Emerging mitigation measures and strategies are needed for riverine ecology to ensure sustainable hydropeaking production in Norway

J. H. Halleraker[1,2], M. S. R. Kenawi[1], J. H. L'Abée - Lund[3], Anders G. Finstad[4] , T. H. Bakken[1] & K. Alfredsen[1]

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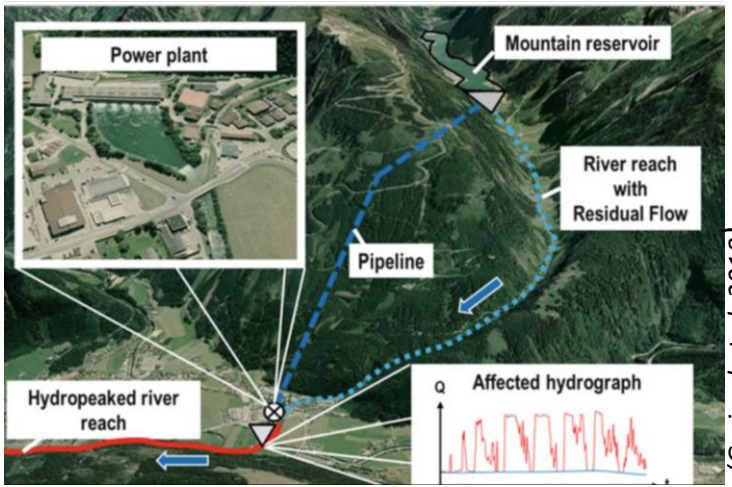
1. SusFlow

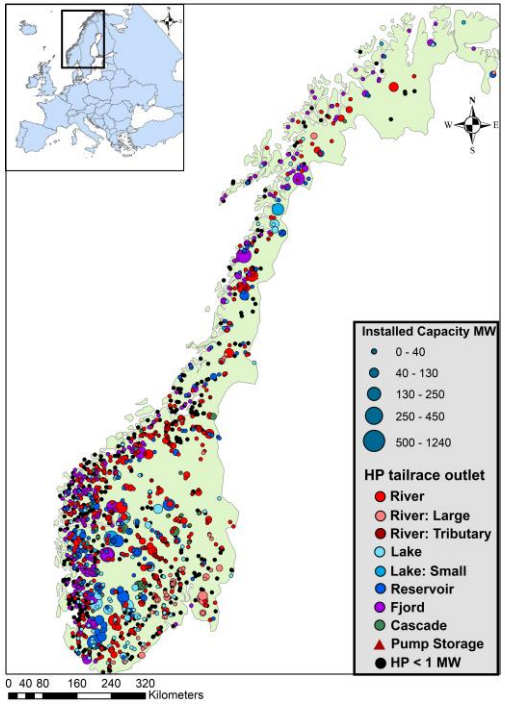
Flow alteration and ecology

EcoPeak - subdaily flow fluctuations

7 SUSTAINABLE ENERGY



(Greimel et al, 2018)



EGU General Assembly 2021

Sub-session Sustainable renewable energy (ERE5.3)

NTNU

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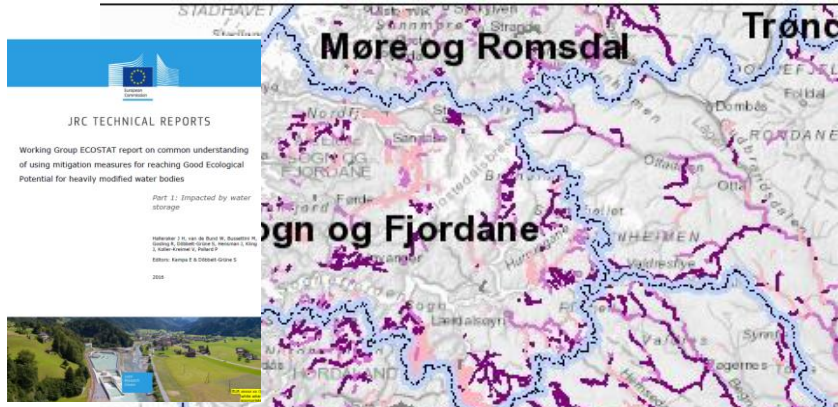
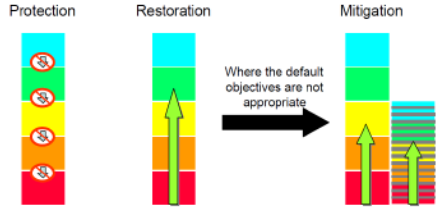
NORWEGIAN ENVIRONMENT AGENCY

Objectives

The emphasise on **downstream water** bodies from hydro turbines operation

- i) ecological risk assessment of **flow ramping**
- ii) relate key findings to management objectives
- ii) evaluate **mitigation measures**
- iv) recommend evidence based management strategies





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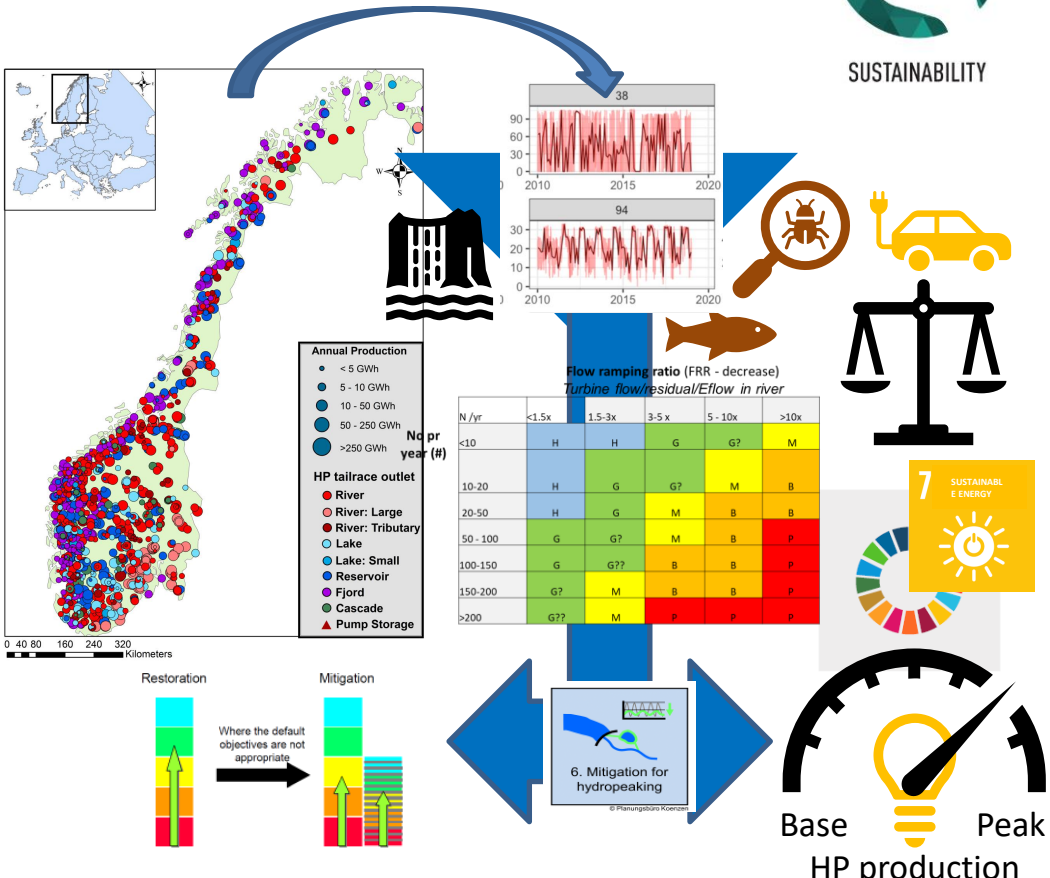
Key steps in the ecological risk assessment

1. Hydro Power (HP) **CHARACTERISTICS**
   - Type and locations of outlets
   - Storage scheme vs RoR HP
   - Max turbine Q
2. **VULNERABILITY:** Ecological sensitivity/ risks
   - Abiotic - water body characteristics
   - Biological conditions
3. **PRESSURE - IMPACTS:** Mode of operation vs efficiency of mitigations
   - Analysis of flow ramping intensity – Q-indicators
   - Multiple pressure modelling
   - Functionality and pending mitigation measures
4. **MITIGATION:** Monitoring and scoring of ecological restoration vs energy potential

- Identification of pending relevant measures as basis for **sustainability evaluation**

	All sizes		>10 MW		1.1-10 MW		<1 MW	
HP tailrace outlets	**n**	**%**	n	%	n	%	n	%
In rivers (> 1 km)	785	51 %	157	47 %	339	50 %	289	56 %
"small lakes"	17	1 %	6	2 %	9	1 %	2	0 %
In lakes/reservoirs	370	24 %	113	34 %	159	23 %	98	19 %
In fjords	359	23 %	56	17 %	174	26 %	129	25 %
Total no	1531		332		681		518	



EcoHydro water body database *N >1690 HPs*

Water body
→ River or Lake or Fjord

Mitigation measures
Eflows, BPV, ORR

N= >1250 , 98, 350

Storage/RoR regimes
MW/GWh
Tailrace water

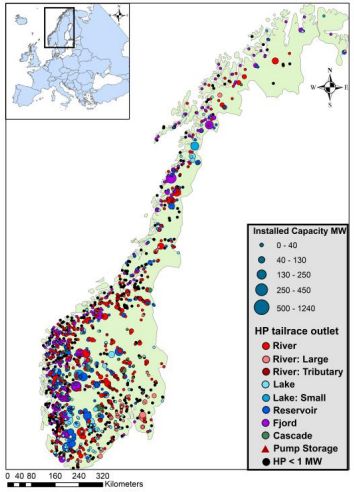
Flow ramping
assessment
Turbine flow

River lengths
By-passed reaches

WFD-data

EcoStatus
Env objectivs
Pending measures

Key species;
Grayling, trout,
anadrome spp,
catadrome spp



SUSTAINABILITY

Norwegian HP outlets

	All *(excl P, PK/cascade/unclassified)*							
	All sizes		**>10 MW**		**1.1-10 MW**		**<1 MW**	
HP tailrace outlet	**N**	**%**	K	%	KS	%	M	%
In rivers (> 1 km)	**785**	**51 %**	**157**	**47 %**	**339**	**50 %**	**289**	**56 %**
"small lakes"	**17**	**1 %**	6	2 %	9	1 %	2	0 %
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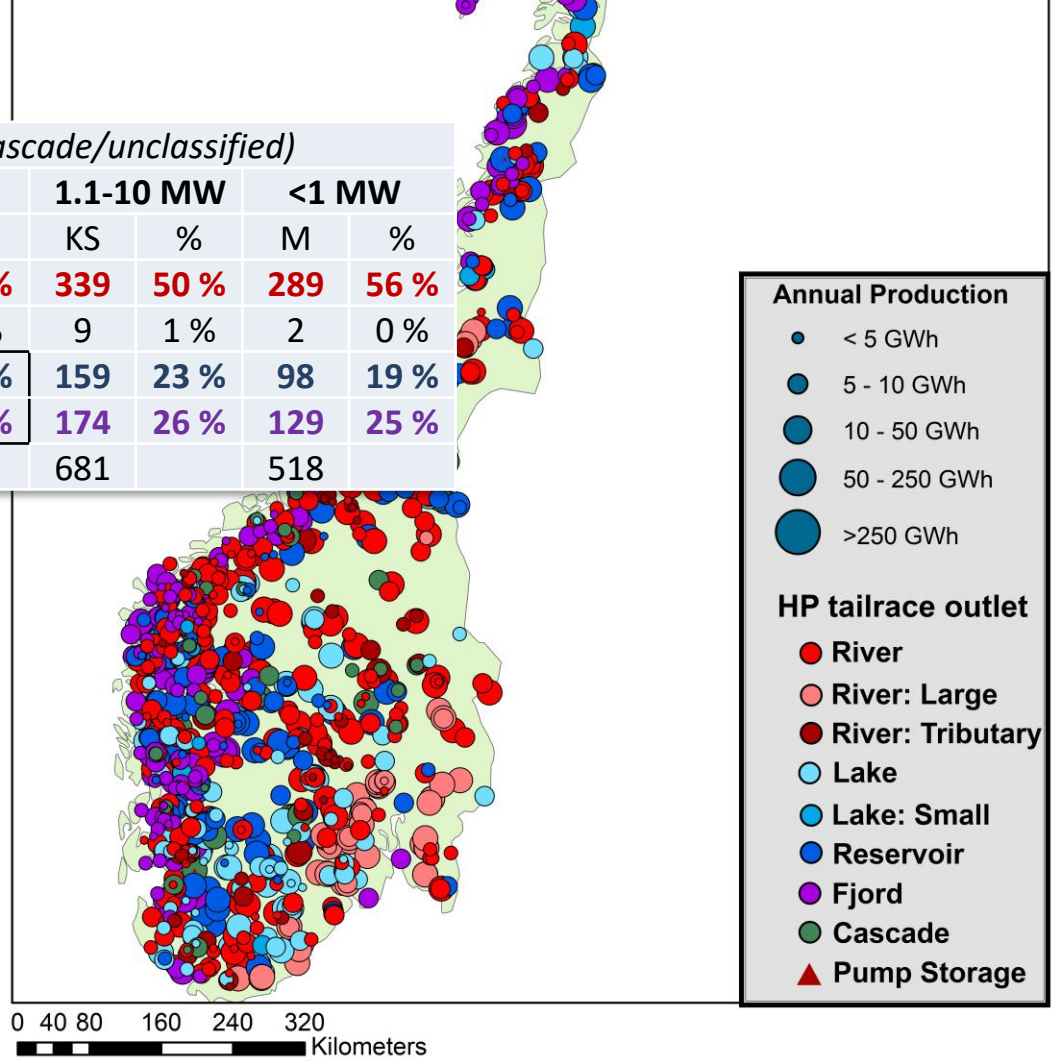


Halleraker et al., in prep

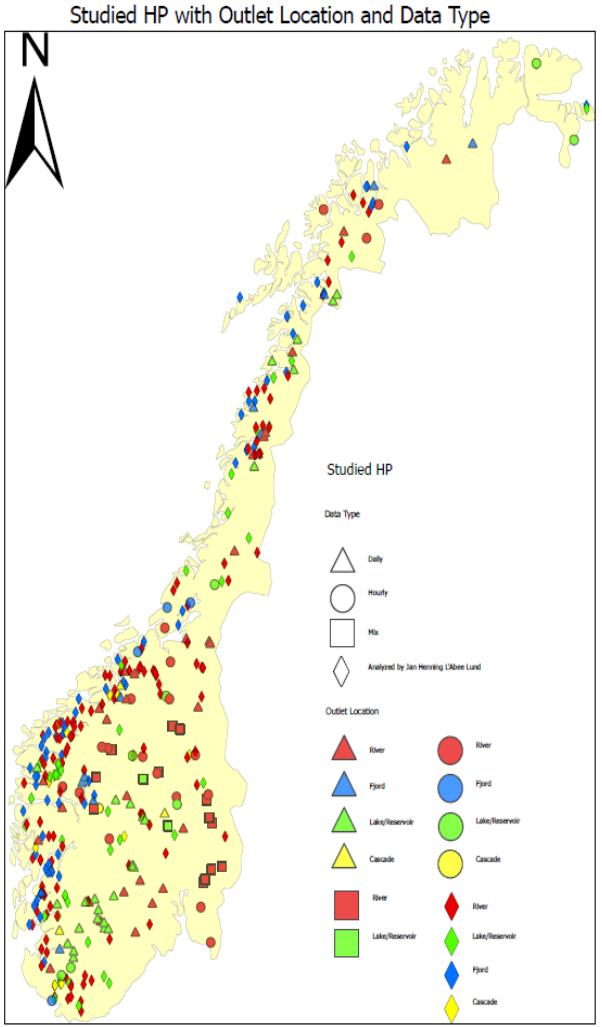
Take home messages;

1. Ecological severe **flow ramping is frequent** in many Norwegian rivers
   - ✓ An issue for all? HP with outlet in **rivers**?
2. Many (**51** %) of our largest HP facilities have outlet into **fjords** or **reservoirs**
   - ✓ peaking without ecological damage without mitigation is likely

Ramping restrictions in Norwegian hydropower licenses

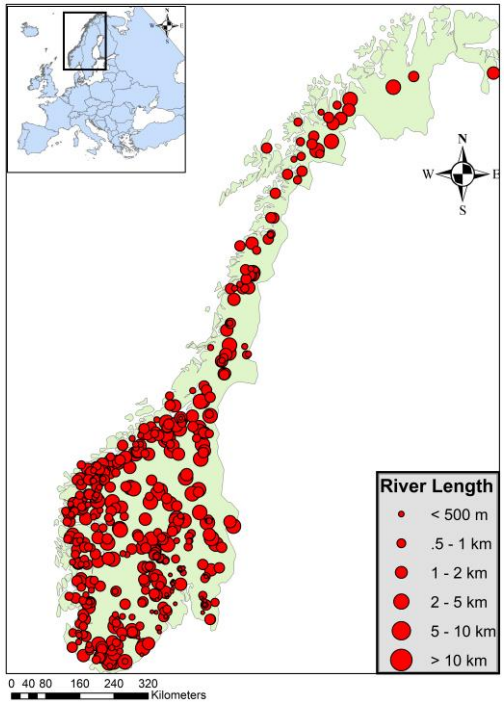
	All sizes		>10 MW		1.1-10 MW	
Operational Ramping Restrictions (ORR)	n	%	n	%	n	%
In license	**>348**	**21 %**	**32**	**9 %**	**277**	**39 %**
Without any restrictions	499	30 %	185	54 %	244	34 %
Total HP (excluding P and PK)	*1652*		*345*		*716*	

1. Most ORR have vague descriptions
   e.g. as slow flow-change as possible, and not related to e.g. downramping speed
2. Few large HP have ORR in license requirement
   An issue in revision of terms presently
3. Several large scale HP license have more detailed ORR description in National **salmon rivers** than others
   e.g. HP 3 – Alta – no more than 2 m^3/s daily change (16-33 m^3/s)



Halleraker et al., in prep

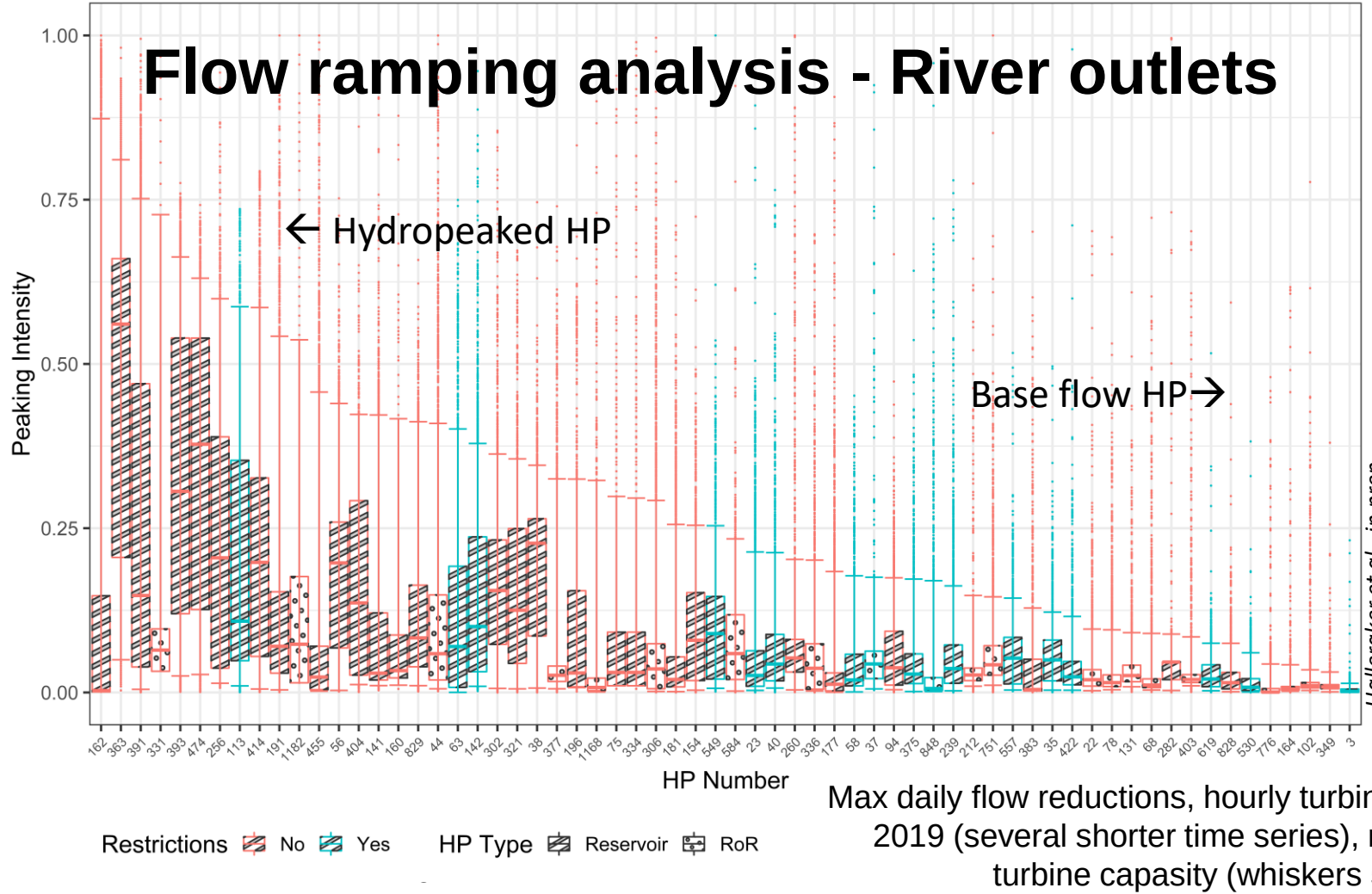
Key results from our assessment



- About 51 % of the HPs (ca **80TWh**) have tailrace into shorter rivers (<1 km) or directly into fjords or lake/reservoirs.
  - Many of the largest HPs are in this category (e.g 50 HP> 500 MW).
- Close to 800 HP might have downstream impacts on rivers
  - > 0.5 km; about 49 % of all HP, in total of ca **56 TWh**)
- Probably **> 3 000 km of regulated rivers** in Norway therefor might need more ecosystem-based mode of HP operation (*flow modification restoration or additional mitigation measures*).

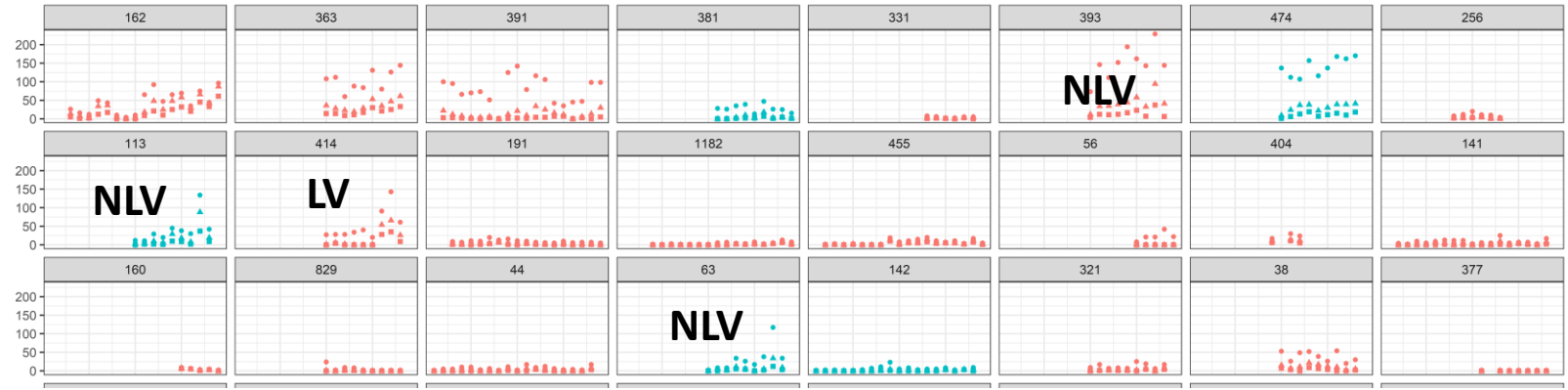
SUSTAINABILITY

Flow ramping analysis - River outlets



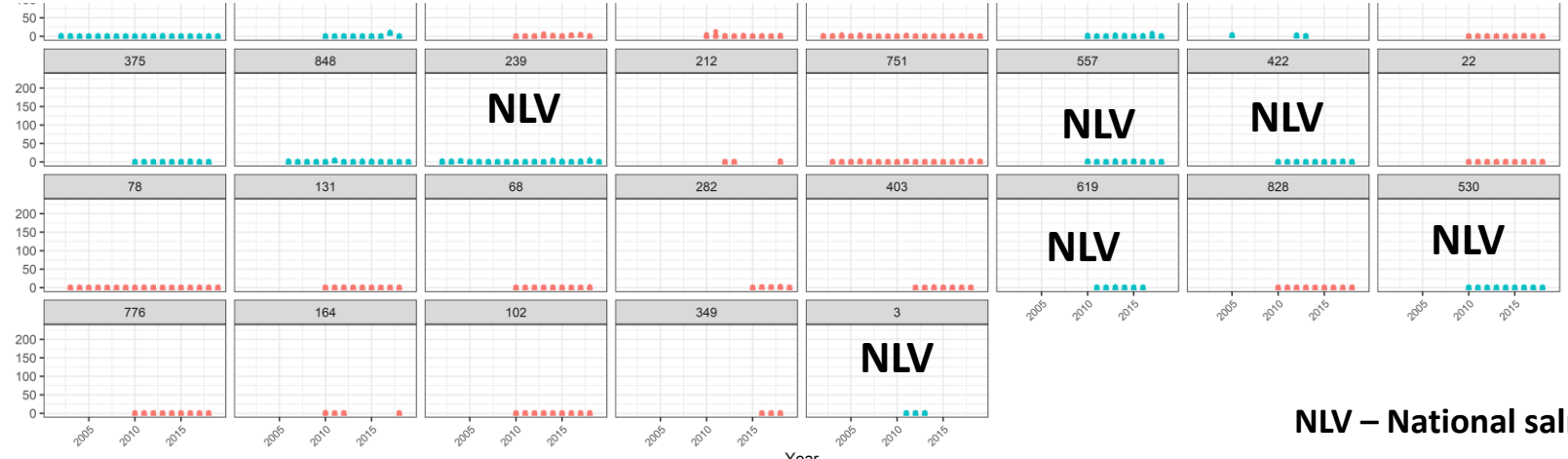
SUSTAINABILITY

Max daily flow reductions, hourly turbine discharge 2010-2019 (several shorter time series), normalised by max turbine capasity (whiskers 5%ile and 95 %ile)



SUSTAINABILITY

Restrictions ● No ● Yes Annual No. Peaks > ● 75% ▲ 90% ■ 95%



Halleraker et al.,(in prep.)

NLV – National salmon rivers

Flow ramping rules and ecological impacts are well documented

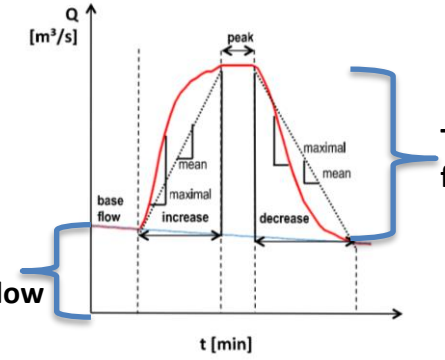
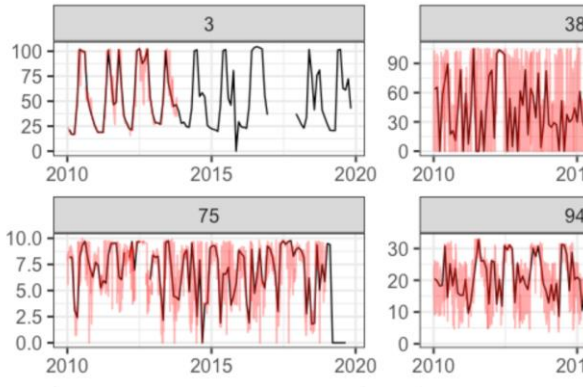
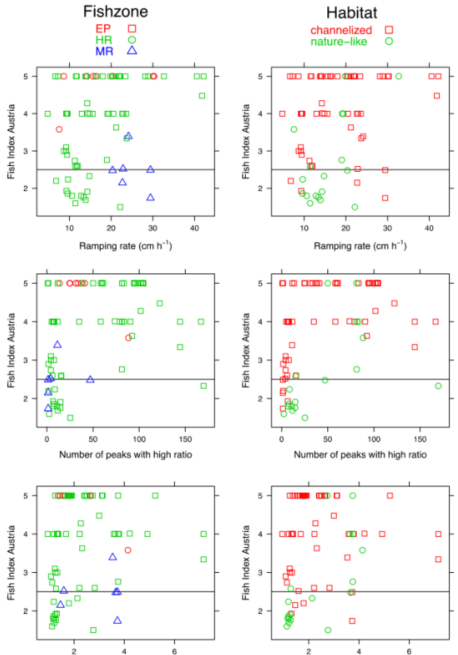


Figure 1. Schema of hydrological variables derived from flow curves. This figure is available in colour online at wileyonlinelibrary.com/journal/rra

Turbine HP flow

Residual-/ seasonal E-flow





sustainability

MDPI

Review

Life Stage-Specific Hydropeaking Flow Rules

Daniel S. Hayes [1,2,*], Miguel Moreira [3], Isabel Boavida [3], Melanie Haslauer [1], Günther Unfer [1], Bernhard Zeiringer [1], Franz Greimel [1], Stefan Auer [1], Teresa Ferreira [2] and Stefan Schmutz [1]

sustainability

MDPI

Article

The Impact of Hydropeaking on Juvenile Brown Trout (*Salmo trutta*) in a Norwegian Regulated River

Svein Jakob Saltveit [1,*], Åge Brabrand [1], Ana Juárez [2], Morten Stickler [3,4] and Bjørn Otto Dønnum [5]

[1] Freshwater Ecology and Inland Fisheries Laboratory, Natural History Museum, University of Oslo,

RIVER RESEARCH AND APPLICATIONS
River Res. Applic. **31**: 919–930 (2015)
Published online 7 August 2014 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/rra.2795

RESPONSE OF FISH COMMUNITIES TO HYDROLOGICAL AND MORPHOLOGICAL ALTERATIONS IN HYDROPEAKING RIVERS OF AUSTRIA

S. SCHMUTZ[a,b], T. H. BAKKEN[b], T. FRIEDRICH[a], F. GREIMEL[a], A. HARBY[b], M. JUNGWIRTH[a], A. MELCHER[a], G. UNFER[a] AND B. ZEIRINGER[a]

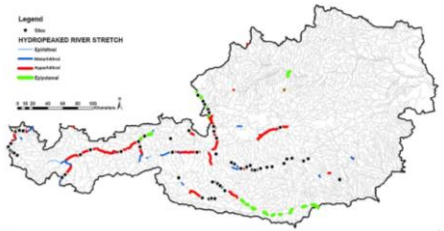
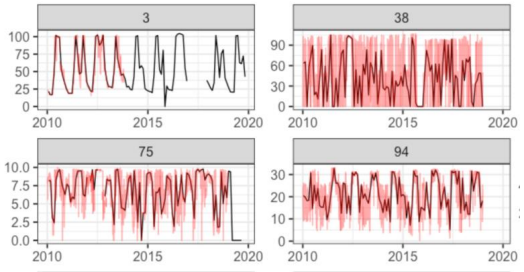
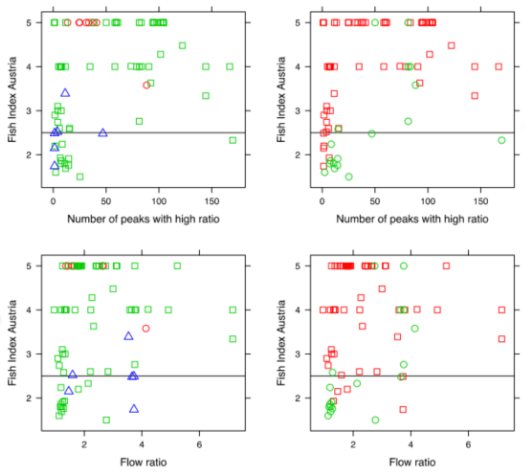


Figure 2. River stretches affected by hydropeaking, fish zones and fish sampling sites in Austrian rivers. This figure is available in colour

Ecological impact modelling for river WBs





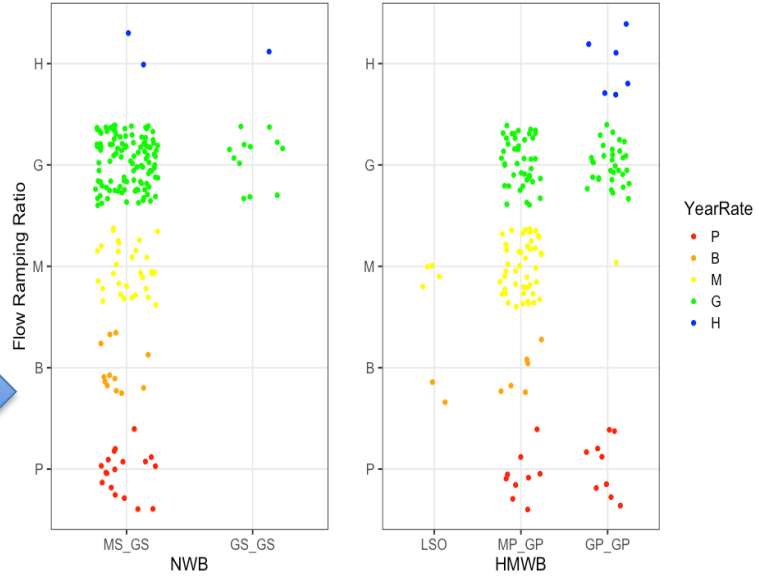
Schmutz et al, 2015

Flow ramping ratio (FRR - decrease)

Turbine flow/residual/Eflow in river

No pr year (#)

N /yr	<1.5x	1.5-3x	3-5 x	5 - 10x	>10x
<10	H	H	G	G?	M
10-20	H	G	G?	M	B
20-50	H	G	M	B	B
50 - 100	G	G?	M	B	P
100-150	G	G??	B	B	P
150-200	G?	M	B	B	P
>200	G??	M	P	P	P



Ecological mitigation (DIPSIR)

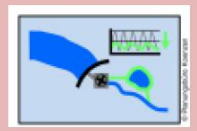
SUSTAINABILITY

The Green Deal Electrification

Drivere

Tiltak

Construction/technical measures to mitigate negative effects of hydropeaking*



Altered flow Habitat degradation

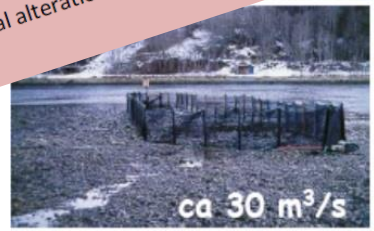
Påvirkninger

Effekt

Loss of biota/ biodiversity

Water temp Ecological status/potential

Tilst



Construction/technical measures to mitigate negative effects of hydropeaking*

- Mitigate short term/rapid flow level changes due to hydropeaking, e.g via balancing reservoirs (internal/external), relocating tailrace
- Install by-pass valves (for damping sudden drop in discharge)
- Improving in-channel structures to reduce velocities and provide shelter
- See row "Environmental flow" for reducing ramping rate and row "Modification or manage operations or structures (e.g. sluices)" for operational measures
- See also row "Rehabilitation of physicochemical alteration, including mitigation of downs case of thermo-peaking or saturopeaking

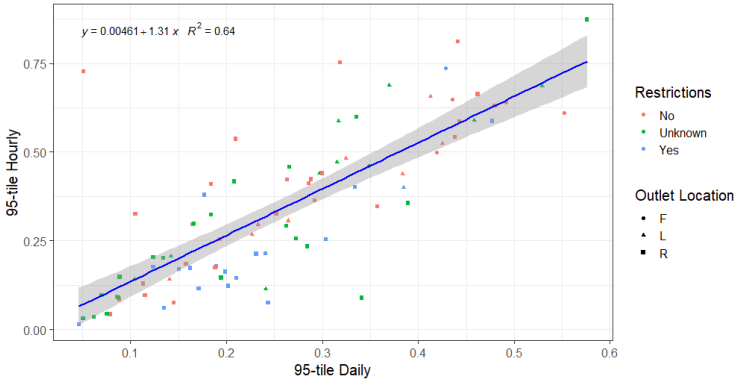
Emerging ecosystem-based measures … gate riverine ecological impact downstream hydropo… cilities in Europe

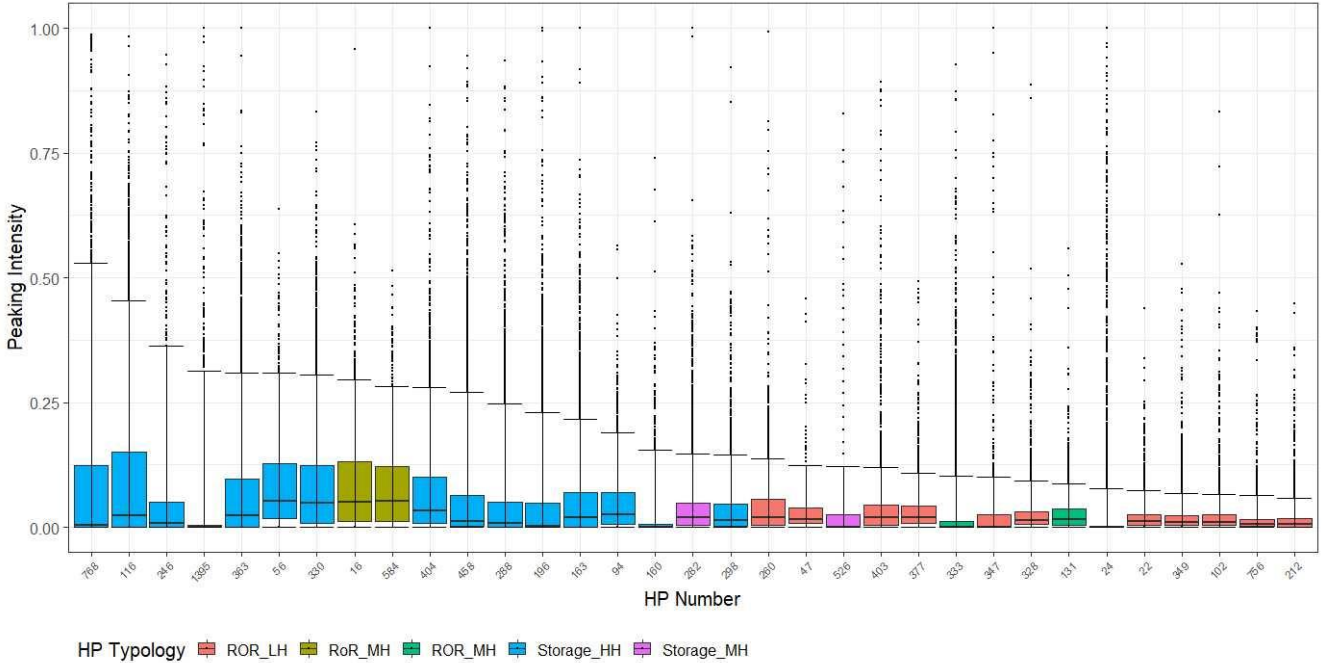
Daily data (only) River outlets_no restrictions

→ indicative flow ramping signals and identify need for ecological mitigation

- 768 Lakshola – R3 (A)
- 116 Grytten – R5 (A)
- 246 Lio – R3 (Storaure)*
- 1395 Mælfoss -
- 363 Savalen – R4 (Grayling)
- 56 Dale II (A) *
- 330 Rana – R3 (A)
- 16 Bardufoss – R3
- 584 Hellandsfoss – R3
- 404 Straumsmo – R5 *
- 458 Tunnsjødal – R5
- 196 Kalvedalen – R4
- 94 Skagen – R4
- 282 Mykstufoss – R5
- 298 Nedre Røssåga – R4 (A)

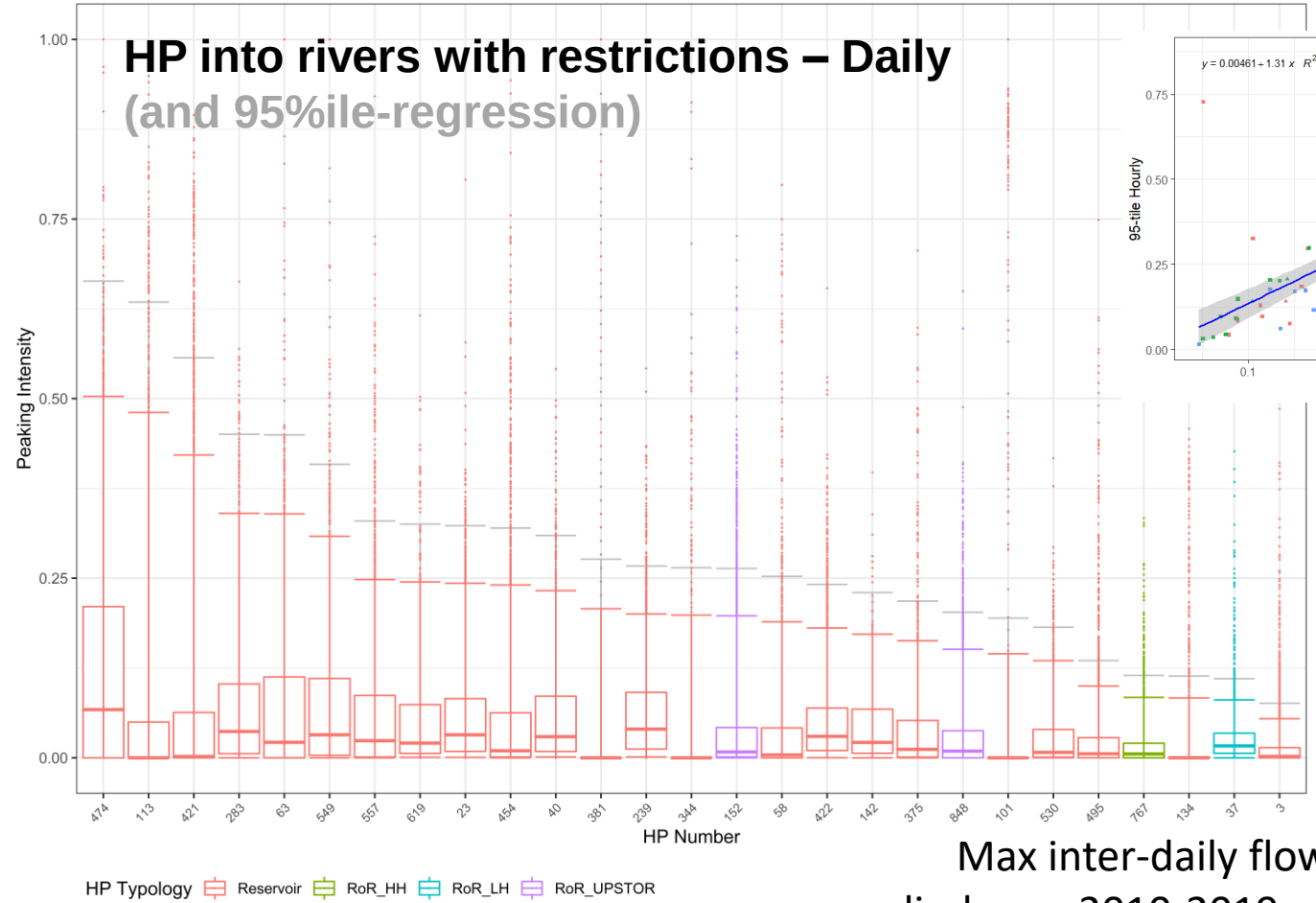
(*) Stranding reported

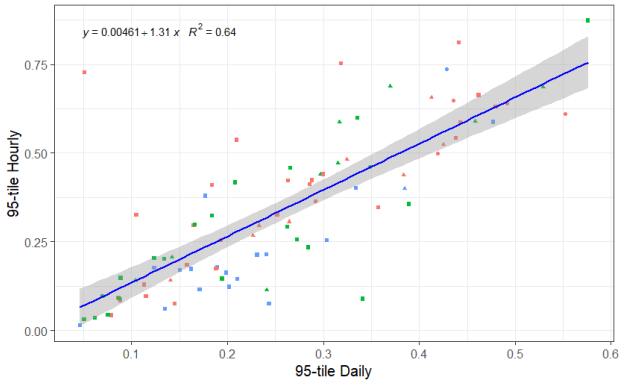




NTNU Knowledge for

HP into rivers with restrictions – Daily
(and 95%ile-regression)





Max inter-daily flow reductions, DAILY turbine discharge 2010-2019, normalised by max turbine capasity (whishkers 95 %ile), (and 95%ile-regression)

Key findings for sustainable management

- ✓ Ecological severe **flow ramping is frequent** in many Norwegian rivers
- ✓ Many HP operating in National **salmon rivers** seems **to practise gentle flow ramping**
- ✓ Ecological severe flow ramping, seems to be partly overlooked, and not sufficiently mitigated in many Norwegian rivers
- ✓ The screening criteria for **EUs taxonomy of sustainable hydropower** highlights mitigation of hydropeaking

measures to ensure minimum ecological flow (including mitigation of rapid, short-term variations in flow or hydro-peaking operations) and sediment flow;

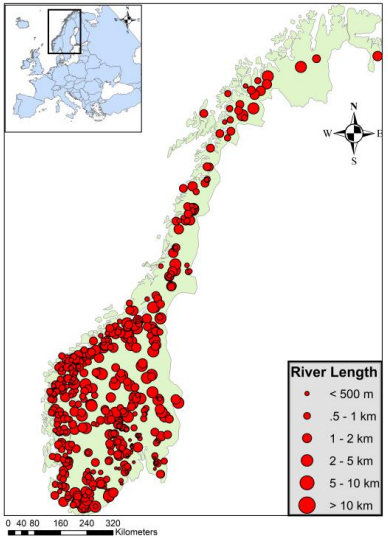
measures to protect or enhance habitats.

- ✓ Norway as a "green battery" need then to step up ecological mitigation and monitoring to ensure sustainability
  - ✓ Pri 1: Peaking mainly **from HP without river impacts**
  - ✓ Pri 2: avoid rapid/frequent flow ramping in the most sensitive ecological emergence windows

SUSTAINABILITY

Flow ramping ratio (FRR - decrease)

No pr year (#) N /yr	<1.5x	1.5-3x	3-5 x	5 - 10x	>10x
<10	H	H	G	G	M
10-20	H	G	G	M	B
20-50	H	G	M	B	B
50 - 100	G	G	M	B	P
100-150	G	G	B	B	P
150-200	G	M	B	B	P
>200	G	M	P	P	P



Questions?

FINANCING A SUSTAINABLE EUROPEAN ECONOMY

SUSTAINABILITY

Thanks for your interest
in this project ☺

© Markus Zeh
«Rolls Royce Mitigation» of Hydroeaking in the alps