HydroCen

HydroCen

NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

"The hundred year war" of Hydropower and fish migration, is history!: what do we know now and what can we do?

Ana T. Silva; Researcher, Norwegian Institute for Nature Research (NINA)

5 February 2020

NTNU SINTEF NINA Norsk institutt for naturforskning

Hundred Years' War (1337–1453)
England v.s France

Hydropower v.s Fish migration / conservation

NINA
Norwegian Institute for Nature Research

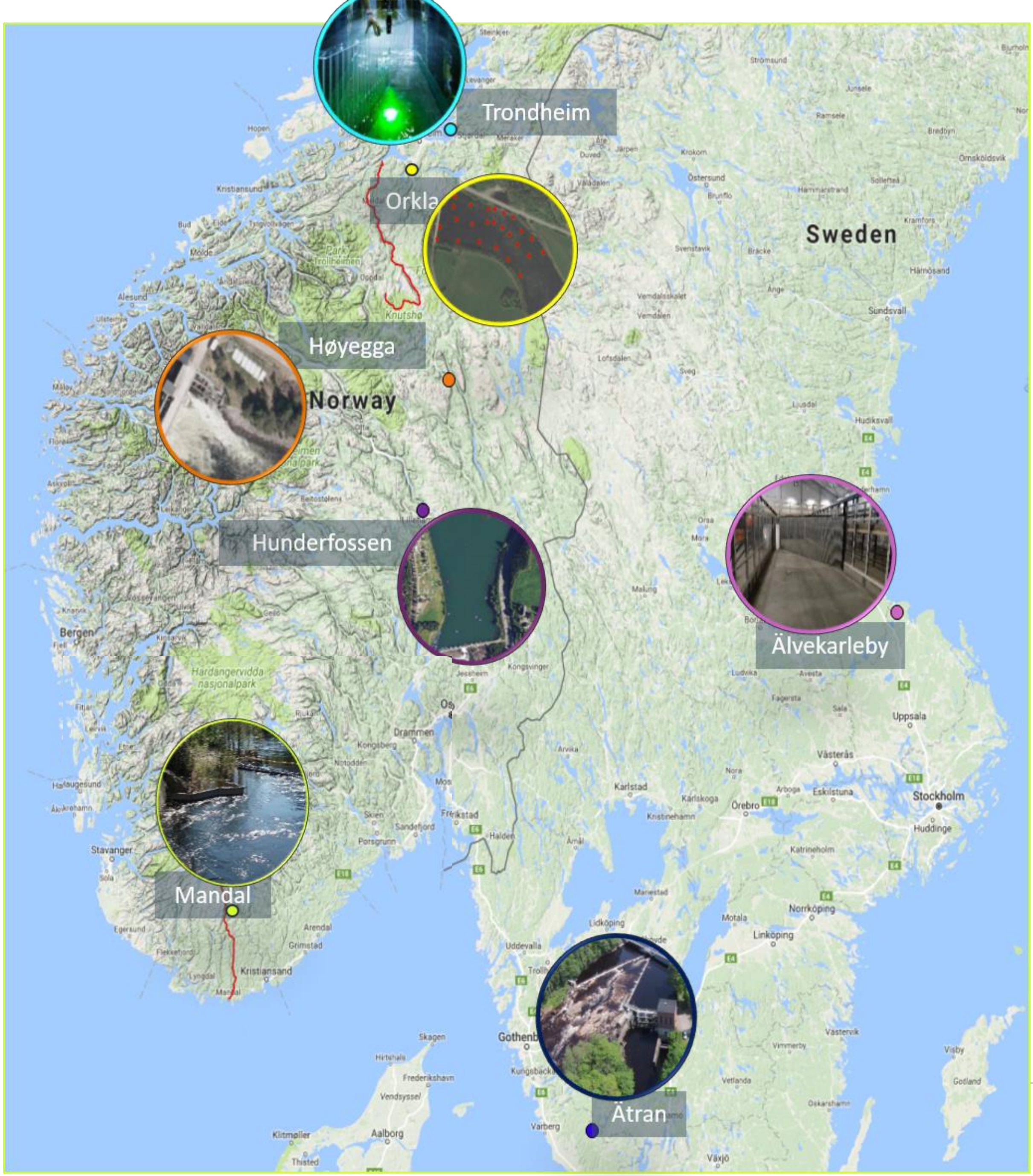
The Research Council of Norway
EnergiX program

SAFEPASS

Safe and efficient two-way migration for salmonids and European eel past hydropower structures (2015-2019)

- The largest research effort on fish migration solutions ever in Norway
- Funded by the Norwegian Research council, 12 HP-companies and management
- Approximately 25 mill NOK (2,5 mill EUR)


NSERC
CRSNG



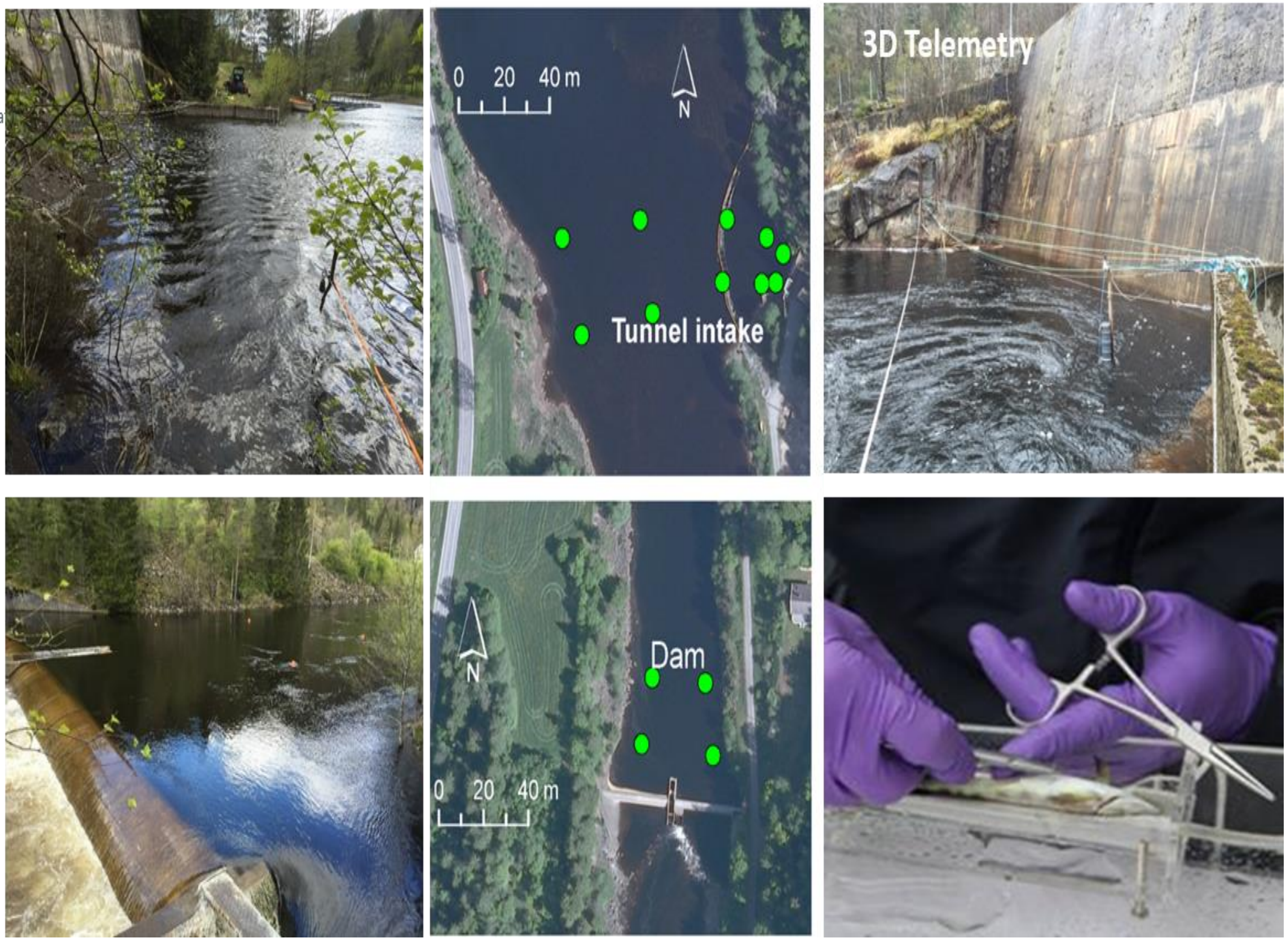
Atlantic salmon
(*Salmo salar*)

European eel
(*Anguilla anguilla*)

Brown trout
(*Salmo trutta*)

HydroCen

SWIMMING BEHAVIOUR v.s HYDRAULICS MANDAL RIVER (salmon smolts)



SSIM

YAPS

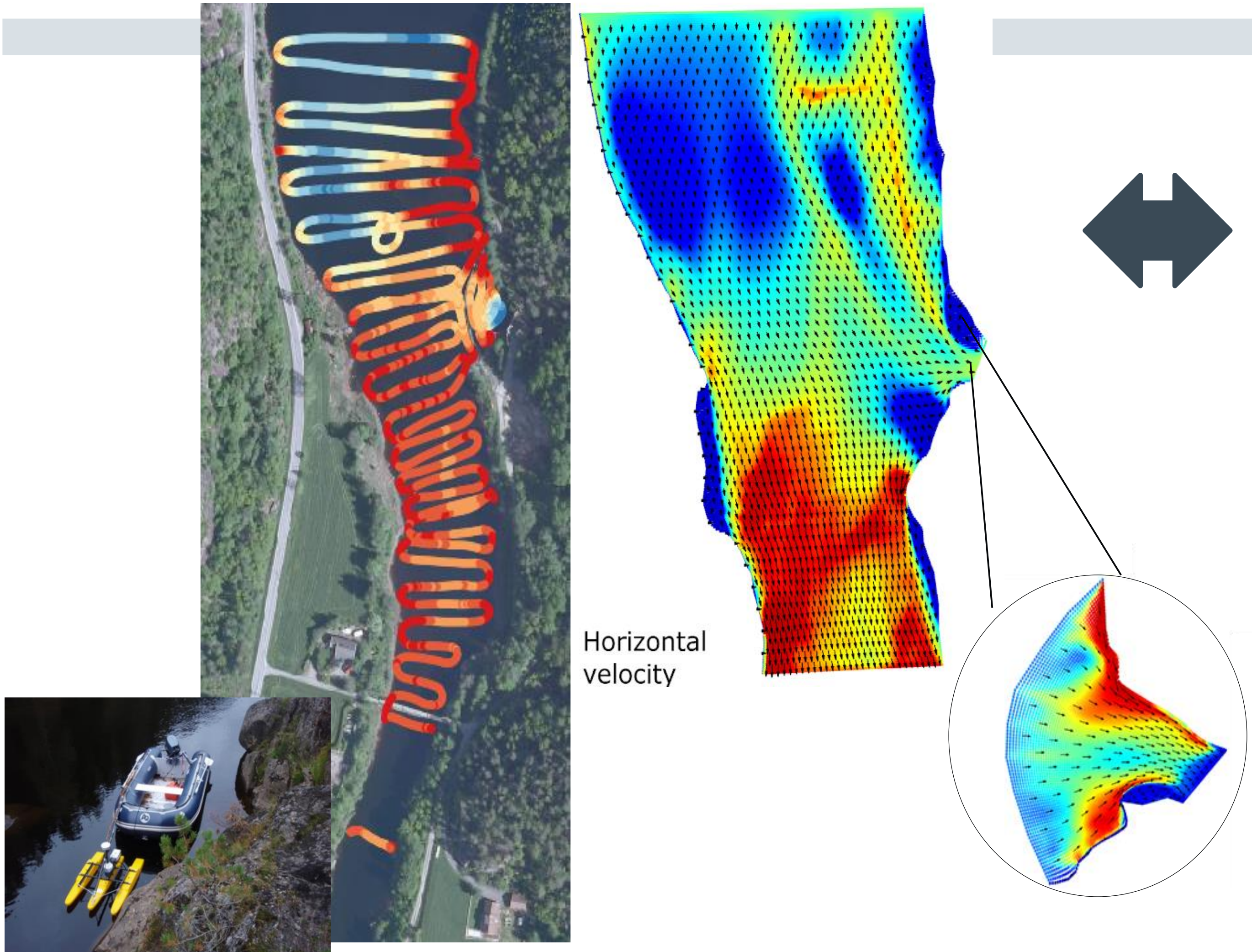
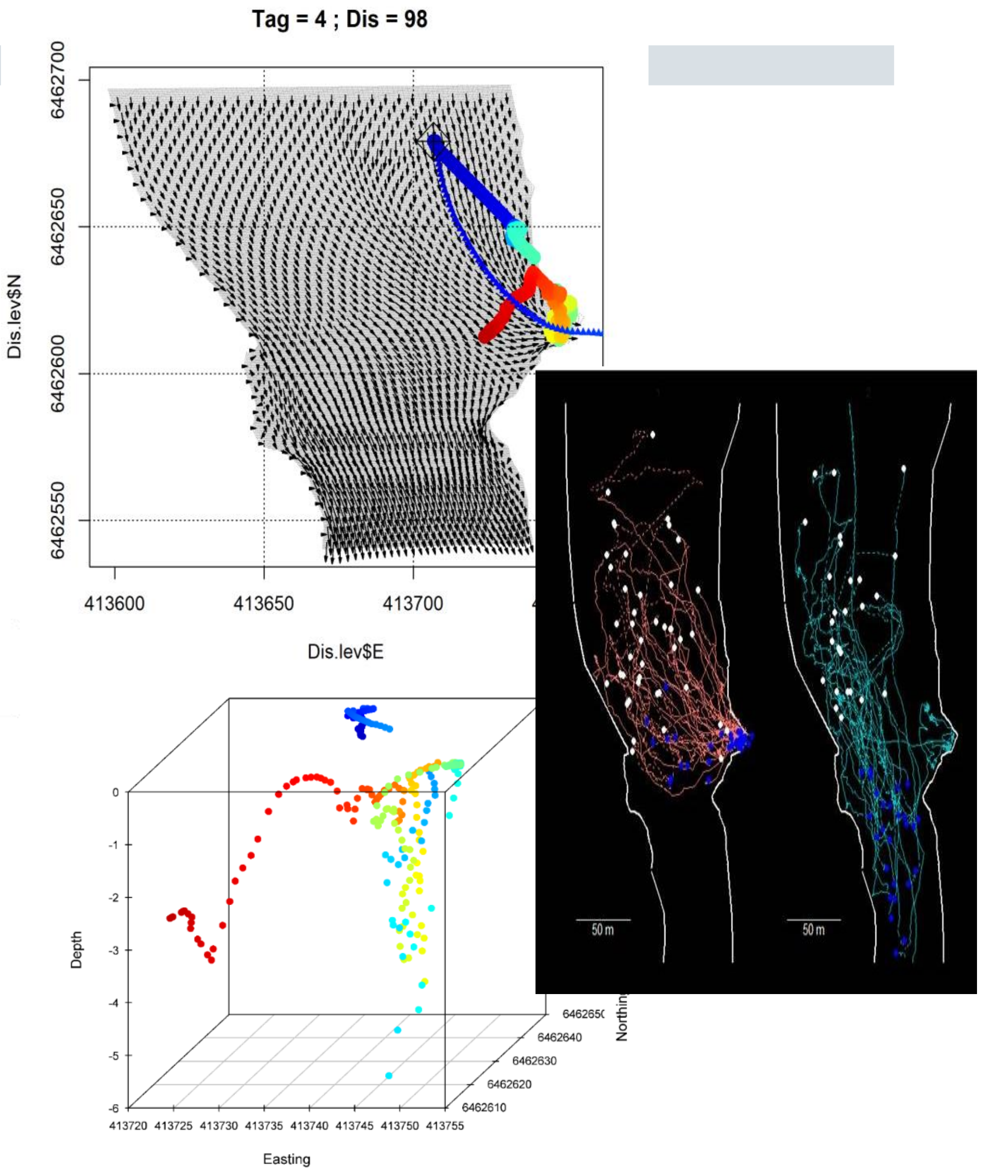
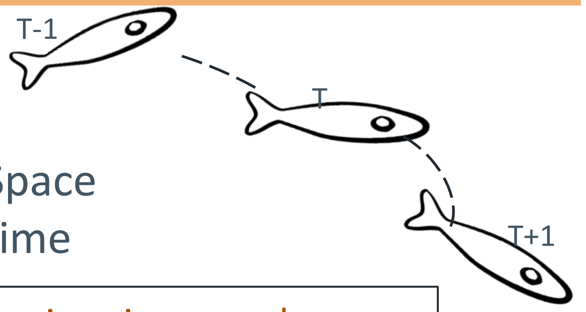


Photo: Hans-Petter F.



Hydraulics

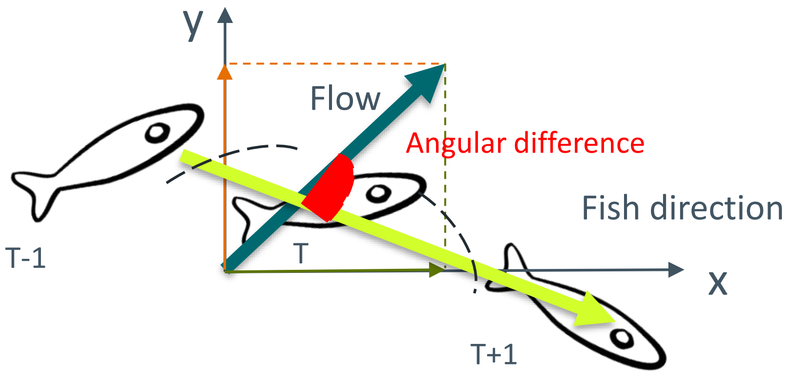
Fish swimming speed



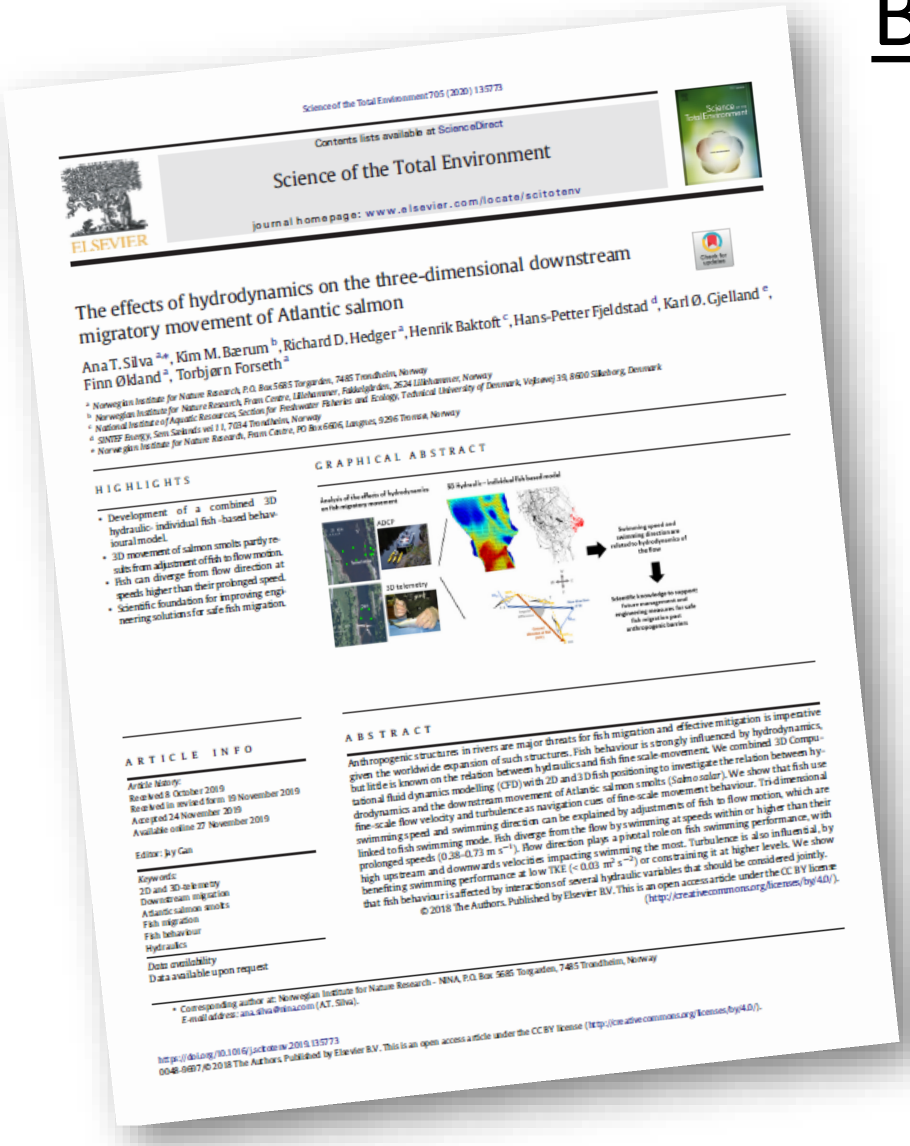
ΔSpace
Δtime

Fish swimming speed =
Groundspeed – flow speed

Fish swimming direction (angular difference)



Behavioural models for fish swimming speed and fish swimming direction



Science of the Total Environment 705 (2020) 135773

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The effects of hydrodynamics on the three-dimensional downstream migratory movement of Atlantic salmon

Ana T. Silva [a,*], Kim M. Bærum [b], Richard D. Hedger [a], Henrik Baktoft [c], Hans-Petter Fjeldstad [d], Karl Ø. Gjelland [e], Finn Økland [a], Torbjørn Forseth [a]

[a] Norwegian Institute for Nature Research, P.O. Box 5685 Torgarden, 7485 Trondheim, Norway

[b] Norwegian Institute for Nature Research, Fram Centre, Lillehammer, Fakkelgården, 2624 Lillehammer, Norway

[c] National Institute of Aquatic Resources, Section for Freshwater Fisheries and Ecology, Technical University of Denmark, Vejlsøvej 39, 8600 Silkeborg, Denmark

[d] SINTEF Energy, Sem Sælands vei 11, 7034 Trondheim, Norway

[e] Norwegian Institute for Nature Research, Fram Centre, PO Box 6606, Langnes, 9296 Tromsø, Norway

HIGHLIGHTS

- Development of a combined 3D hydraulic- individual fish -based behavioural model.
- 3D movement of salmon smolts partly results from adjustment of fish to flow motion.
- Fish can diverge from flow direction at speeds higher than their prolonged speed.
- Scientific foundation for improving engineering solutions for safe fish migration.

GRAPHICAL ABSTRACT

ADCP

3D telemetry

Swimming speed and swimming direction are related to hydrodynamics of the flow

Scientific knowledge to support future management and engineering measures for safe fish migration past anthropogenic barriers

ARTICLE INFO

Article history:
Received 8 October 2019
Received in revised form 19 November 2019
Accepted 24 November 2019
Available online 27 November 2019

Editor: Jay Gan

Keywords:
2D and 3D-telemetry
Downstream migration
Atlantic salmon smolts
Fish migration
Fish behaviour
Hydraulics

Data availability
Data available upon request

ABSTRACT

Anthropogenic structures in rivers are major threats for fish migration and effective mitigation is imperative given the worldwide expansion of such structures. Fish behaviour is strongly influenced by hydrodynamics, but little is known on the relation between hydraulics and fish fine scale-movement. We combined 3D Computational fluid dynamics modelling (CFD) with 2D and 3D fish positioning to investigate the relation between hydrodynamics and the downstream movement of Atlantic salmon smolts (*Salmo salar*). We show that fish use fine-scale flow velocity and turbulence as navigation cues of fine-scale movement behaviour. Tri-dimensional swimming speed and swimming direction can be explained by adjustments of fish to flow motion, which are linked to fish swimming mode. Fish diverge from the flow by swimming at speeds within or higher than their prolonged speeds (0.38–0.73 m s^{-1}). Flow direction plays a pivotal role on fish swimming performance, with high upstream and downwards velocities impacting swimming the most. Turbulence is also influential, by benefiting swimming performance at low TKE (< 0.03 $m^2 s^{-2}$) or constraining it at higher levels. We show that fish behaviour is affected by interactions of several hydraulic variables that should be considered jointly.

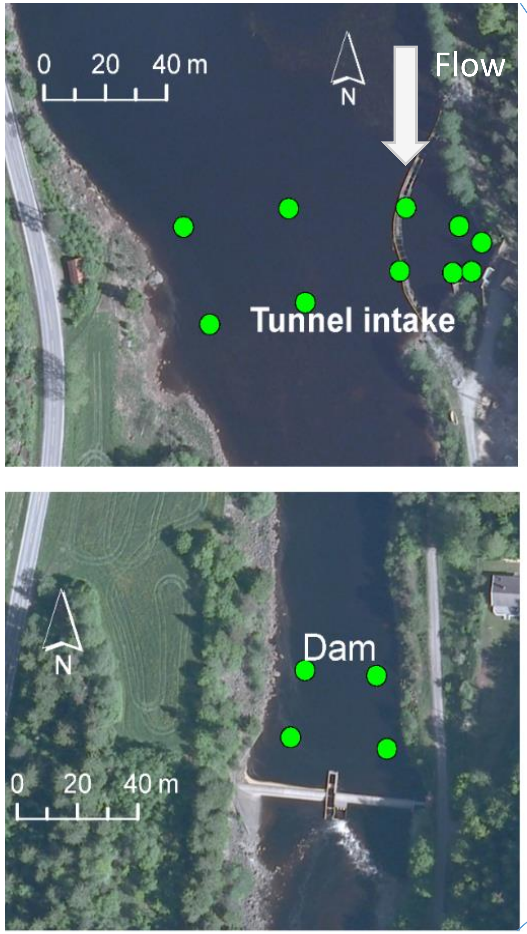
* Corresponding author at: Norwegian Institute for Nature Research - NINA, P.O. Box 5685 Torgarden, 7485 Trondheim, Norway
E-mail address: ana.silva@nina.com (A.T. Silva).

https://doi.org/10.1016/j.scitotenv.2019.135773

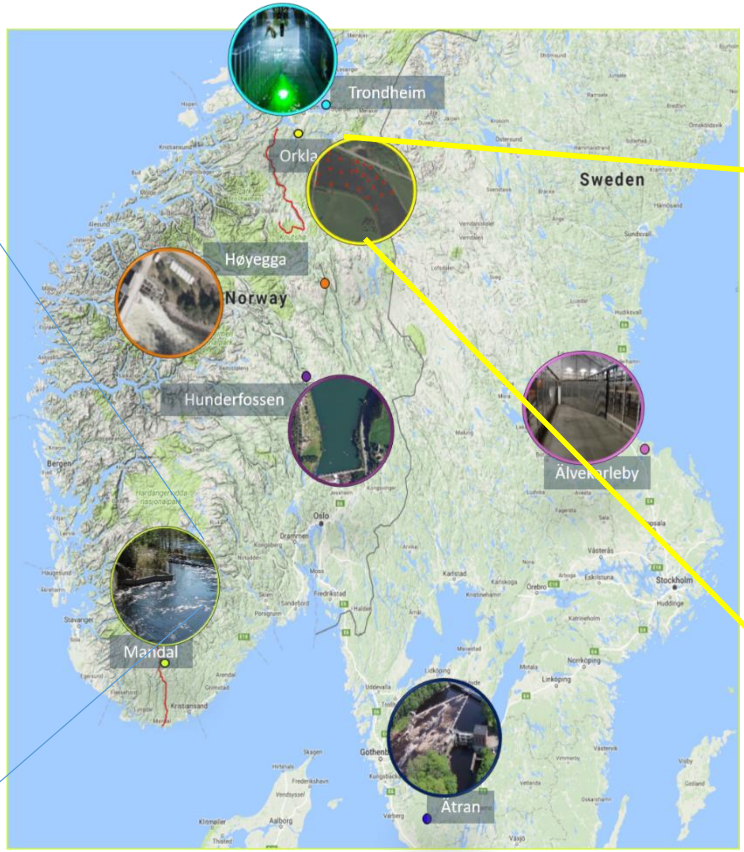
- Fish diverge from the flow at speeds higher than their sustained swimming speed (>0.38 m s^{-1})
- Direction of the flow strongly influences fish swimming behaviour
- Fish final destination depends on location of approach and percentage of flow to the tunnel

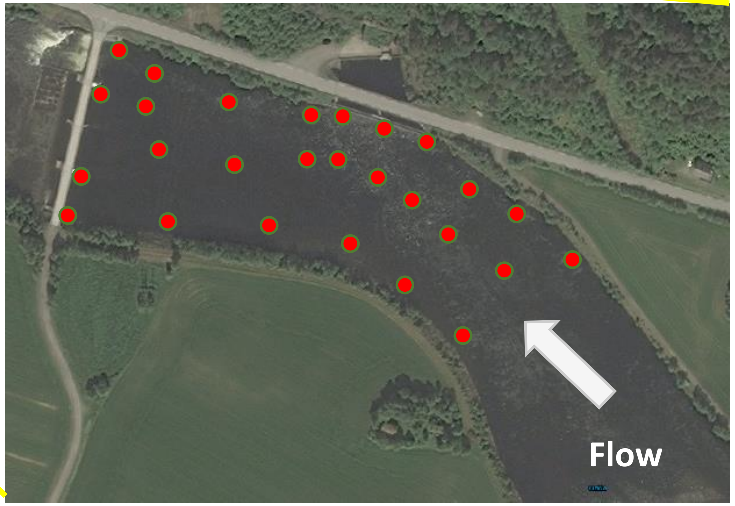
Silva, et al. 2020 The effects of hydrodynamics on the three-dimensional downstream migratory movement of Atlantic salmon, *Science of The Total Environment*, Volume 705

Validation of the models



Mandal

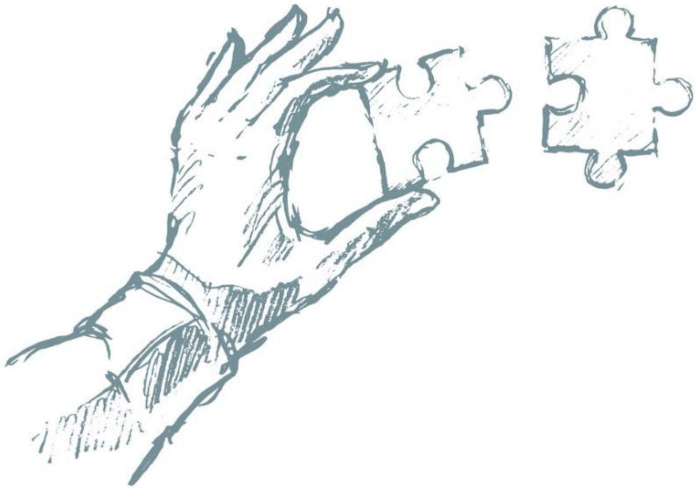




Orkla

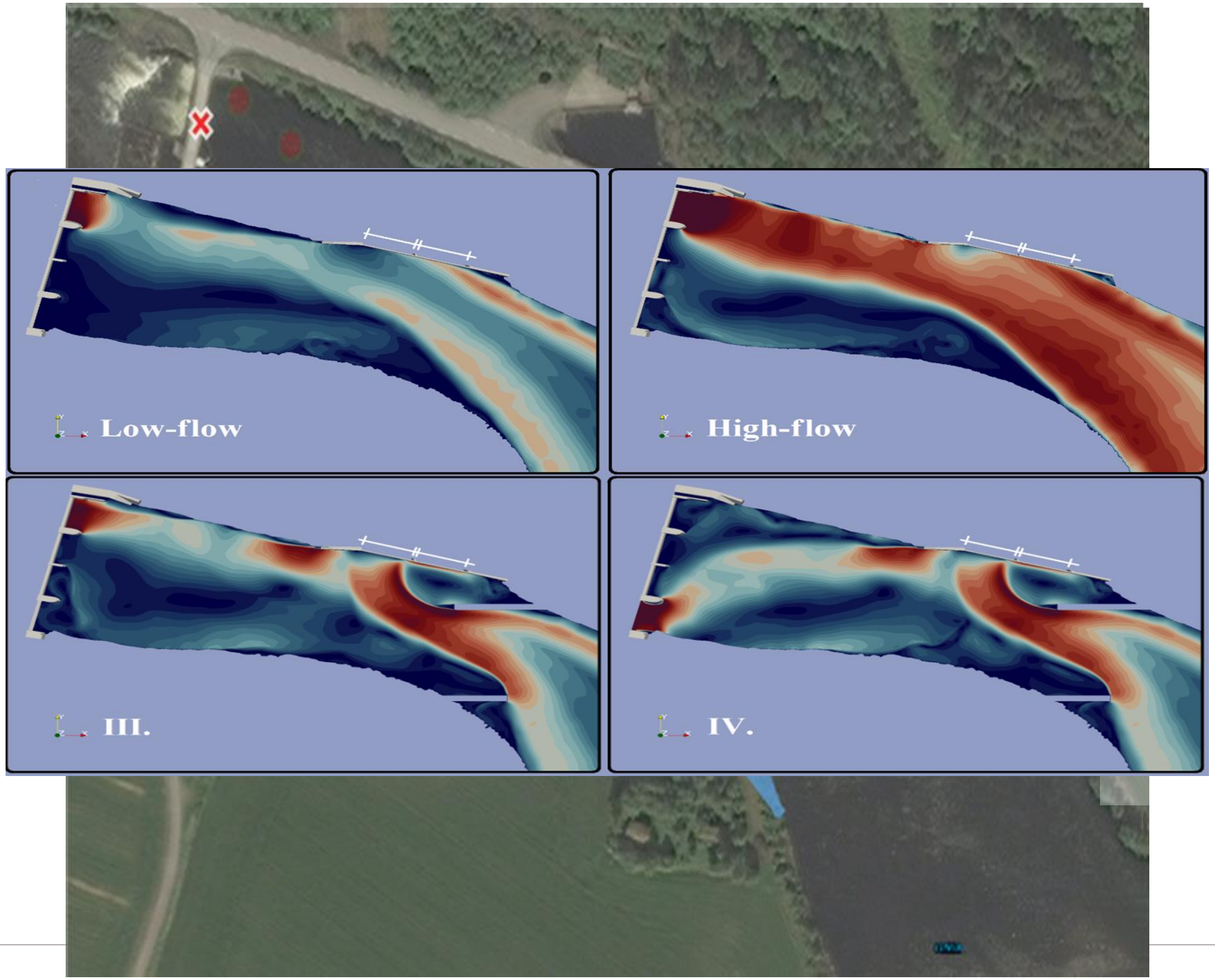
Paper in prep.

Engineering solutions for safe fish migration



Orkla river (smolts)

Mitigation measures:



Operational changes at the dam:

- Opened southern gate (AOG)

Permanent modifications:

- Spurs a.k.a: flow deflectors
- Riverbank regulation

Seasonal modification:

- Floating fish guidence booms (rack vs solid)


Received: 11 October 2018 | Revised: 16 June 2019 | Accepted: 17 June 2019
DOI: 10.1002/eco.2131

WILEY

RESEARCH ARTICLE

Modelling mitigation measures for smolt migration at dammed river sections

Marcell Szabo-Meszaros[1] | Torbjørn Forseth[2] | Henrik Baktoft[3] | Hans-Petter Fjeldstad[4] | Ana T. Silva[2] | Karl Øystein Gjelland[5] | Finn Økland[2] | Ingebrigt Uglem[2] | Knut Alfredsen[1]

[1]Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[2]Norwegian Institute for Nature Research (NINA), Trondheim, Norway
[3]National Institute of Aquatic Resources, Technical University of Denmark, Silkeborg, Denmark
[4]SINTEF Energy Research, Trondheim, Norway
[5]Norwegian Institute for Nature Research (NINA), Tromsø, Norway

Correspondence
Marcell Szabo-Meszaros, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, S. P. Andersens 5, Trondheim 7491, Norway.
Email: marcell.szabo-meszaros@ntnu.no

Funding information
Norges Forskningsråd, Grant/Award Number: 244022

Abstract

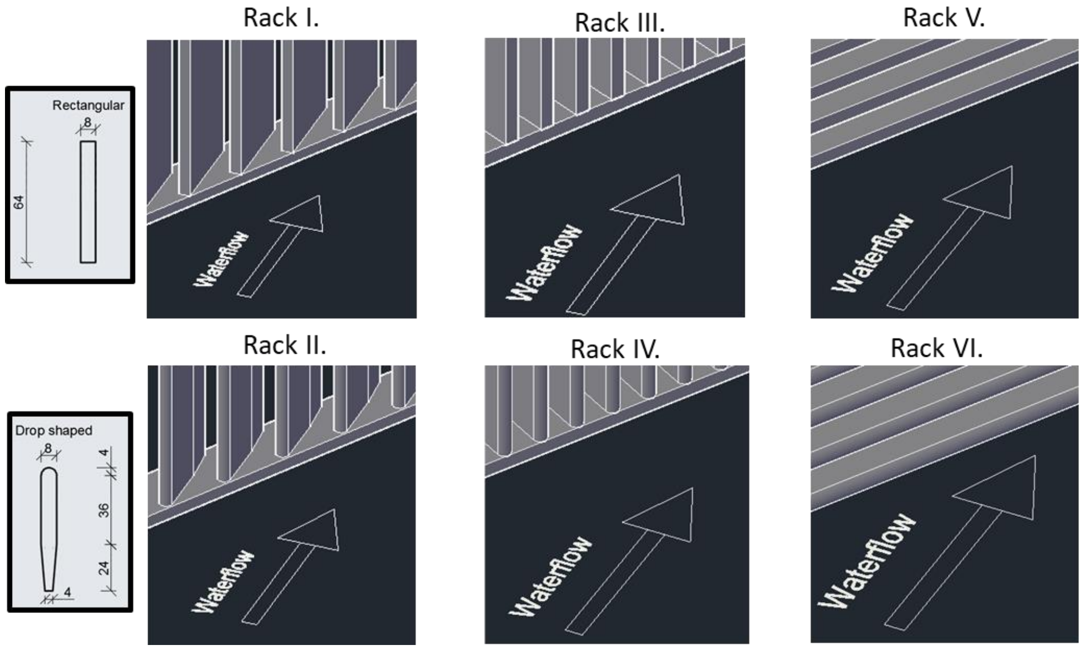
There is no generic solution to establish safe passage of downstream-migrating fish passed hydropower facilities, and mitigation measures are species and site specific. Development of solutions is thus often based on "trial and error," and modelling-based approaches may significantly reduce cost and time to arrive at successful mitigation. Here, we explore such an approach by combining data on fish migration and hydraulic modelling. First, we performed a positional telemetry study at a dammed section of a Norwegian river, where 100 Atlantic salmon smolts were tagged to track their downstream movement at the vicinity of a hydropower intake channel and bypass gates. An explanatory model was developed to explore mechanisms of migration route, into the intake towards the turbines or through the bypass gates. Next, flow conditions during the smolt run was numerically modelled to explore the physical environment of the tracked smolts. The joint results from the two approaches supported the general assumption that downstream migration is strongly influenced by flow patterns and showed that fish entering the study site closer to the riverbank where the intake channel is located were more likely to enter the intake due to the strong currents towards the intake. Finally, a suite of measures to guide salmon smolts past the hydropower intake were proposed based on the findings and local conditions and tested by hydraulic modelling. We found that most of the measures that were likely candidates for field trials would most likely fail at improving safe passage, and only a rack-type guiding boom was promising. The presented combination of telemetry migration data and hydraulic modelling illustrates the value of evaluation of mitigation measures prior to implementation.

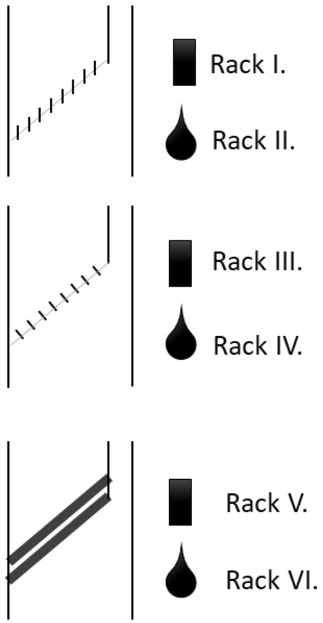
KEYWORDS
Atlantic salmon, downstream migration, ecohydraulics, hydraulic modelling, mitigation assessment

	AOS	Spurs	Riverbank	Floating booms	
				Rack	Solid
Implementation*	Low	High	High	Moderate	Moderate
Maintenance*	-	(Low)	(Low)	Moderate	Low
Effect on migration**	Neutral	Negative	Neutral	Positive	Negativ

Szabo-Meszaros, et al. (2018) Experimental hydraulics on fish-friendly trash-racks: an ecological approach. Ecological Engineering

Fish Friendly thrashracks (Lab study)






Ecological Engineering 113 (2018) 11–20
Contents lists available at ScienceDirect
Ecological Engineering
journal homepage: www.elsevier.com/locate/ecoleng

Experimental hydraulics on fish-friendly trash-racks: an ecological approach

Marcell Szabo-Meszaros[a,*], Christy Ushanth Navaratnam[a], Jochen Aberle[a,b], Ana T. Silva[c], Torbjørn Forseth[c], Olle Calles[d], Hans-Petter Fjeldstad[e], Knut Alfredsen[a]

[a] Department of Civil and Environmental Engineering, NTNU, S. P. Andersens 5, Trondheim, 7491, Norway
[b] Leichtweiß-Institut für Wasserbau, Technische Universität Braunschweig, 38106, Braunschweig, Germany
[c] Norwegian Institute for Nature Research (NINA), Høgskoleringen 9, Trondheim, 7043, Norway
[d] Department of Biology, Karlstad University, S-651 88, Karlstad, Sweden
[e] SINTEF Energy Research, Sem Sælandsvei 11, Trondheim, 7048, Norway

ARTICLE INFO

Keywords:
Flow hydrodynamics
Intake
Turbulence
V3V
Fish migration

ABSTRACT

The obstruction of fish migratory routes by hydroelectric facilities is worldwide one of the major threats to freshwater fishes. During downstream migration, fish may be injured or killed on the trash-racks or in the hydropower turbines. Fish-friendly trash-racks that combine both ecological and technical requirements are a solution to mitigate fish mortality at a low operational cost. This study presents results from an experimental investigation of head-losses and the hydrodynamic performance of six angled trash-rack types with 15 mm bar spacing, varying bar-setup (vertical-streamwise, vertical-angled and horizontal bars) and bar profiles (rectangular and drop shape) under steady flow conditions. The trash-racks were positioned at 30° to the wall of the flume and combined with a bypass at their downstream end. The impact of the different trash-rack types on the upstream flow field was characterized using Image based Volumetric 3-component Velocimetry (V3V) and at the bypass-entrance using an Acoustic Doppler Velocimeter (ADV). The results show that trash-racks with vertical-streamwise and horizontal oriented bars with drop-shape profiles have similar head-losses (13% difference), while trash-racks with vertical-angled bars provide 3–8 times larger head-losses compared to the remaining configurations. The velocity measurements showed that the highest flow velocities occurred for configurations with vertical-angled bars (0.67 m s^{-1} and 0.81 m s^{-1} on average, respectively). Turbulence related parameters (e.g. Reynolds shear stresses and Turbulent kinetic energy) were also investigated to evaluate the performance of the alternative trash-racks from both, engineering and ecological perspectives.

1. Introduction

River fragmentation by hydroelectric facilities is a well-known phenomenon affecting native migratory fish (Larinier, 2001). For example, the populations of anadromous Atlantic salmon (*Salmo salar*) and the endangered catadromous European eel (*Anguilla Anguilla*) decreased significantly in Europe due to the hydropower dams (Hindar et al., 2003; ICES, 2001). This problem is typically associated with the demanding passage through the artificial barriers in both up- and downstream directions (Calles and Greenberg, 2009; Larinier, 2008; Lundqvist et al., 2008; Martignac et al., 2013). During downstream migration, fish face diverted paths as the streamflow is divided at the intake of a hydropower plant (HPP). The entrance to the intake channel is in most cases equipped with trash-racks to protect the turbines from debris, sediment and floating ice (Mosonyi, 1991). They are typically perpendicularly oriented to the flow with 50–150 mm bar spacing (Mosonyi, 1991) and can therefore, besides their operational purpose,

be used to prevent larger fish from entering the intake of a HPP. The trash-racks can affect migrating fish as they delay migration significantly or cause injuries, sometimes lethal, depending on the size and type of the HPP and its intake structures (Bruijs and Durif, 2009). The mortality associated with hydropower intakes and turbines may be high when fish are either small enough to swim/drift through the trash-rack bars and pass through the turbines or large enough to be pinged onto the trash-rack surface in cases when the approach flow exceeds their swimming capability (Adam and Bruijs, 2006). One solution is the adoption of alternative designs of trash-racks, which prevents both rack passage, impingement and guide the fish towards a bypass (Calles et al., 2013).

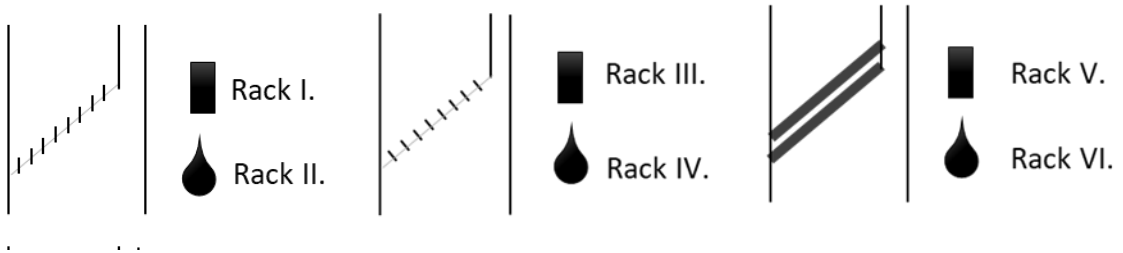
Several studies have explored different fish friendly trash-racks designs (Amaral et al., 2002; Boubee and Williams, 2006; Larinier, 2008). One approach is to reduce the bar spacing to prevent juvenile fish from passing through the bars (Bruijs and Durif, 2009), another is to incline the trash-racks from the bottom (so called inclined trash-

* Corresponding author.
E-mail address: marcell.szabo-meszaros@ntnu.no (M. Szabo-Meszaros).

https://doi.org/10.1016/j.ecoleng.2017.12.032
Received 3 July 2017; Received in revised form 18 December 2017; Accepted 22 December 2017

Considering		Rack I.	Rack II.	Rack III.	Rack IV.	Rack V.	Rack VI.
Operation cost	to build	+	+	−		−	
	to maintain			+	+	−	−
	revenue decline		+	−	−		+
Bypass	velocities		+	−	−		+
	accelerations		+	−	−		+
Upstream side (PIV)	vel. distribution	+	+		−		
	accelerations		+		−		
	turbulence				−		+

Rack label



Marcell Szabo-Meszaros et al, 2018. Experimental hydraulics on fish-friendly trash-racks: an ecological approach. Ecological Engineering, 113, Pages 11-20,

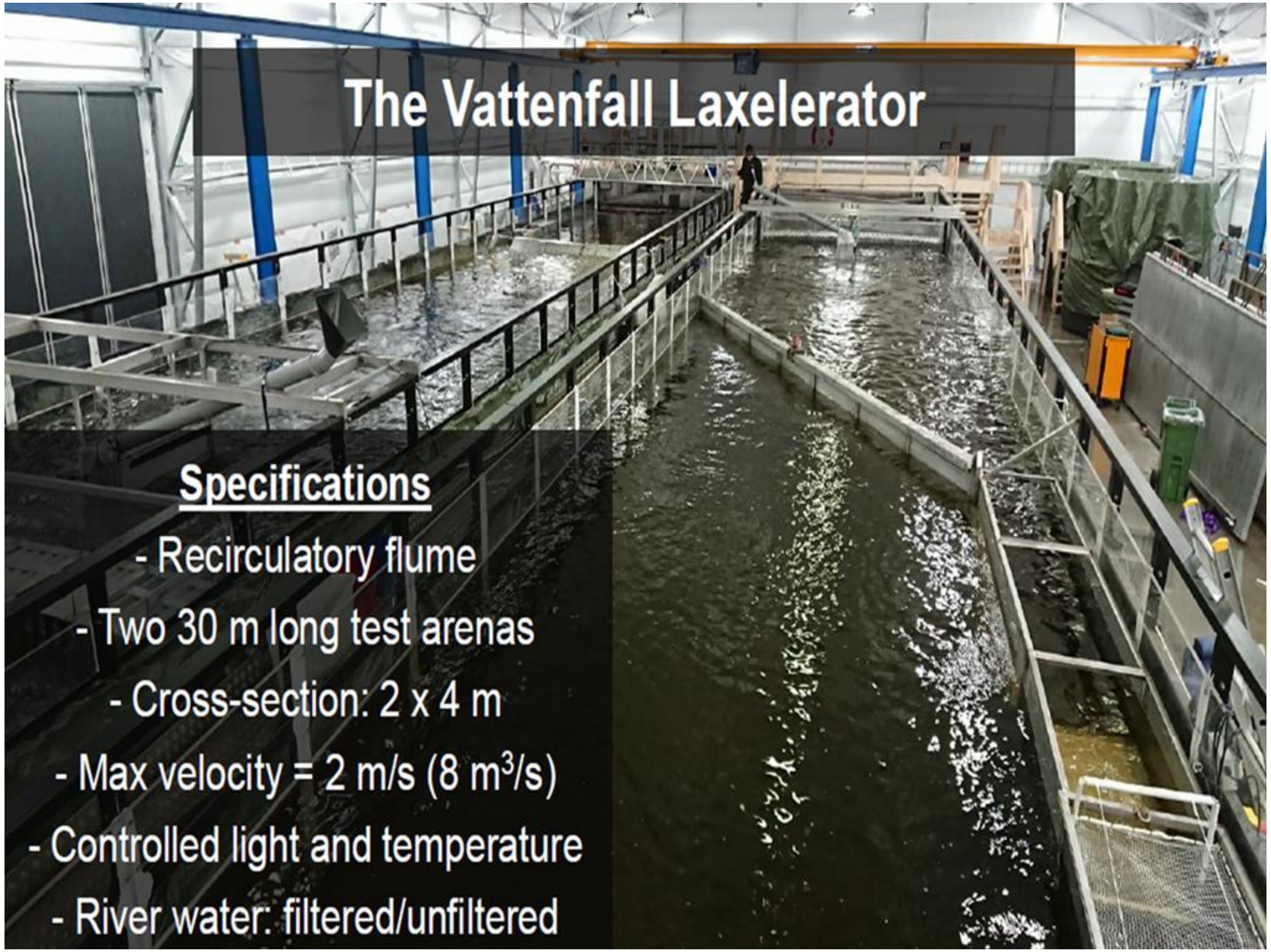
HydroCen

SAFEPASS

VATTENFALL

KARLSTAD UNIVERSITY

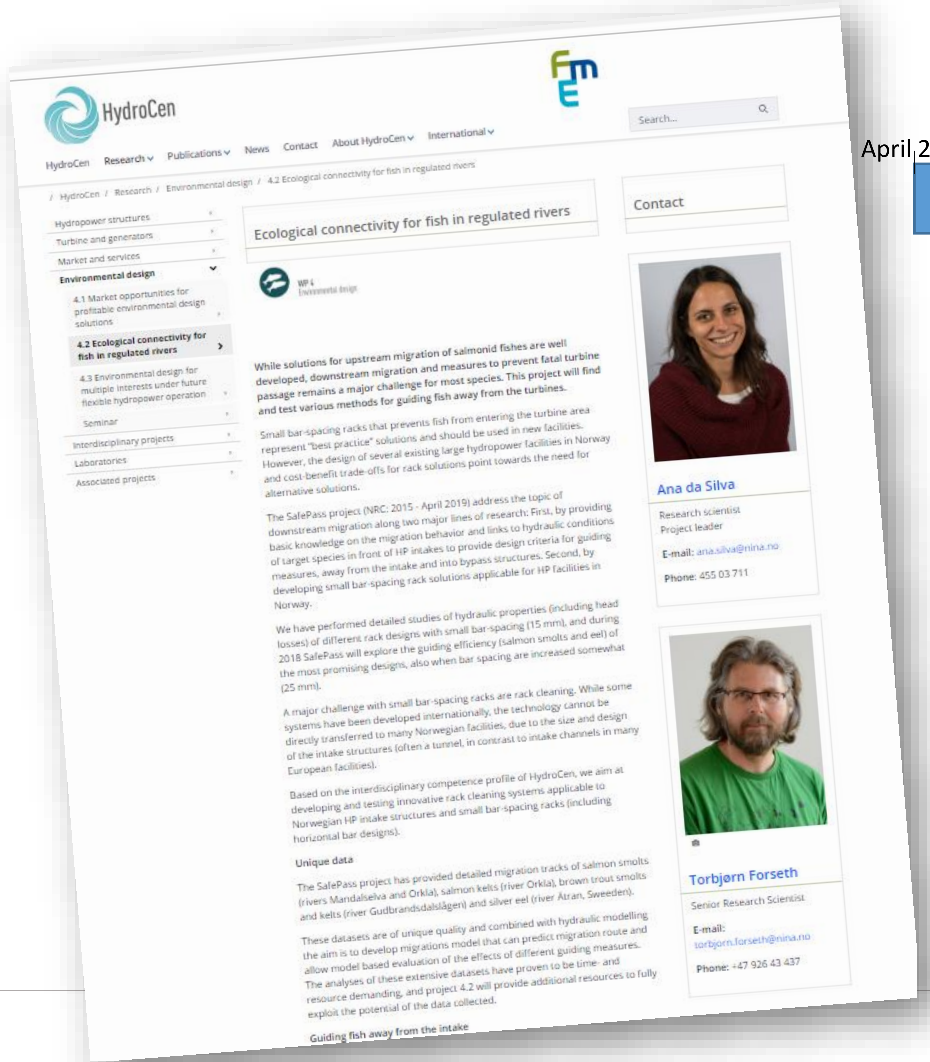
KAU.SE EDUCATION FUTUR



FISH GUIDING STRUCTURES

HydroCen

HYDROCEN



HydroCen

HydroCen | Research | Publications | News | Contact | About HydroCen | International

Search...

/ HydroCen / Research / Environmental design / 4.2 Ecological connectivity for fish in regulated rivers

- Hydropower structures
- Turbine and generators
- Market and services
- Environmental design
  - 4.1 Market opportunities for profitable environmental design solutions
  - 4.2 Ecological connectivity for fish in regulated rivers
  - 4.3 Environmental design for multiple interests under future flexible hydropower operation
  - Seminar
- Interdisciplinary projects
- Laboratories
- Associated projects

Ecological connectivity for fish in regulated rivers

While solutions for upstream migration of salmonid fishes are well developed, downstream migration and measures to prevent fatal turbine passage remains a major challenge for most species. This project will find and test various methods for guiding fish away from the turbines.

Small bar-spacing racks that prevents fish from entering the turbine area represent "best practice" solutions and should be used in new facilities. However, the design of several existing large hydropower facilities in Norway and cost-benefit trade-offs for rack solutions point towards the need for alternative solutions.

The SafePass project (NRC: 2015 - April 2019) address the topic of downstream migration along two major lines of research: First, by providing basic knowledge on the migration behavior and links to hydraulic conditions of target species in front of HP intakes to provide design criteria for guiding measures, away from the intake and into bypass structures. Second, by developing small bar-spacing rack solutions applicable for HP facilities in Norway.

We have performed detailed studies of hydraulic properties (including head losses) of different rack designs with small bar-spacing (15 mm), and during 2018 SafePass will explore the guiding efficiency (salmon smolts and eel) of the most promising designs, also when bar spacing are increased somewhat (25 mm).

A major challenge with small bar-spacing racks are rack cleaning. While some systems have been developed internationally, the technology cannot be directly transferred to many Norwegian facilities, due to the size and design of the intake structures (often a tunnel, in contrast to intake channels in many European facilities).

Based on the interdisciplinary competence profile of HydroCen, we aim at developing and testing innovative rack cleaning systems applicable to Norwegian HP intake structures and small bar-spacing racks (including horizontal bar designs).

Unique data

The SafePass project has provided detailed migration tracks of salmon smolts (rivers Mandalselva and Orkla), salmon kelts (river Orkla), brown trout smolts and kelts (river Gudbrandsdalslågen) and silver eel (river Ätran, Sweeden).

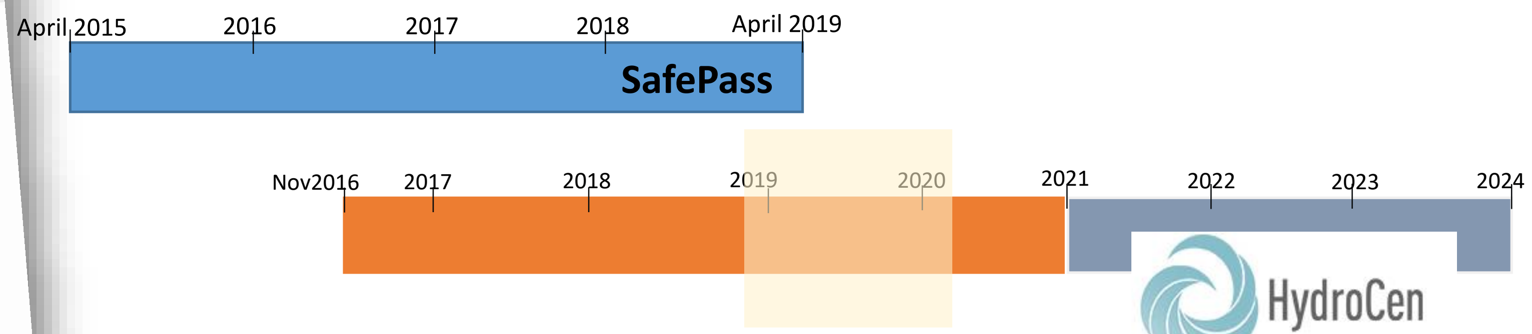
These datasets are of unique quality and combined with hydraulic modelling the aim is to develop migrations model that can predict migration route and allow model based evaluation of the effects of different guiding measures. The analyses of these extensive datasets have proven to be time- and resource demanding, and project 4.2 will provide additional resources to fully exploit the potential of the data collected.

Guiding fish away from the intake

Contact

Ana da Silva
Research scientist
Project leader
E-mail: ana.silva@nina.no
Phone: 455 03 711

Torbjørn Forseth
Senior Research Scientist
E-mail: torbjorn.forseth@nina.no
Phone: +47 926 43 437



WP 4
Environmental design

4.2. Ecological connectivity for fish in regulated rivers

Collaboration and augmentation are the foundational principles of innovation.

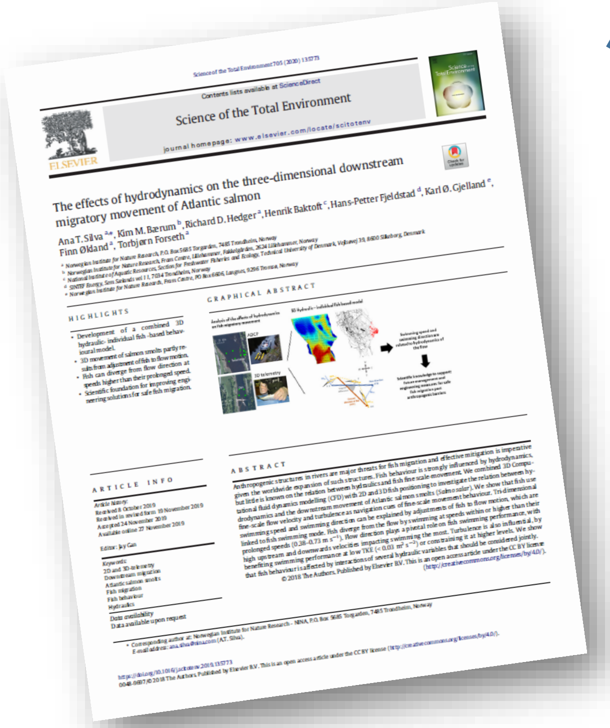
Vaclav Smil

National (Norway) Collaboration

International Collaboration

FROM THEORY TO PRACTICE

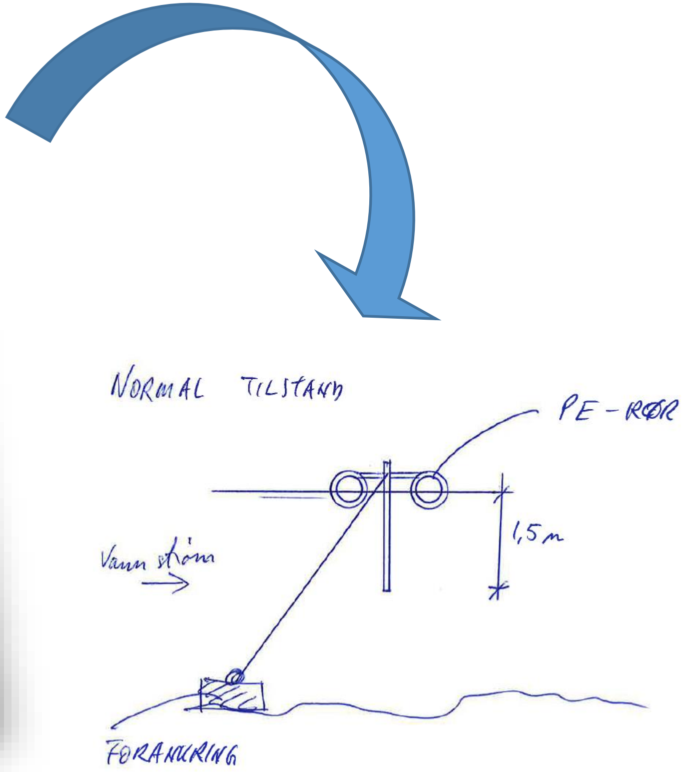
ETH zürich
Department of Civil, Environmental and Geomatic Engineering
Laboratory of Hydraulics, Hydrology and Glaciology

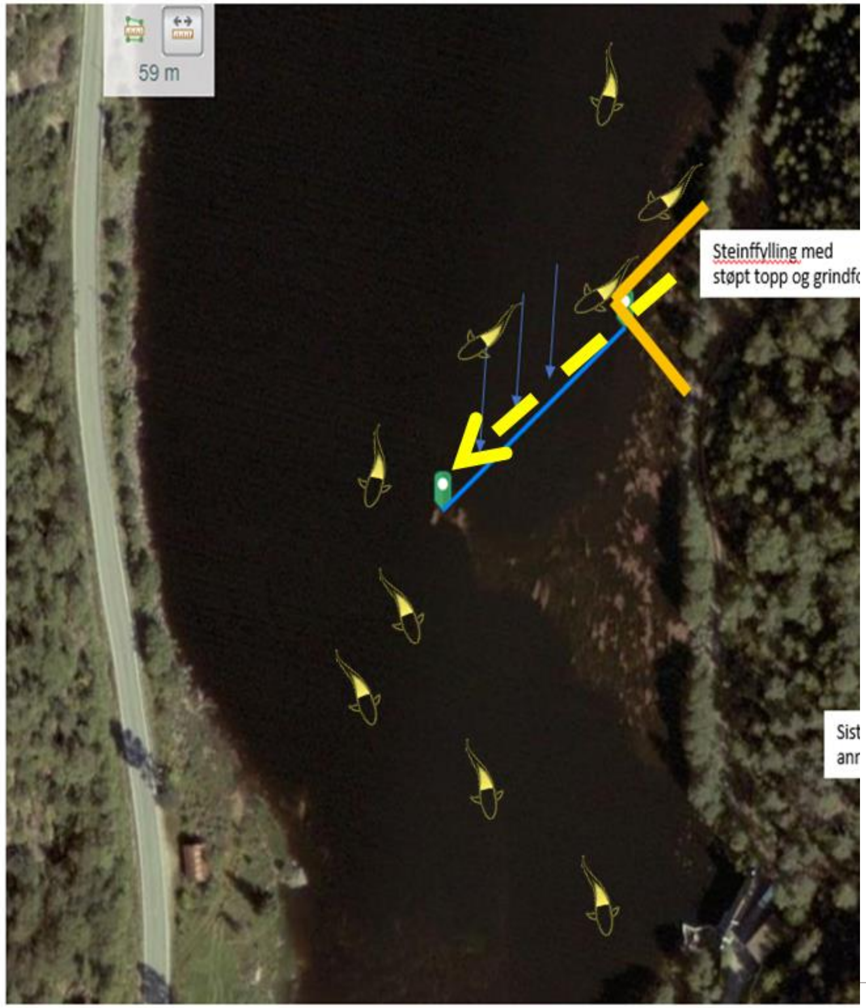


Science of the Total Environment 705 (2020) 135773
Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

The effects of hydrodynamics on the three-dimensional downstream migratory movement of Atlantic salmon

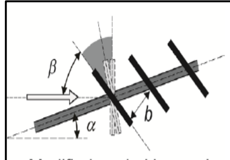
Ana T. Silva, Kim M. Bærum, Richard D. Hedger, Henrik Baktoft, Hans-Petter Fjeldstad, Karl Ø. Gjelland, Finn Økland, Torbjørn Forseth



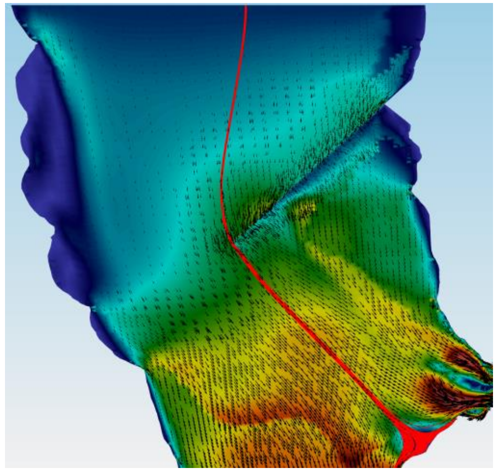


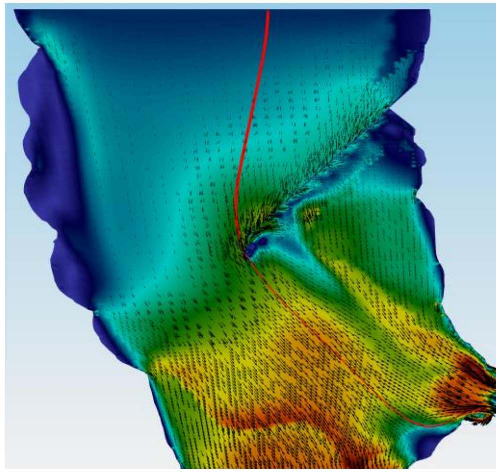
Guidance structure

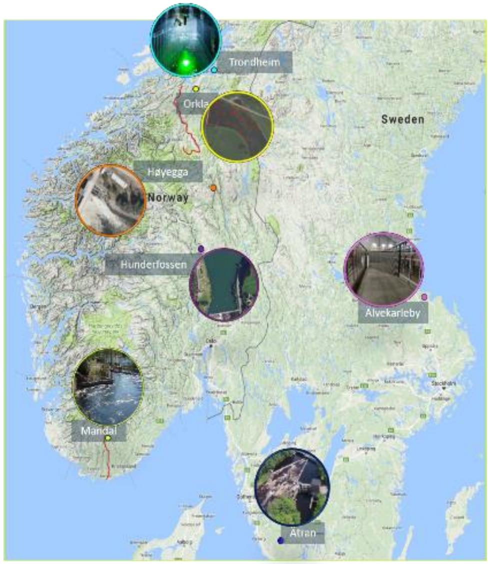
- ~ 62 m long (several panels)
- 1.5m deep
- Bar space: 50 mm
- Bar thickness: 10mm
- Bar length : 100 mm
- Bar type : angled bar rack (90) or modified angled bar rack



Modified angled bar rack







Predict fish movement
(Individual based model)

Improvement of future management and engineering solutions for safe fish migration

Dr. R. Andrew Goodwin

Future opportunities for collaborative work with USA

Thank you!

ana.silva@nina.no

HydroCen

FME

www.hydrocen.no
Twitter: @FMEHydroCen
LinkedIn: HydroCen
Flickr: HydroCen

Office:
The Waterpower Laboratory, NTNU
Alfred Getz vei 4
Gløshaugen, Trondheim

NTNU SINTEF NINA Norsk institutt for naturforskning NVKS NORSK VANNKRAFTSENTER