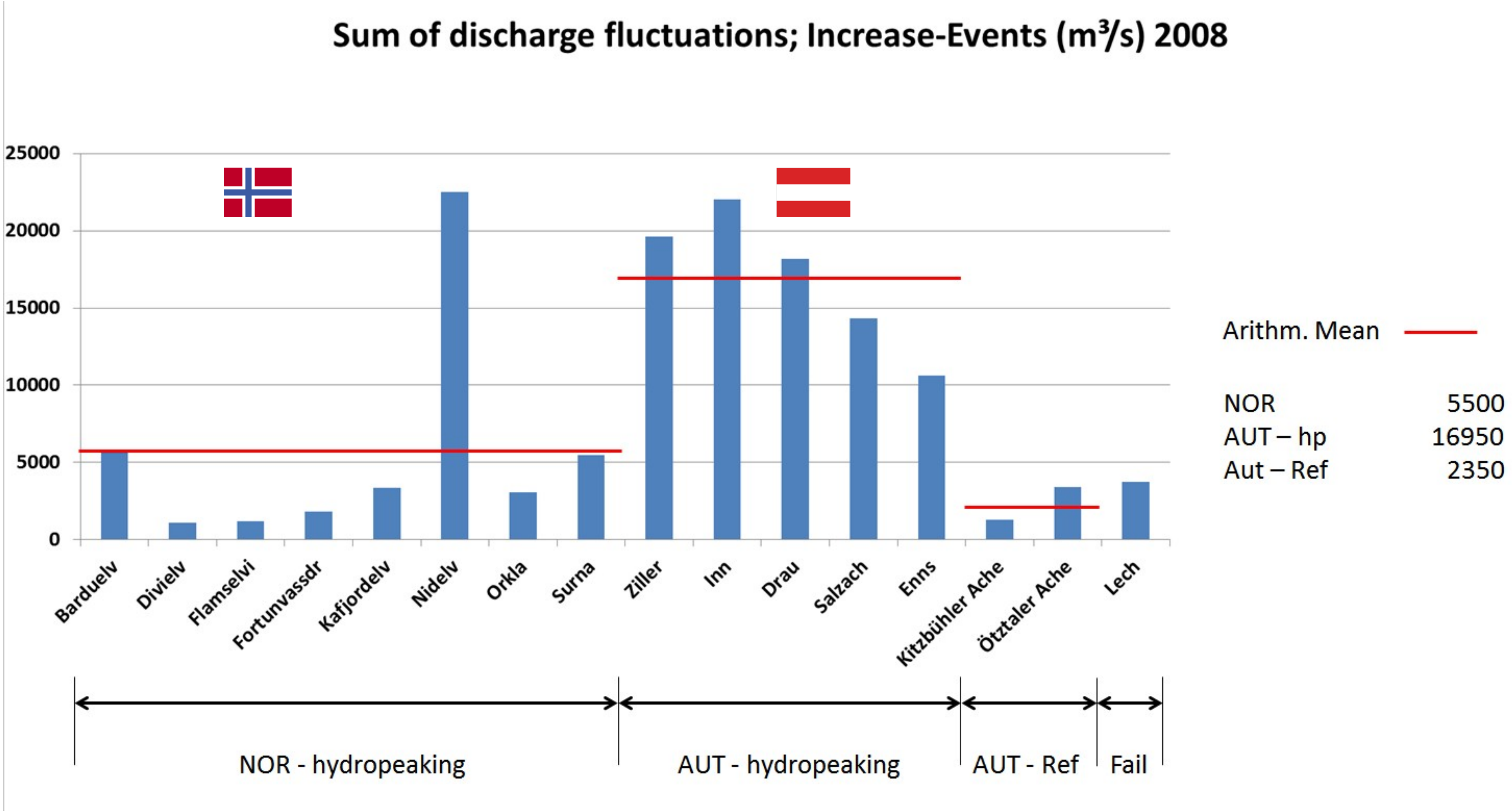
Development of a computer-based wave detector - Observed parameters



Parameters
(Increase=IC and decrease=DC)

- Duration dt (min)
- Mean IC/DC [m^3/s/min]
- Maximum IC/DC [m^3/s/min]
- Total IC/DC dQ IC/DC [m^3/s/event]

Norwegian, Austrian and Reference Rivers Sum dQ_IC – Events 2008 (m^3/s) (n=500)



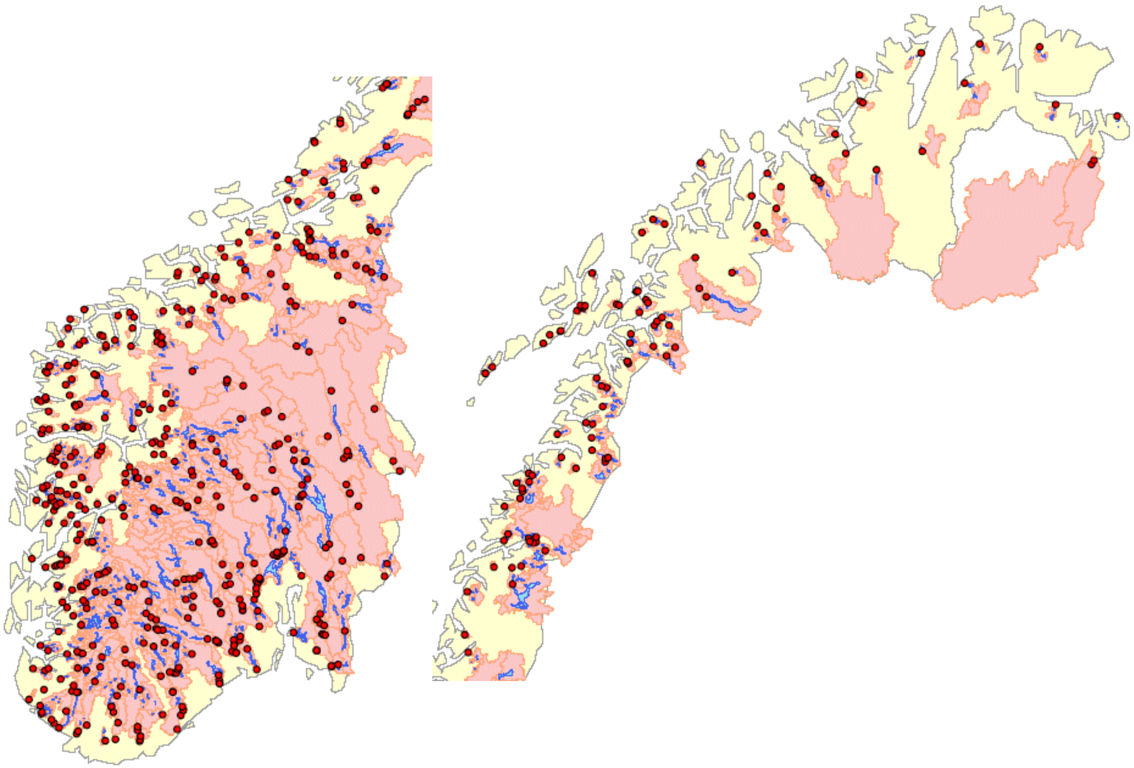

Hydro storage –
a renewable battery

Norwegian hydropower

Natural lakes used as reservoirs

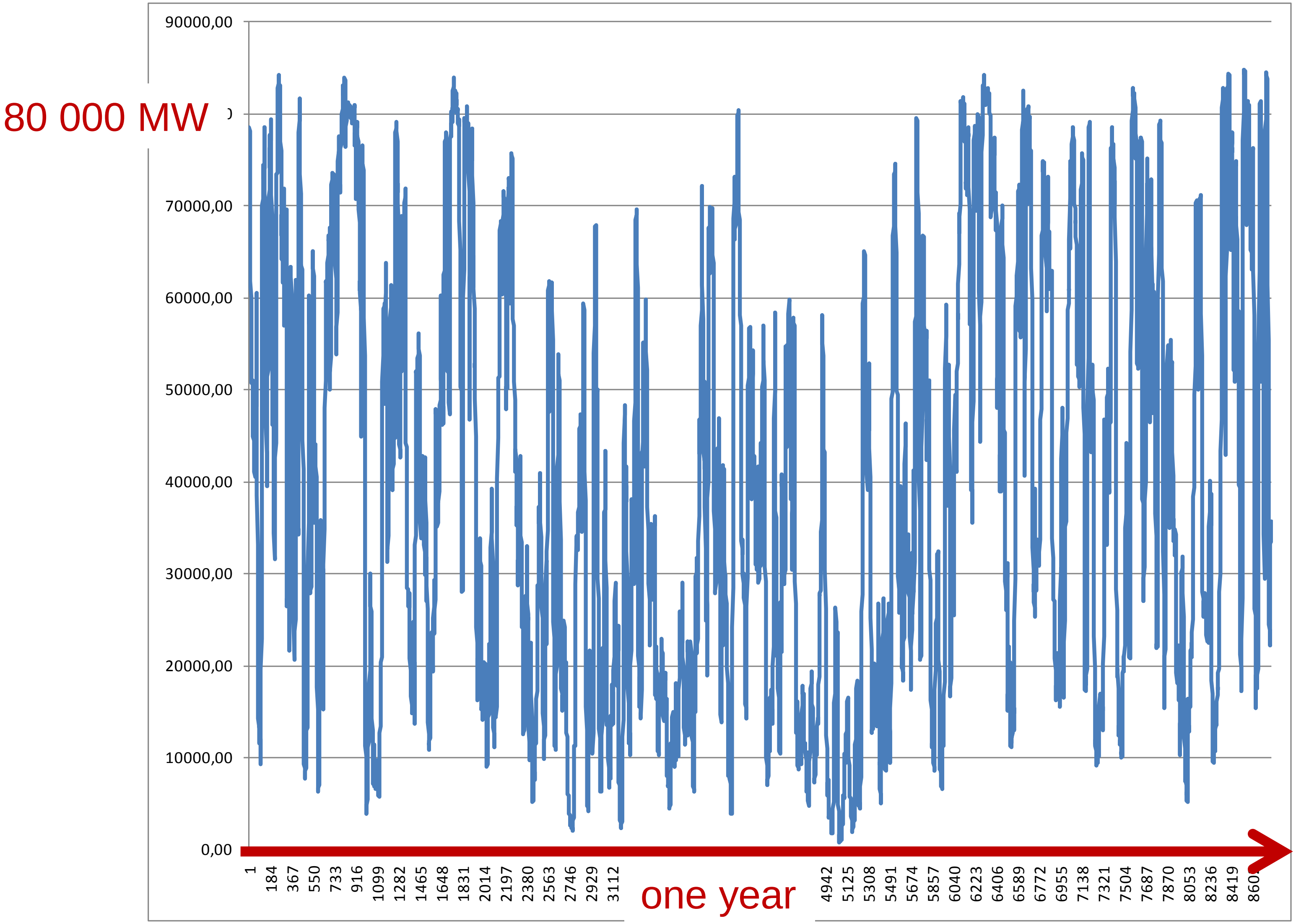
Multi-year reservoirs

Norway

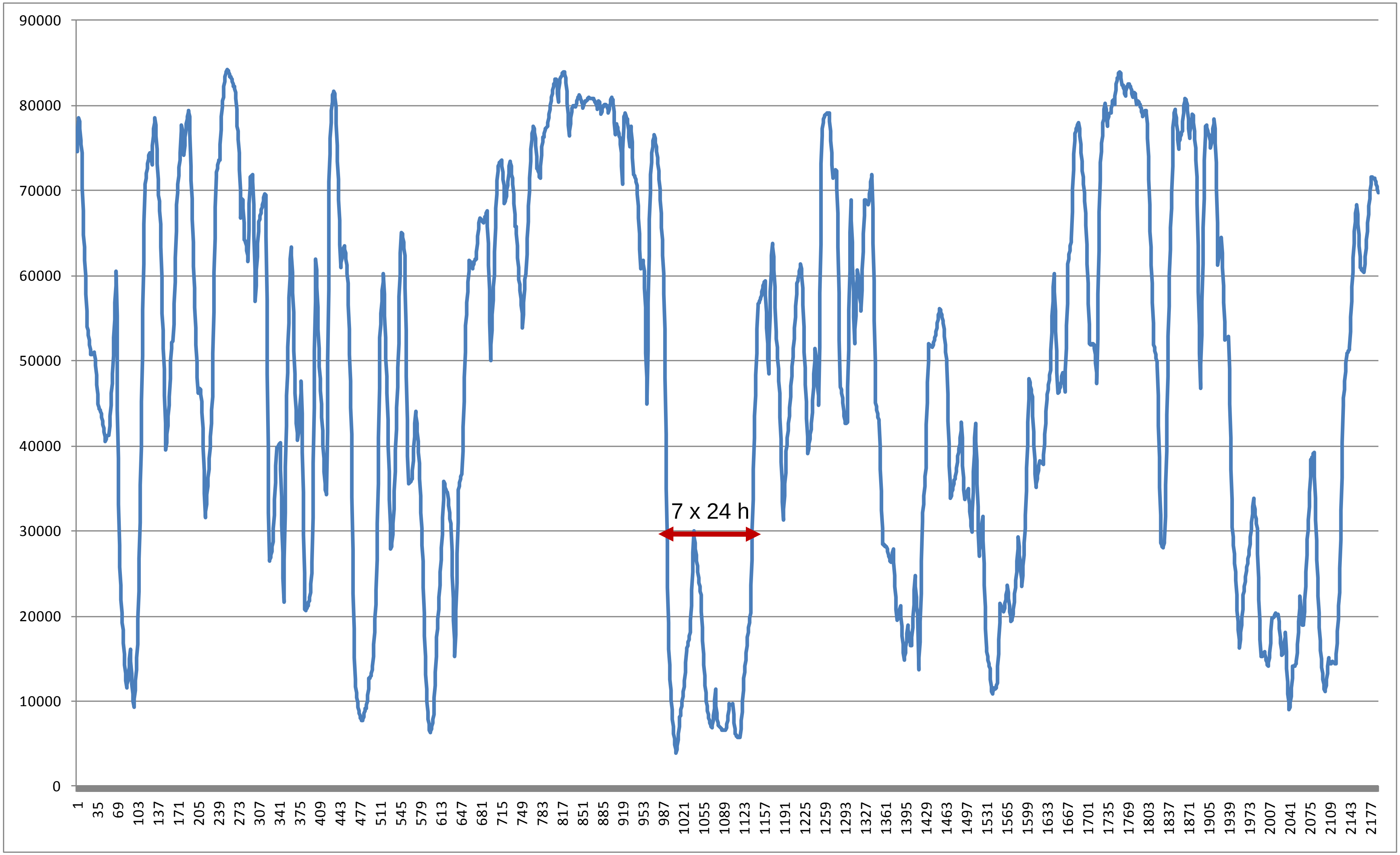


- Hundreds of large reservoirs
- 20 reservoirs with more than 100 Mm^3 both up- and downstream

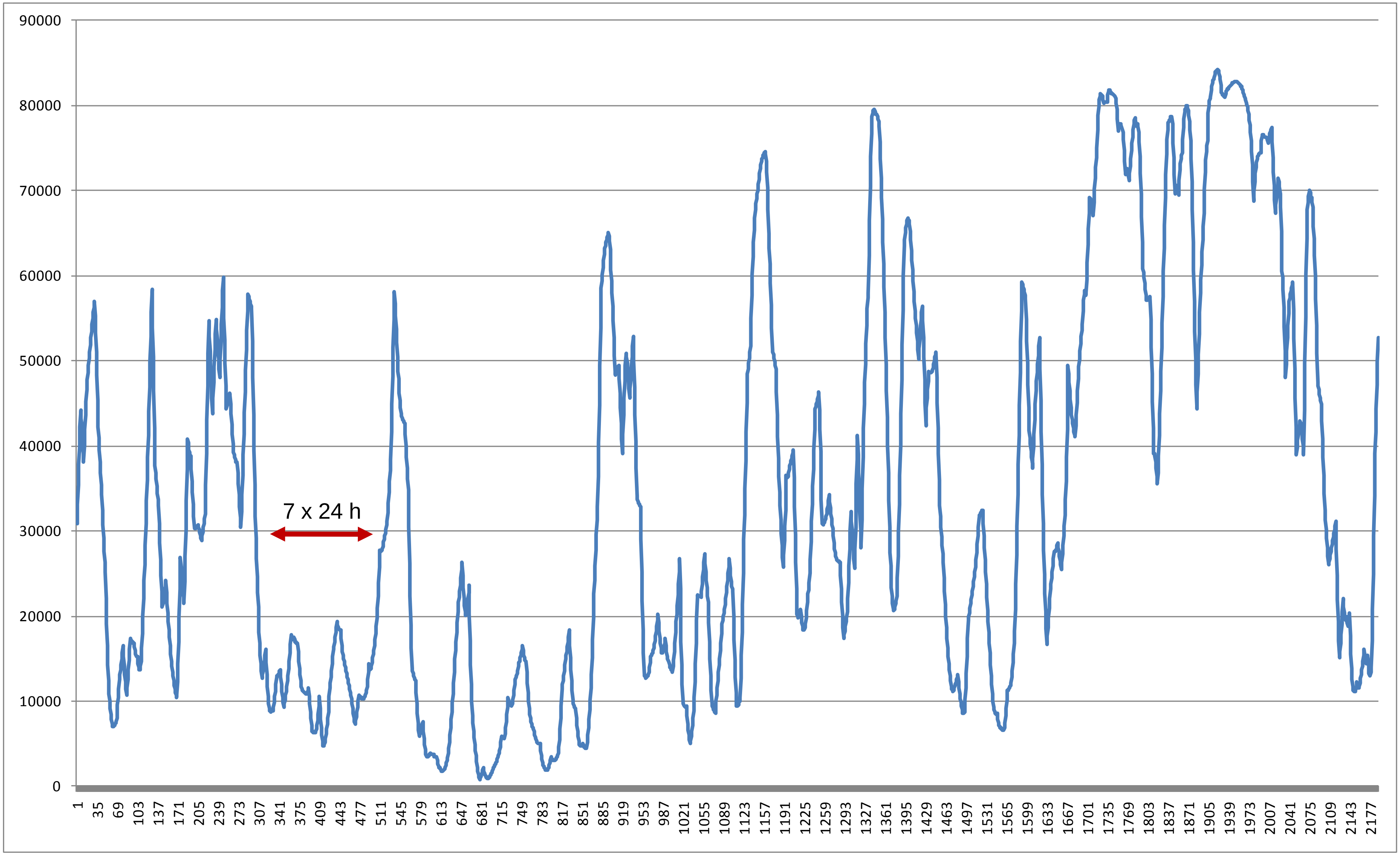
Simulated wind production in the North Sea area in 2030 – 100 000 MW installed capacity



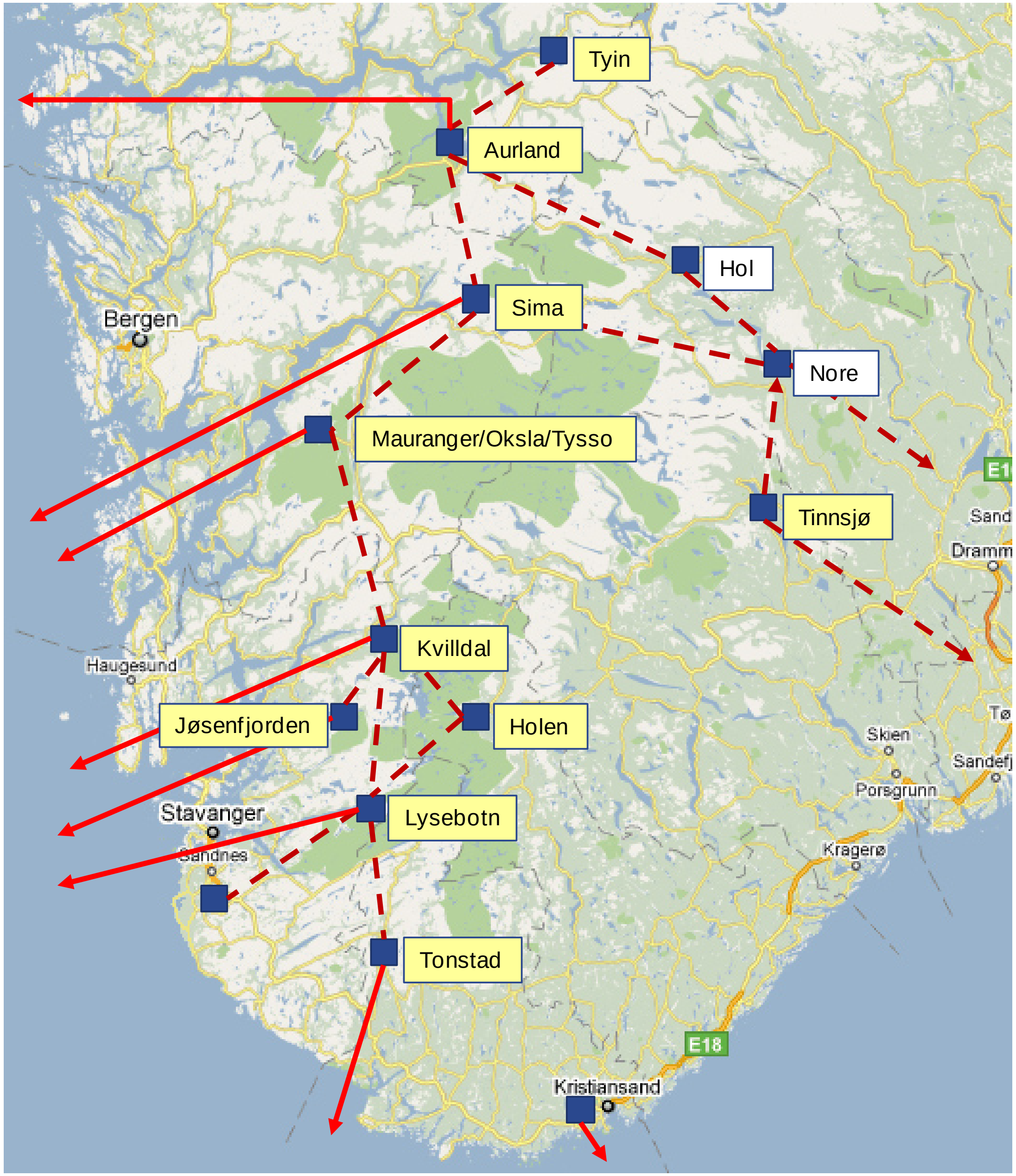
January - March



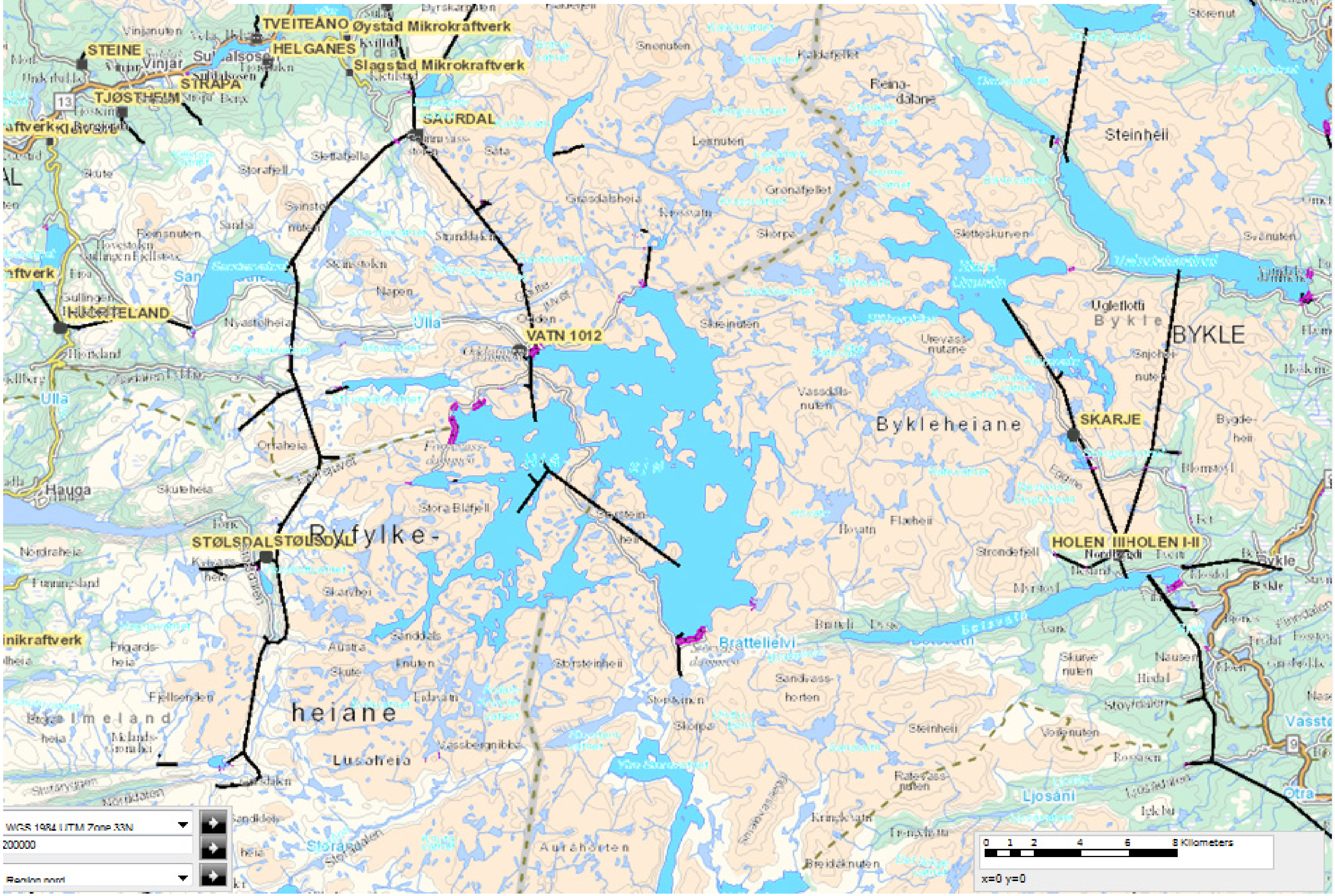
July - September



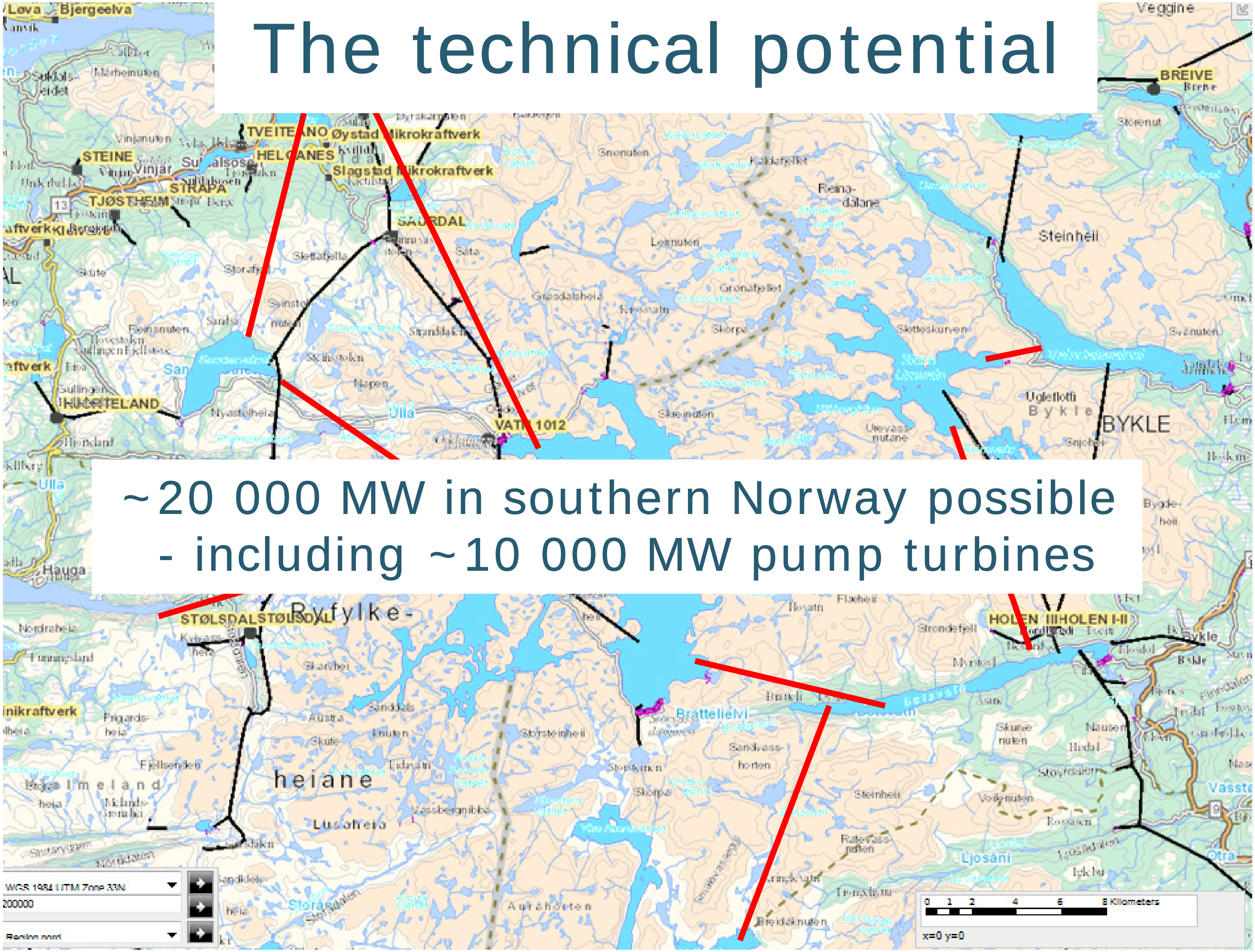
CEDREN Case study 2030



The technical potential

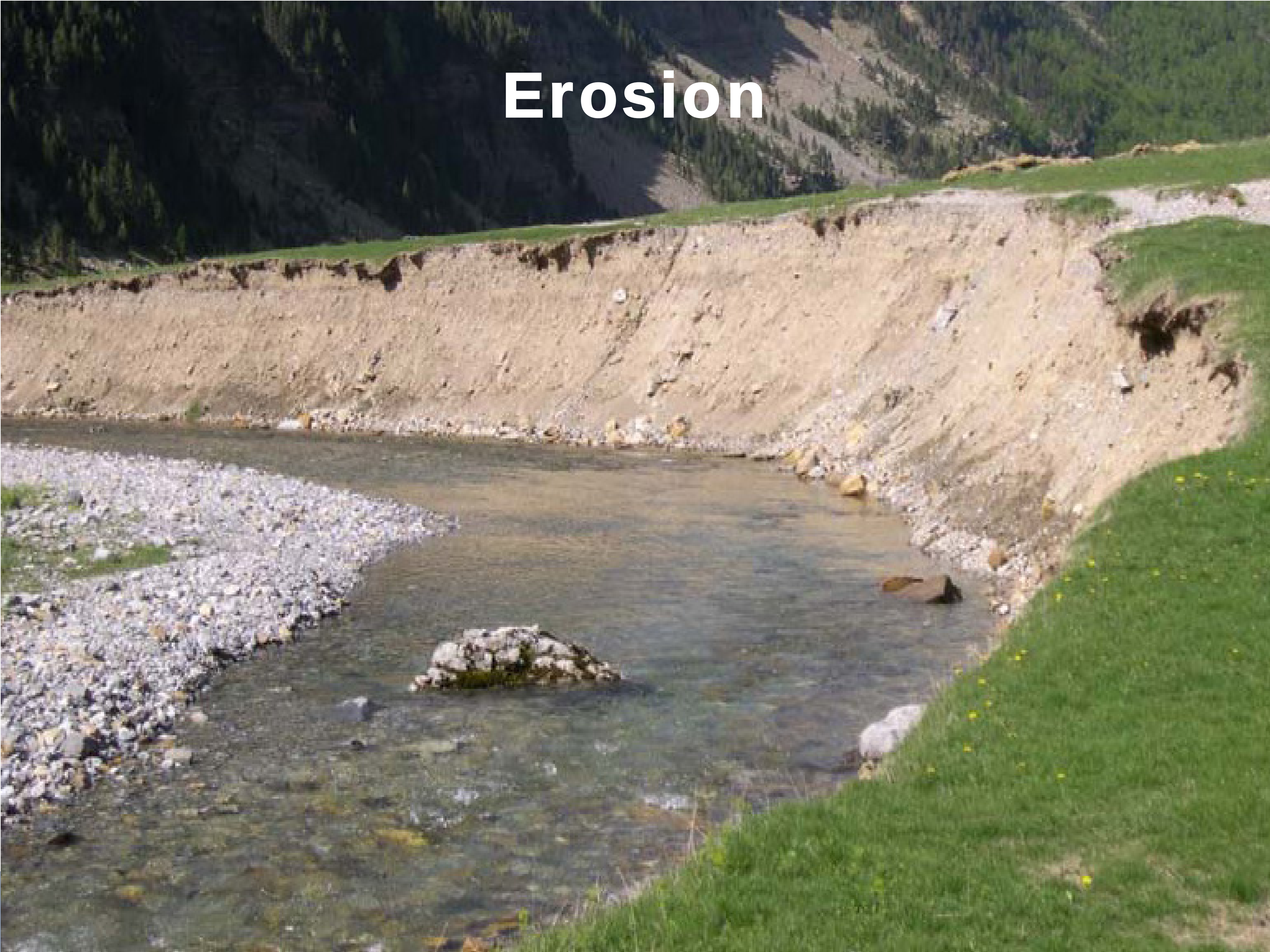


The technical potential

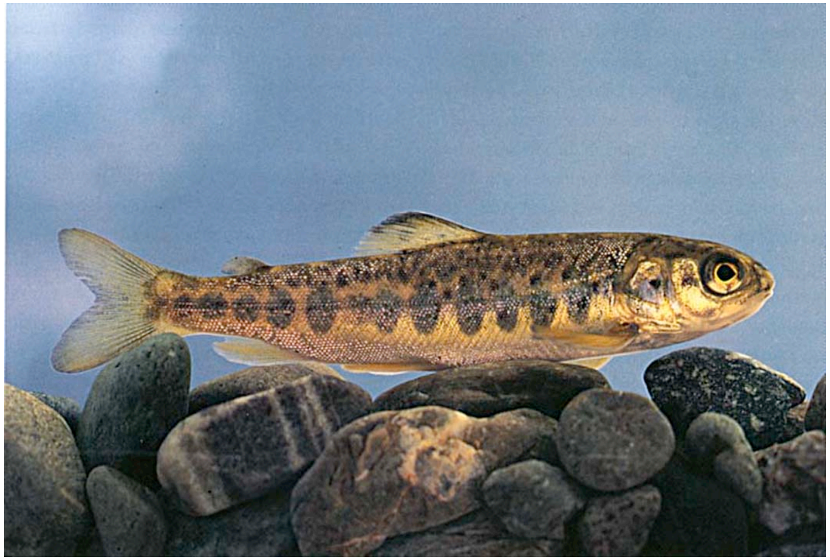


~20 000 MW in southern Norway possible
- including ~10 000 MW pump turbines


Environmental impacts


Erosion

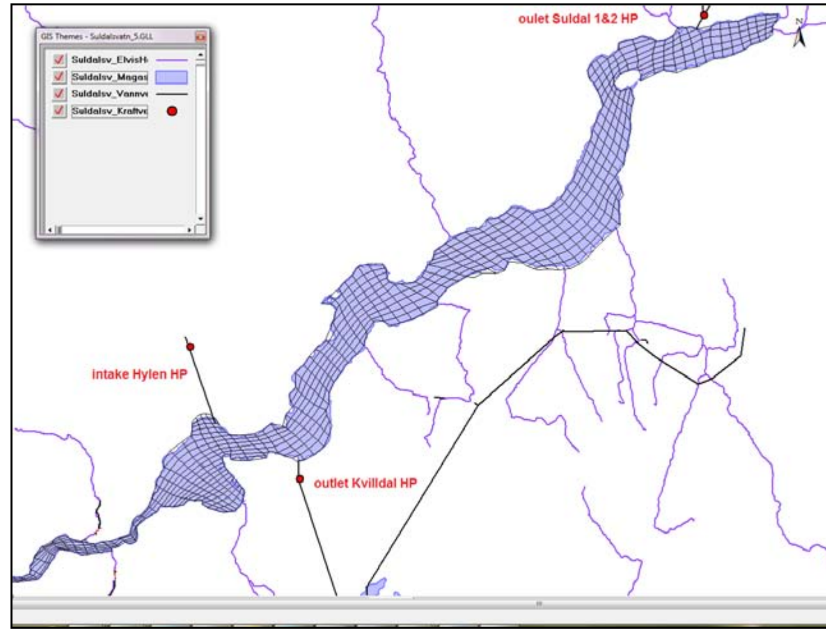
Threatening biodiversity ?



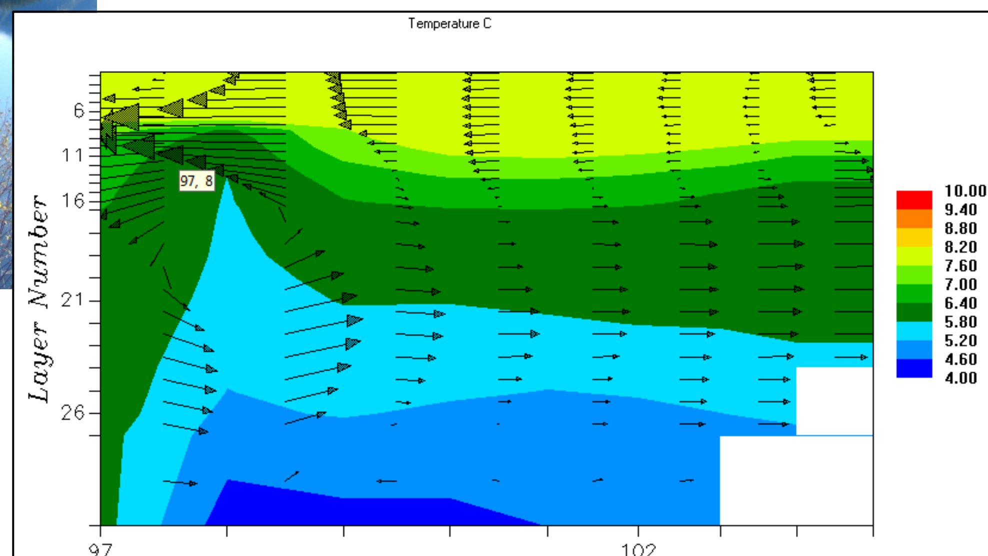
Impacts on fish?


Unsafe ice conditions ?

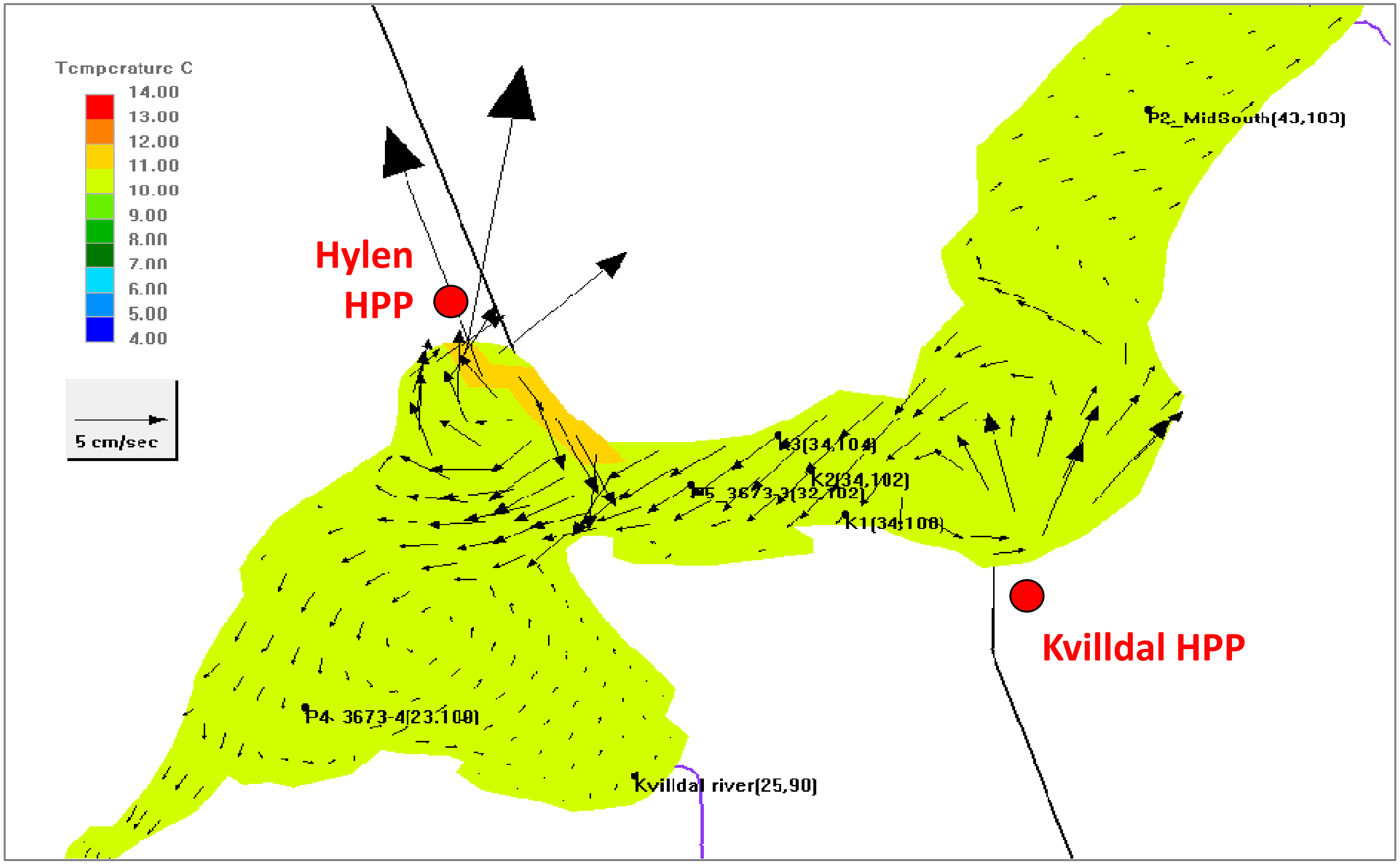
Detailed simulations of PSP with outlet into Suldalsvatn



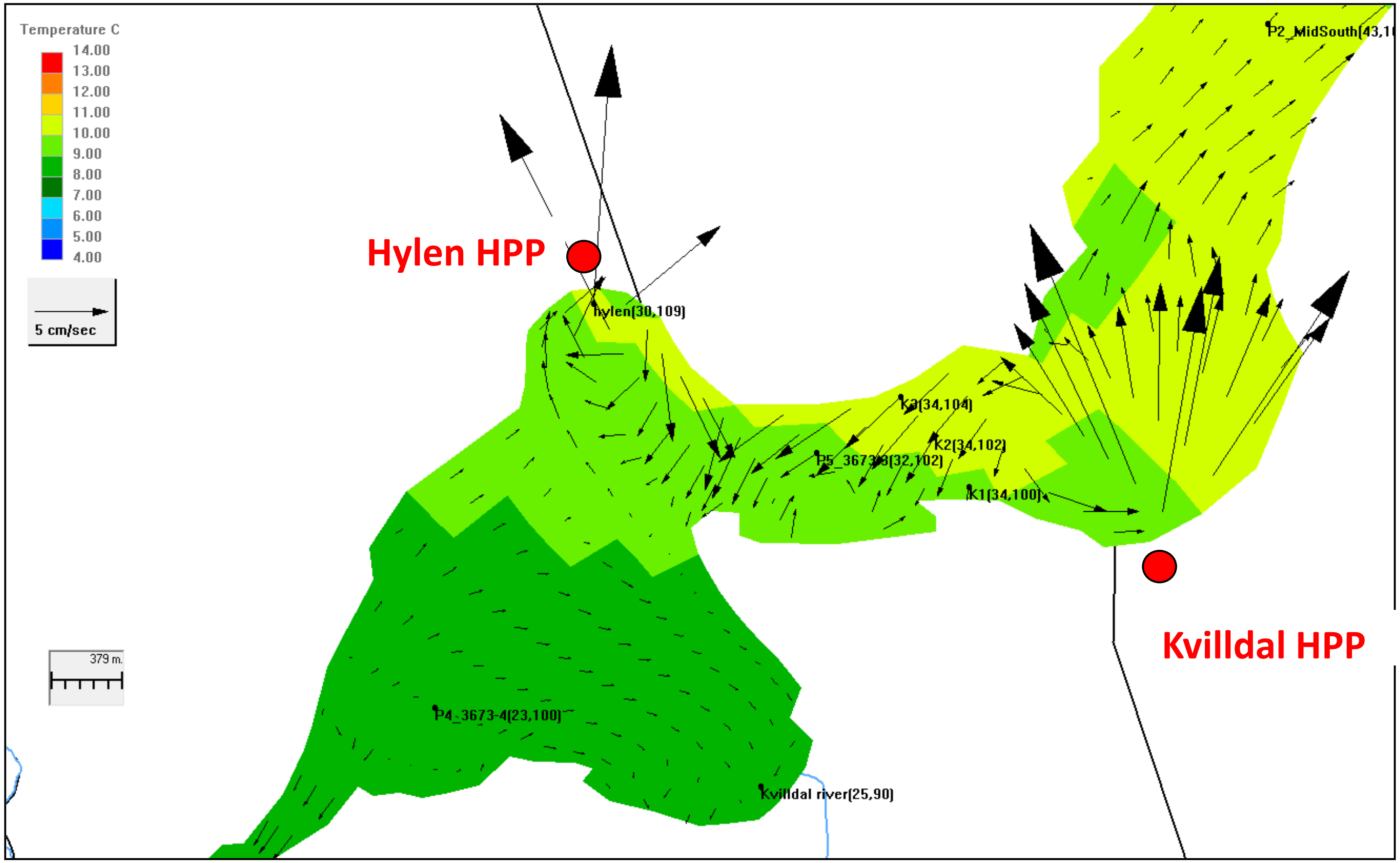
Simulations with GEMSS



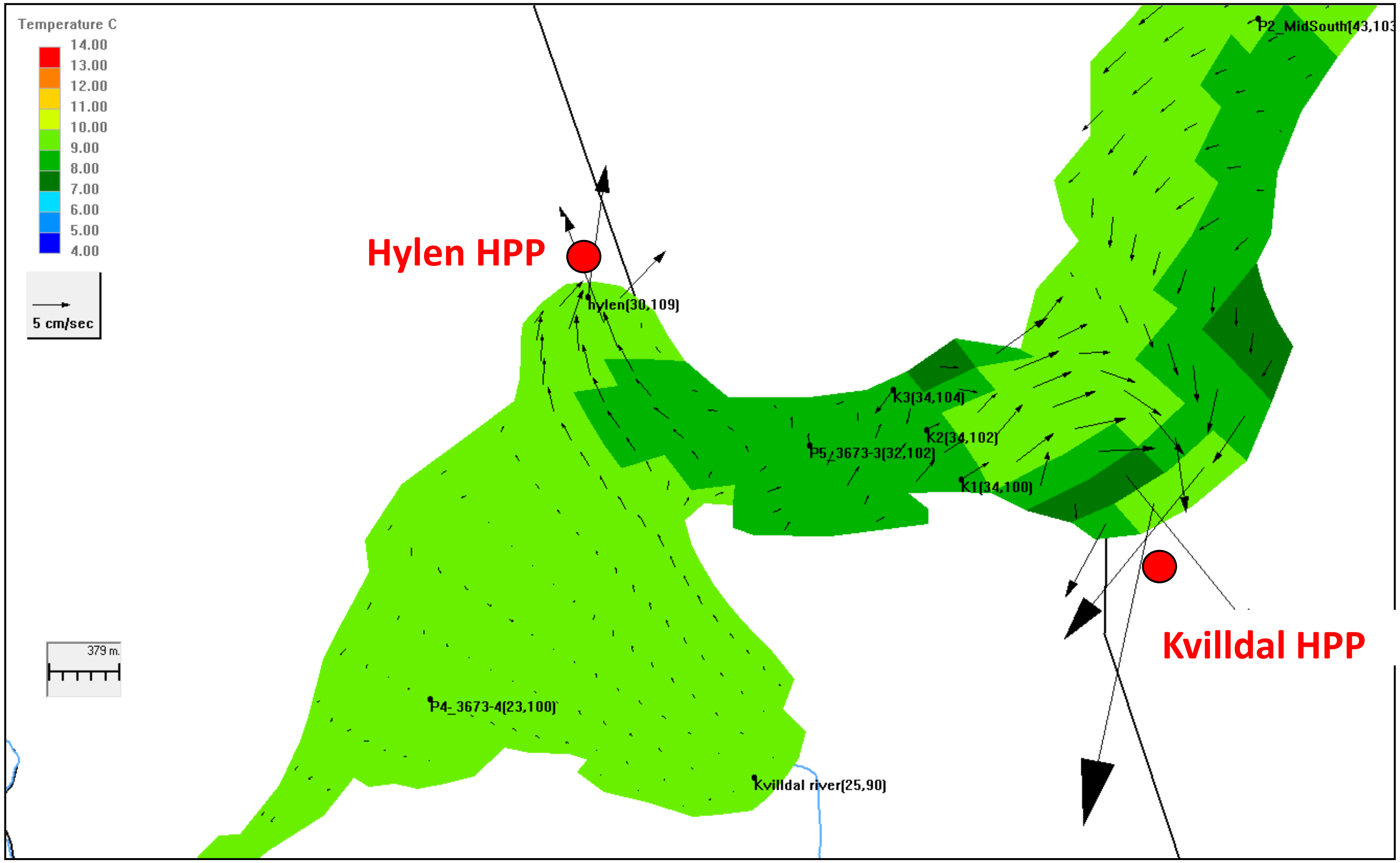
10 m depth in summer - today



10 m depth in summer – with PSP Production phase

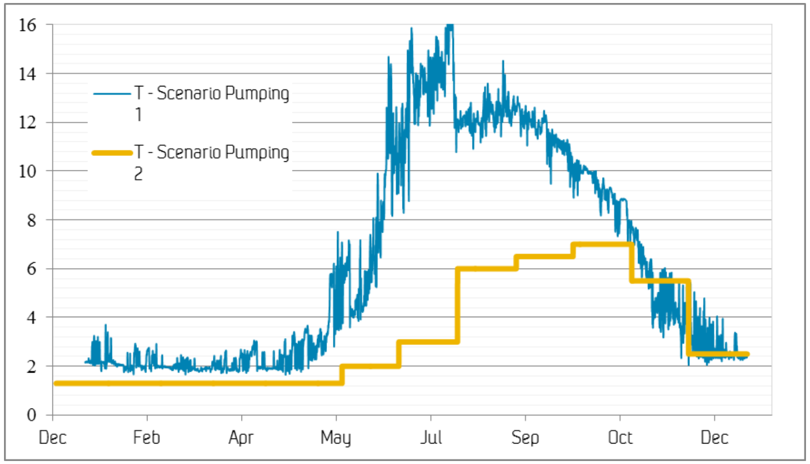


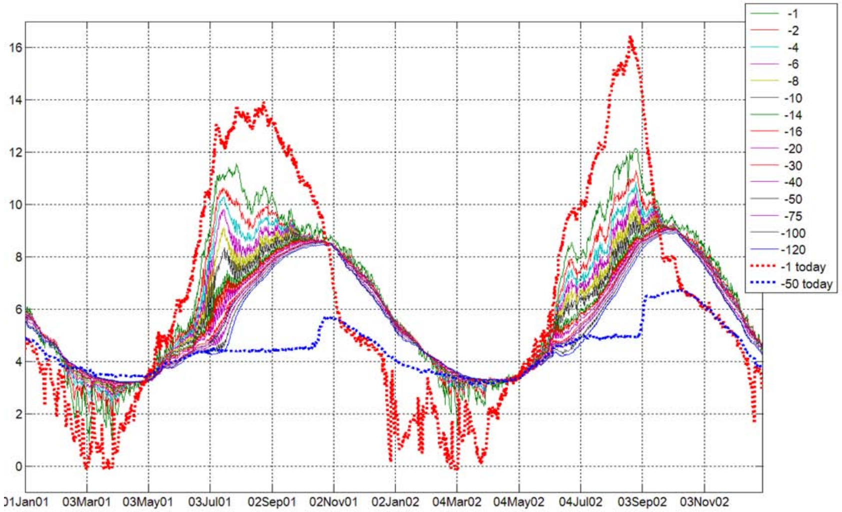
10 m depth in summer – with PSP Pumping phase



Results

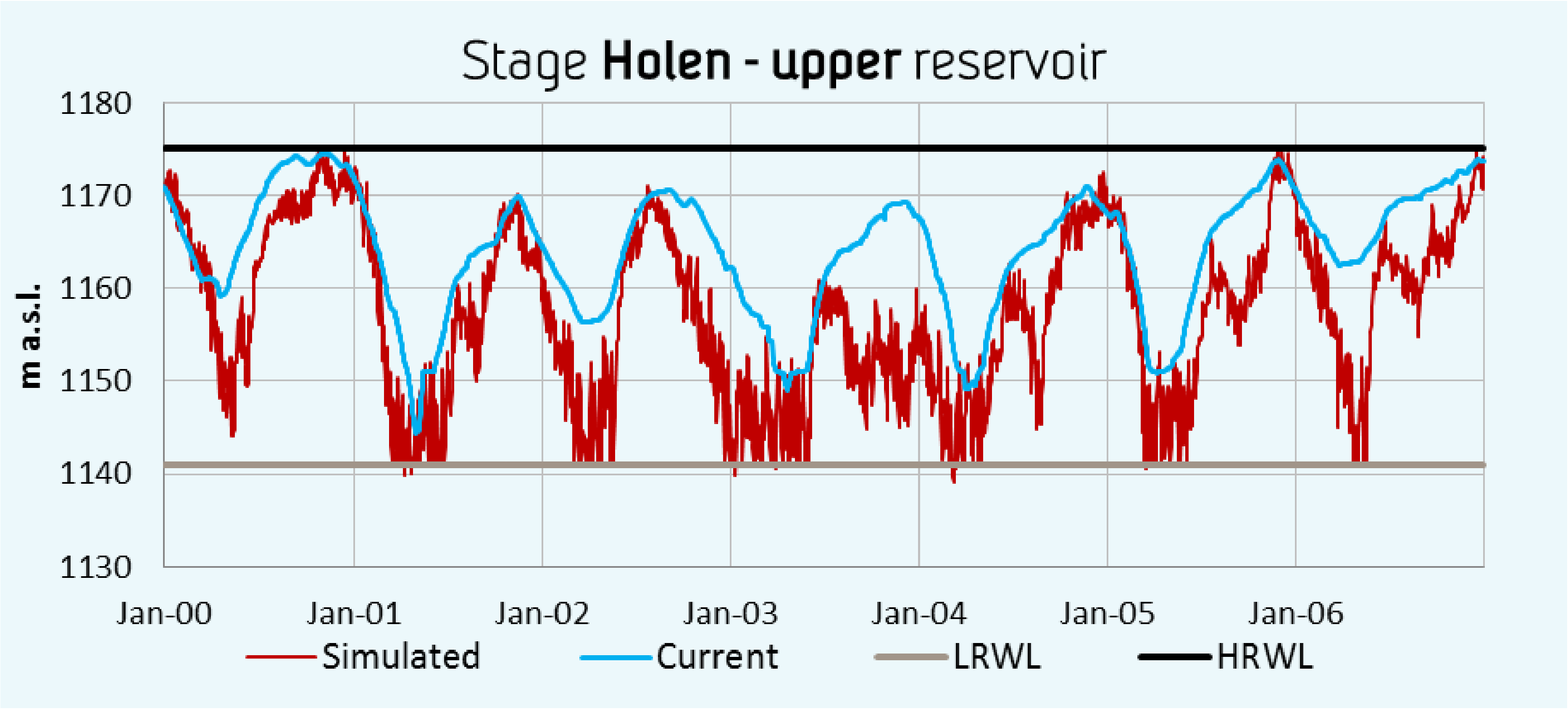
- Intense vertical mixing through the water column
- Colder temperature in the downstream river Suldalslågen during summer and autumn if water comes directly from Blåsjø
- Strong currents appear next to the new power plant



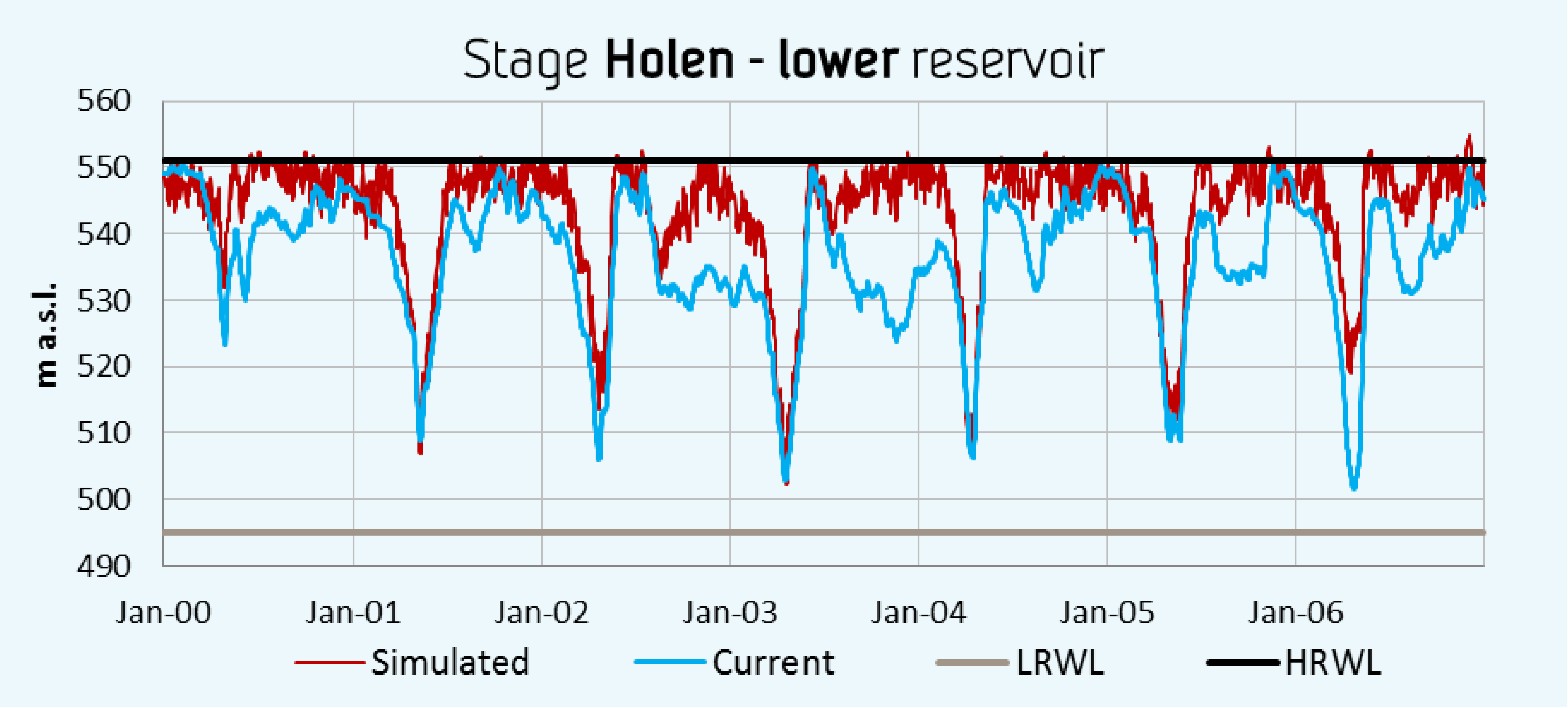


Drawdown zone exposed – changed pattern?

Water level variations



Water level variations

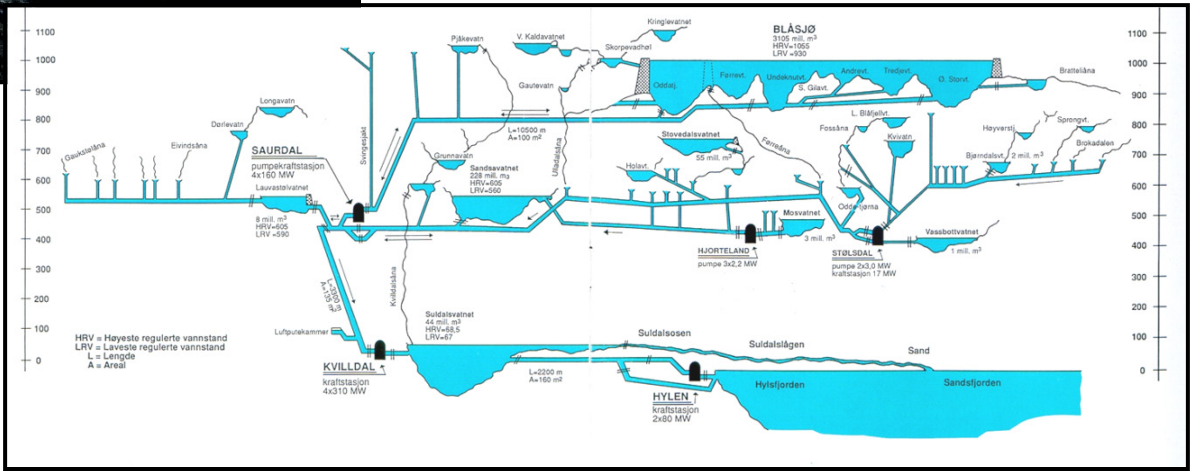


Social acceptance

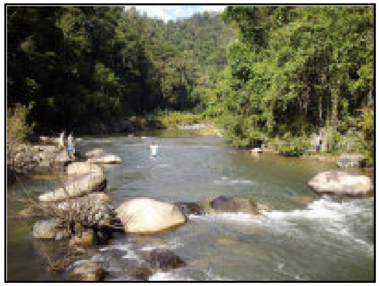
Large plants – large impacts?

Long history of conflicts

Resistance formed the environmental movement



Source: Statkraft



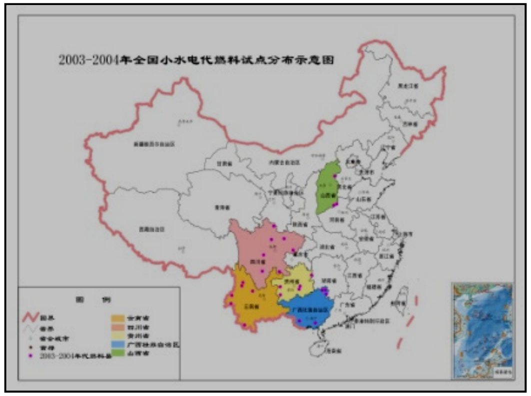
Small plants – small impacts?

Accumulated effects?

An extreme example from China

<u>Small hydropower (< 50 MW):</u>

- More than **1000** plants built
- Producing **2.5 TWh/a**



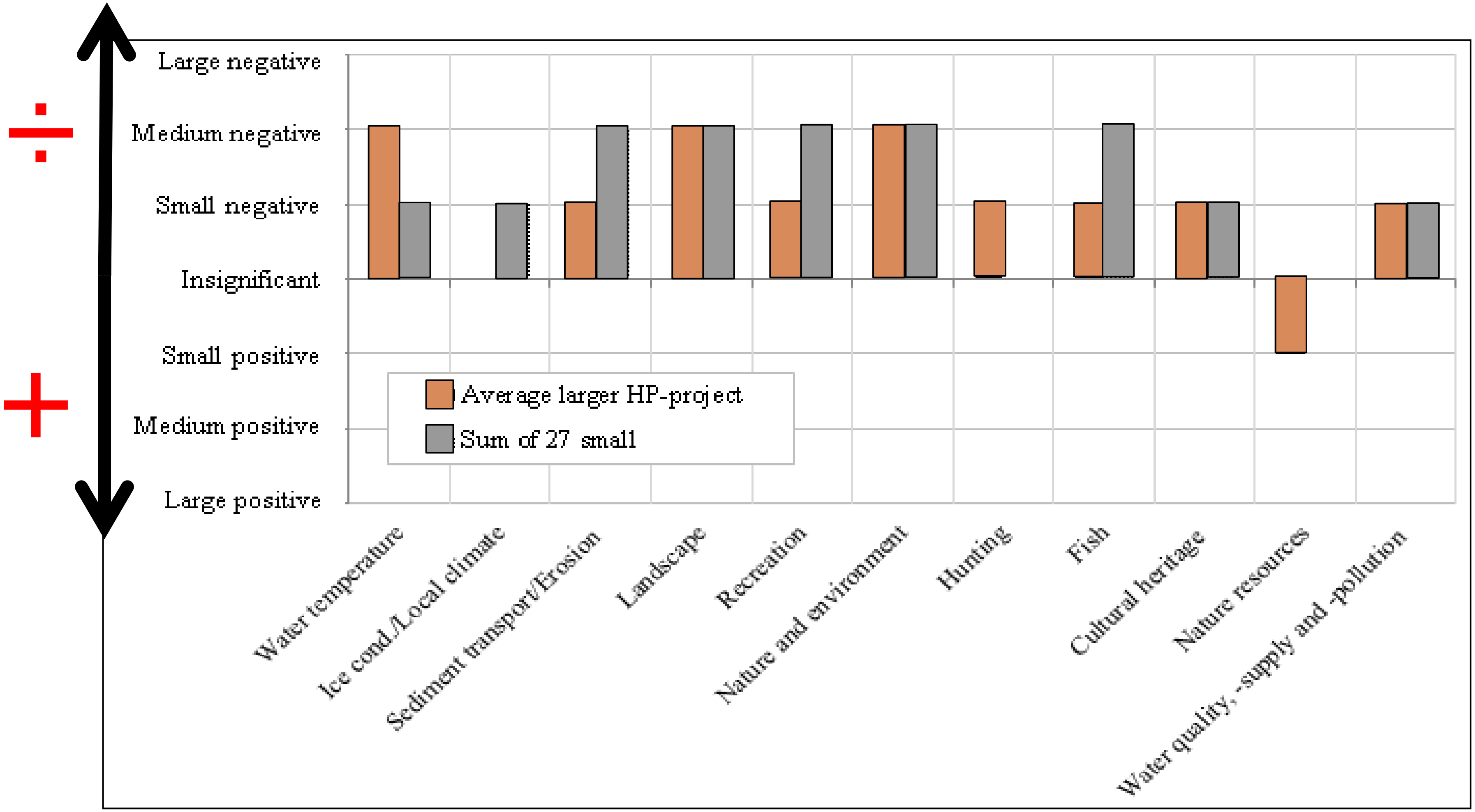
<u>XXLarge Three Gorges:</u>

- **1** huge plant
- Producing **96 TWh/a**

In order to produce the same energy output from Three Gorges project, approximately **40 000 small** hydropower plants (< 50 MW) must be constructed.

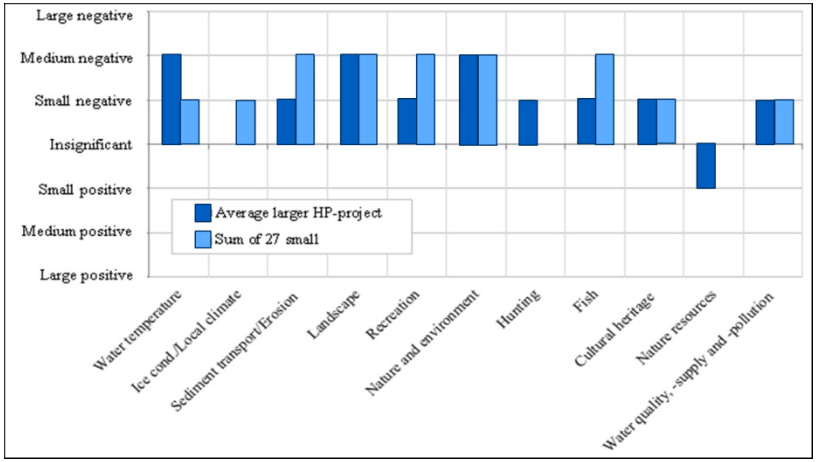
What are the accumulated environmental (and social) impacts?

Results: Comparison of impacts



Comments to the results

- Small-scale HP scores 'worse' (more negative/less positive) on the following topics:
  - Ice conditions/local climate
  - Recreation
  - Fish
  - Nature resources



- Large HP scores 'worse' (more negative) in the category water temperature
- The scores differ with only one impact level

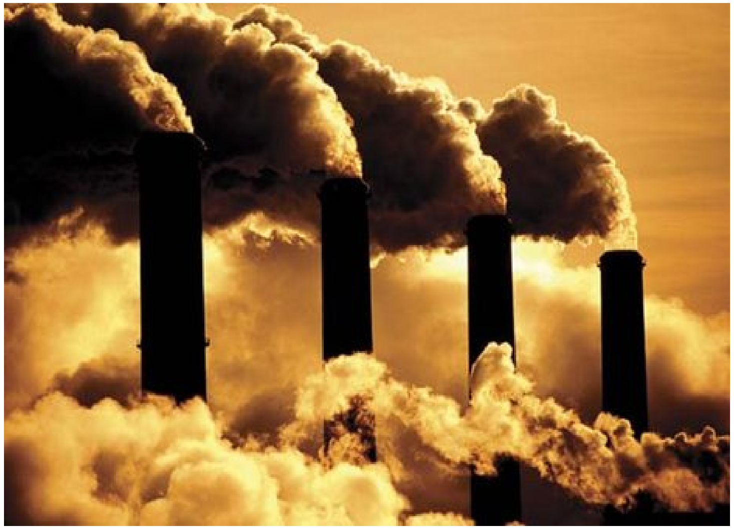
Is salmon more important than moss?

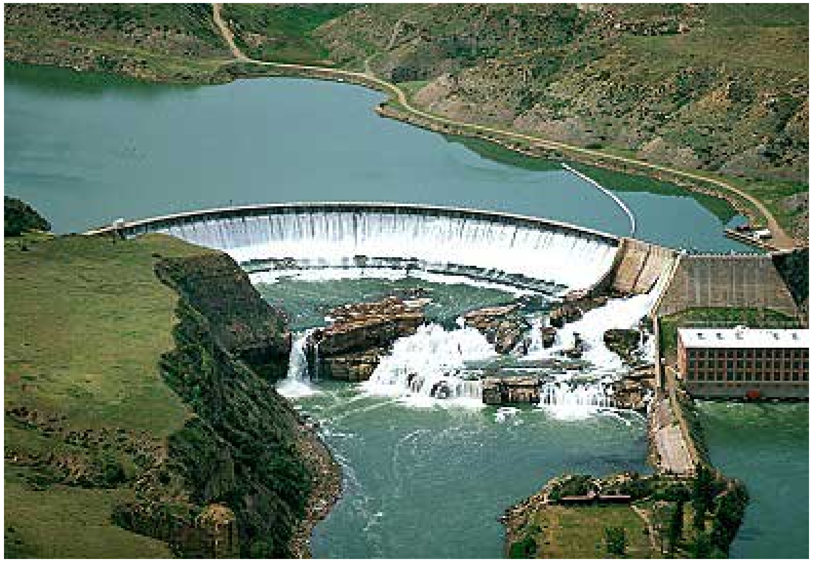
Who to assign values/priorities to the environment?

- Researchers?
- Management authorities?
- The majority?
- Other stakeholders?

Conclusions

- Rivers are smaller, shallower and narrower at the upstream end compared to the downstream end – most of the times
- Rivers are wet – if they are not dry
- Bullet points are boring....





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