# KEY CONSIDERATIONS FOR DEVELOPING BEST-PRACTICE SOLUTIONS FOR SAFEGUARDING DOWNSTREAM FISH MIGRATION AT HYDROPOWER FACILITIES


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# Topics

- Impacts on fish migration in Europe
- Role of hydropower and relevant legislation
- Fish passage at HPP - facilitating downstream migration
- Key considerations to develop effective measures

# Impacts on riverine fish species

- **Weirs** (passability)
  – fragmentation habitat
  – passage upstream + downstream
- **Unsuitability fish ways/passages** (inefficient passability)
  – probably adjustments required for sturgeon
- **Shipping**: damage by ship-screws, especially at low water levels
- **Fisheries**: (by)catch by professional + recreational
- **(Cooling) water intakes** (abstraction)
  – impingement trash racks
- **Hydropower** (safe downstream passage)
  – impingement trash racks, entrainment/turbine passage mortality
  – available alternative routes (findability + accesibility)

**Key impacts**

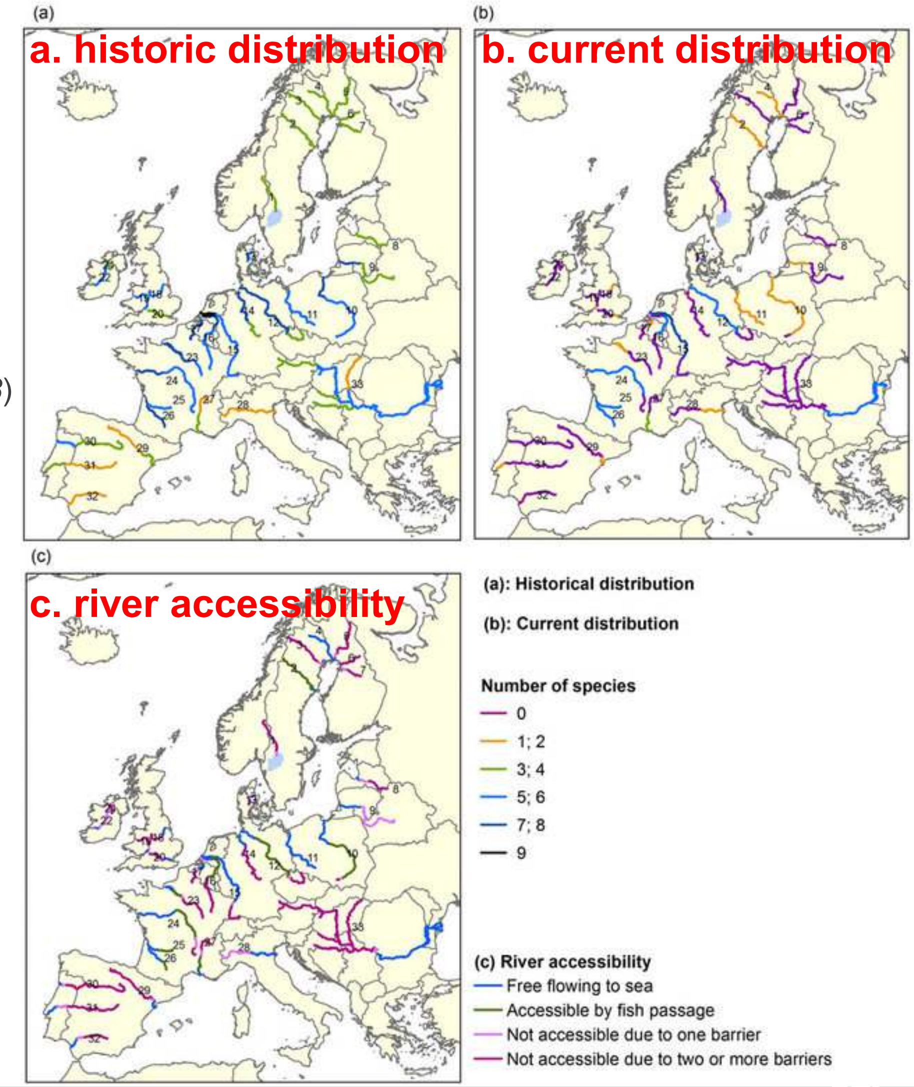
- Loss of connectivity (lateral, longitudinal)
- Altered river flow regimes
- Loss of habitat and biodiversity
- Direct mortality factors (anthropogenic)

*Role and impact of migration barriers and mortality factors depend on fish biology, size (life stage) and habitat connectivity, as well as swimming capacity related to working principle and appropiateness of measures*

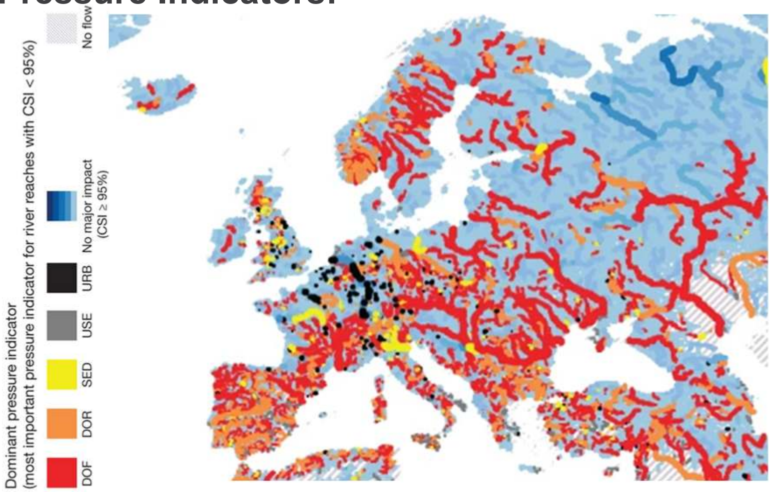
# Habitat connectivity

- Distribution of long-and mid-distance anadromous species in the main stem of large European rivers
  - (a) historical distribution, (b) current distribution and (c) upstream accessibility in 2016

(source: *Van Puijenbroek et al., 2018*)




**Pressure Indicators:**



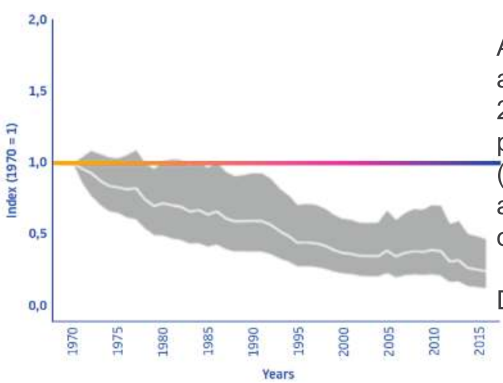

(source: Grill *et al.,* 2018 - Nature)

There is a great need to restore river connectivity (lateral + longitudinal), by facilitating passage (up- and downstream migration) at barriers, among others at hydropower facilities

# Species richness Europe

Areas of highest species richness clearly coincide with the lower parts of the large rivers flowing to the Black and Caspian seas, such as Danube, Bug, Dniestr, Dniepr, Don, Volga and Ural. Eastern and central Europe are also particularly rich, as is all of the Balkan Peninsula, and the catchments of the Elbe and the southern Baltic Sea basin.

(source: *European Red List*)

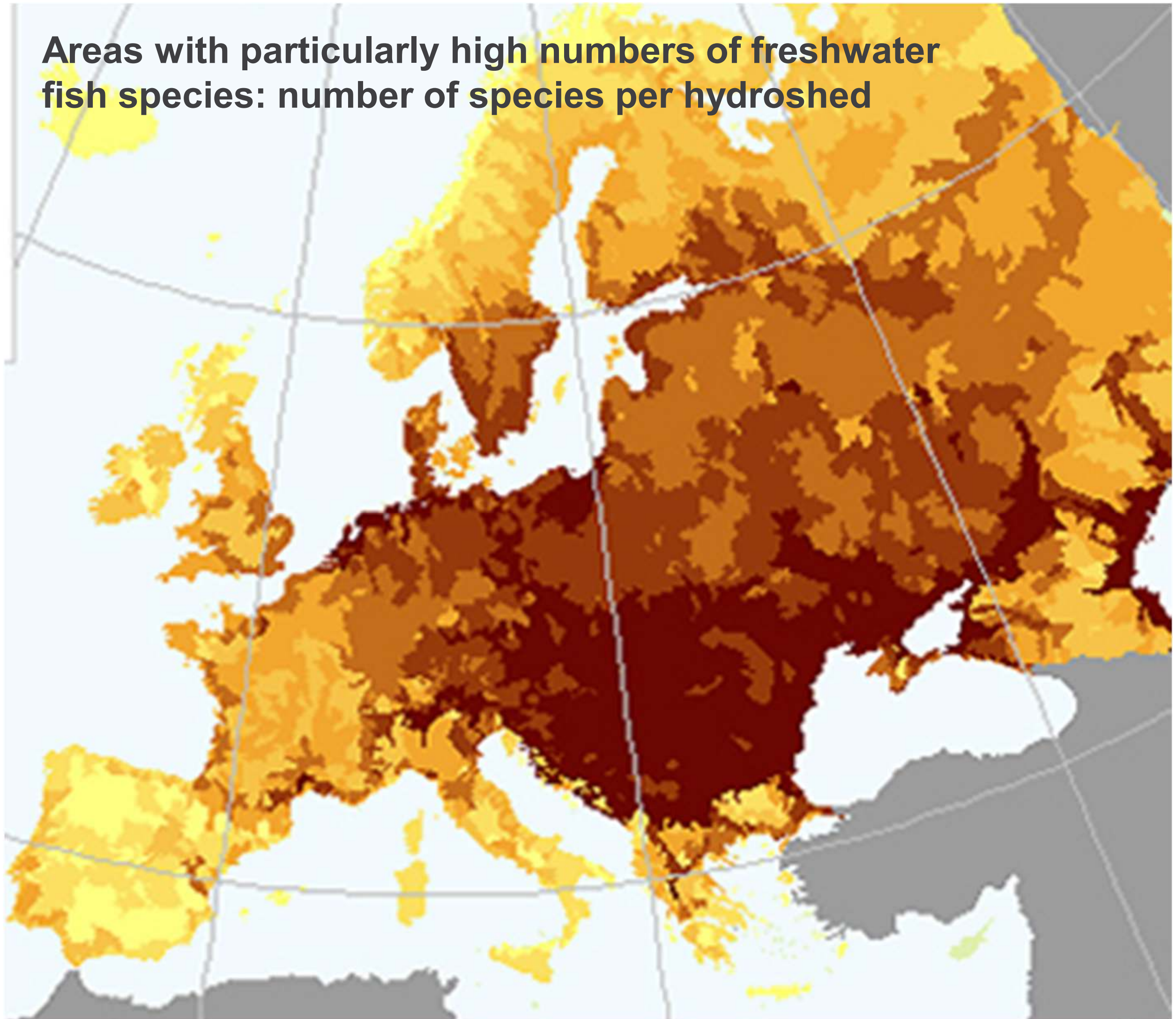



Average change in abundance of -76% 1970 - 2016 of 1,406 monitored populations of 247species (anadromous, catadromous, amphidromous, diadromous or potamodromous).

Decline in Europe: -93%

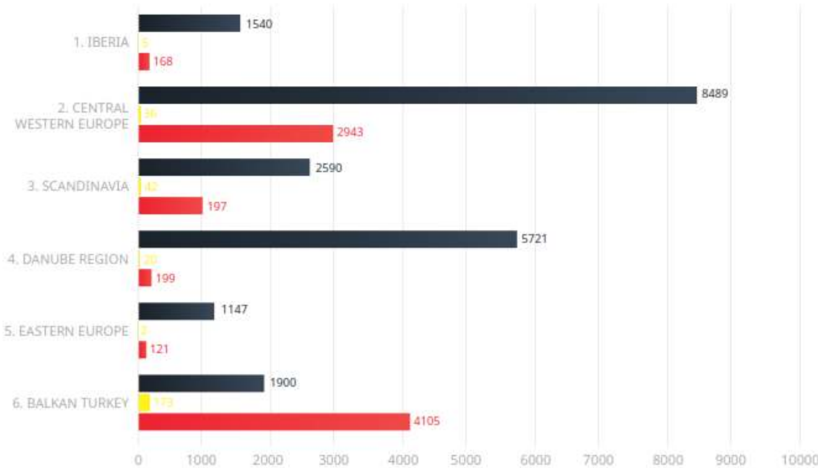
Source: Deinet, *et al.,* 2020. Technical Report.

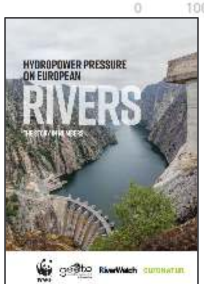
## Areas with particularly high numbers of freshwater fish species: number of species per hydroshed



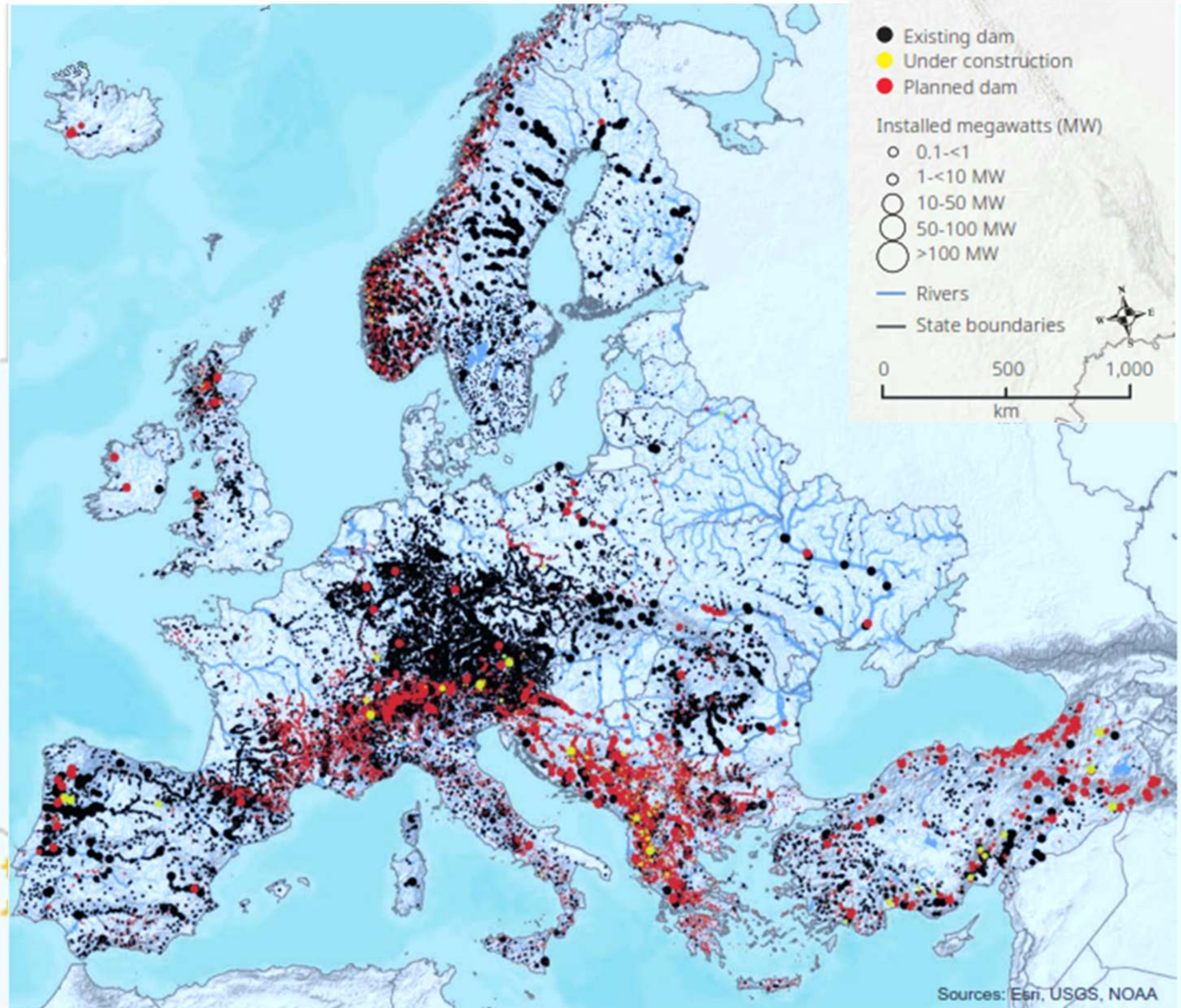
# Hydropower in Europe

Distribution HPP in the different regions:




(source: *WWF, 2019. Hydropower pressure on European rivers: the story in numbers*)



# Role of hydropower in Europe

- Unbalance on power grid (*e.g.* due to production versus consumption, as well increasing share of wind and solar), increases the need for ancillary services to maintaining secure and stable grids
- In this context, hydropower delivers:
  - back-up and reserve capacity
  - quick-start and black start capability
  - regulation and frequency response
  - voltage support to control reactive power
  - inertia

Primary regulation: to balance frequency in grid by automatically adjusting the water flow through such units.

Secondary regulation: units are used to compensate for loss of power production or taking away surplus of power production (which has become more intermittent today)

- Further
  - commitment power sector: leading the required energy transition and secure cost-effective decarbonization, wherein hydropower is one of the key technologies in decarbonization
    - significant amount of balancing power helping efficient integration of variable renewables (wind / solar)
    - one of the most competitive sources of low-carbon electricity with a lifecycle of >80 years
      - despite low operational costs, the high investment for the construction of hydropower infrastructure requires a clear and stable regulatory framework

# Relevant European legislation

- Central pieces of legislation for environmental protection in relation to hydropower are:
  - Water Framework Directive (WFD)
  - Birds/Habitat directive
  - The Eel Regulation
  - Renewable Energy Directive
  - Biodiversity strategy
  - IAS Regulation
  - SEA/EIA Directive
  - National legislation in relevant Member States

*These have impact on current operations and future development of hydropower*

**Other:**

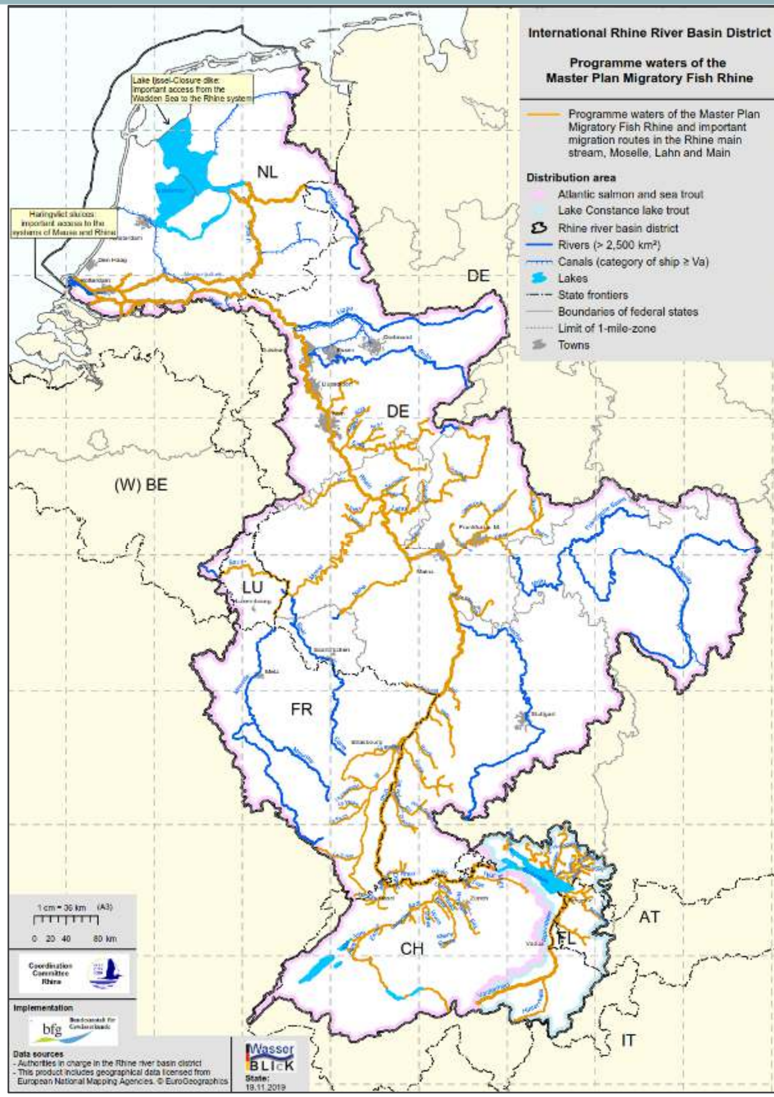
- CITES Annex
- Bonn Convention Conservation of migratory species (CMS) (Annex I & II)
- Bern Convention Wildlife in Europe (Annex II)
- OSPAR Convention
- IUCN red list (critically endangered)

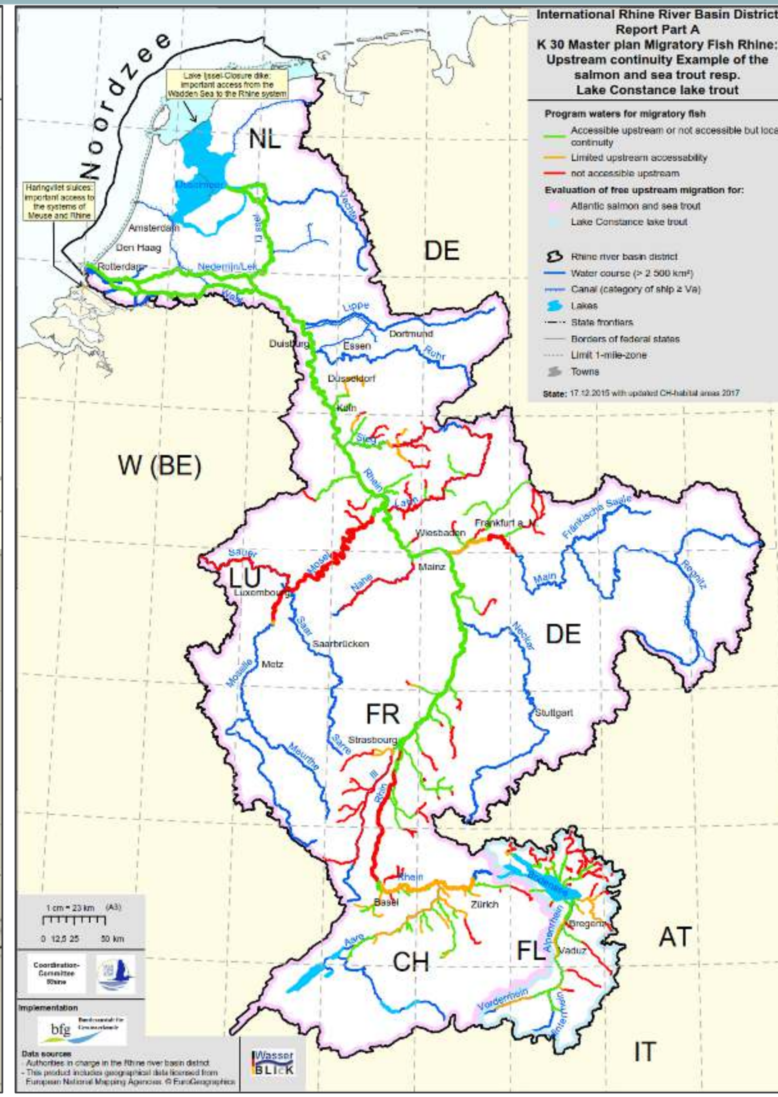
# River Rhine

“Master Plan Migratory Fish Rhine 2018” - an update of the Master Plan 2009

Figures (from Management Plan 2015) show:

- example program water for migratory fish (left) and
- upstream river continuity for migratory fish: example of the salmon, sea trout and lake trout



# Fish passage at hydropower facilities

- Hydropower hydraulic conditions key for efficient operation / electricity production:
  – large part of the river/canal (main flow) passes through the turbines
  – flow velocity at trash racks high (> 1 m/s)
- Migratory species mainly use the main flow of rivers
  – passage via turbine most logical route for fish
  – turbine passage survival related to fish length and turbine type
  – along a full river course, river conditions and habitats change gradually – or instantly, where species should be able to find suitable habitat(s) associated with life stage and routes to disperse/migrate
  – especially regulated rivers have many barriers (weirs, locks, etc, often combined with hydropower) resulting in non-natural hydraulic conditions, as well cumulative impact multiple HPP
- Downstream passage options at hydropower plants:
  – the turbine
  – the weir / spillway
  – a dedicated fish passage/bypass
  – adjacent navigation locks/canals

# Facilitating safe downstream fish passage

- How to get downstream migrating fish
  - AWAY from the HPP intake (preferably at greater distance, avoiding ‘point-of-no-return’)
  - TOWARDS entrance of an (alternative) route for safe passage (findable, accessible, passable!)

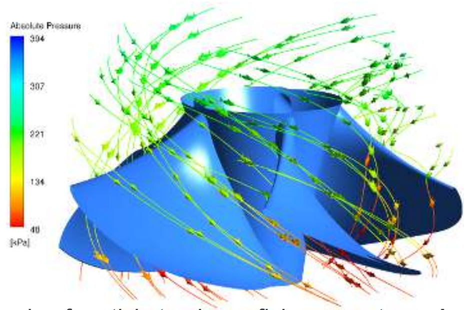
- Downstream migrating fish
  - strongly follow hydraulic triggers during migration for efficiency: use main flow
  - react in front of trash racks – possible reactions include direct passage, hesitation, search-behaviour and upstream movement (flow velocities, depending on bar spacing, magnitude and lay-out of intake area, swimming capacity of fish (life stage, water temperature, etc))

- To get fish out of their ‘natural route’, e.g. main flow in river/canal, the measure should be able to facilitate migration using the natural behaviour (*where physical systems also use behavioural response!*) by
  - affecting fish behaviour – elicit a response which is stronger than the (natural) hydraulic cues
  - provide an alternative route – which is as close as possible to the natural route and fish swim capacity
  - does not elicit hesitation and upstream movement

**Do Best Practices exist?**

# Options to facilitate downstream fish passage at HPPs

- Design & Operation
  - ‘Fish-Friendly’ turbines
  - Adaptive turbine management, requires early-warning arrival (species specific)
- Bypasses / alternative routes
  - a.o. surface (smolts) / bottom (eel) / fishways / weirs / spillways
- Physical
  - Directly at intake
    - Modified trash racks – slope, bar spacing, approach velocity
  - Guidance in approach area (guidance), e.g.
    - Louvres
    - Angled racks
- Behavioural
  - Light
  - Acoustic
  - Artificial flow (FVES), eddies
  - Electric fields



*Example of particle tracks as fish surrogates – Andritz*

**HPPs >100 m³/s**

With increasing scale of HPPs:
- Intake areas are larger
- Hydraulics are more complex
- More options exist for alternative migration routes
- Larger distances to cover by technologies
- Larger distances to cover by fish
- Possible failure modes increase

**Research on measures**

Focus of R&D has changed over time
- Previously strong focus on technology
  - physical guidance, behavioural systems, bypasses
- Currently increased interest in
  - fish response to hydraulic cues, fish-friendly turbines, adaptive turbine management/early warning, prioritizing locations for measures

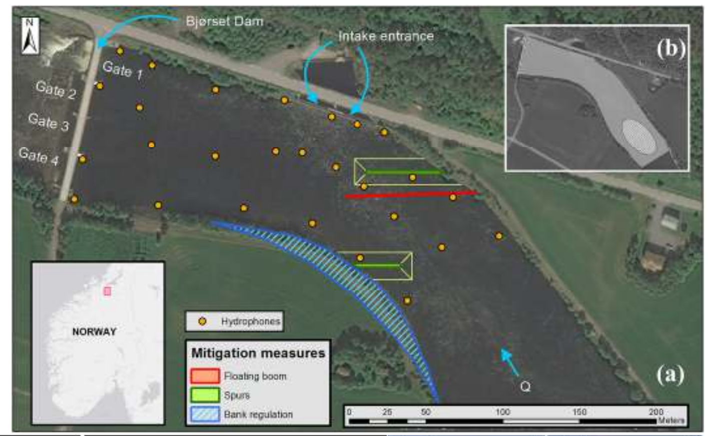
# Selected projects of interest

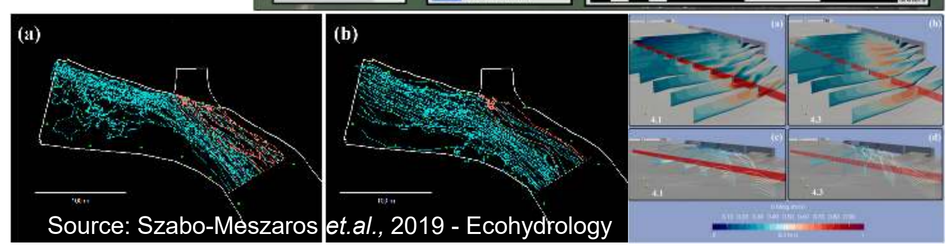
Monitoring studies increase our understanding of fish migration patterns (large scale movement) and behaviour (fine scale) related to environmental and hydraulic cues.

Dominant focus on salmonid species, eel and other riverine species having large migrations, passing multiple barriers.

- LIFE4FISH (EdF Luminus, Belgium)
- AMBER (Europe)
- FIThydro (Europe)
- Aalschutz Initiative (Rheinland-Pfalz + RWE, Germany)
- Krafttag ål (Energiforsk, Scandinavia)
- FishPath (NINA, Norway)
- Forum Fischschutz & Fischabstieg (Germany)

Numerous other (local) initiatives exist (mainly across the EU and in USA), a.o.
- technologies to facilitate migration at HPPs
- adaptive turbine management, including early warning
- novel fish-friendly turbine concepts
- catch & transport
- monitoring studies
  - (3D) hydroacoustic telemetry: long-term migration
  - small-scale behaviour (e.g. Lab-on-a-Fish)
  - mortality (e.g. mortality factors versus survival factors)
- modelling river hydraulics: flow patterns vs migration route
- river habitat connectivity




Source: Szabo-Meszaros *et.al.*, 2019 - Ecohydrology

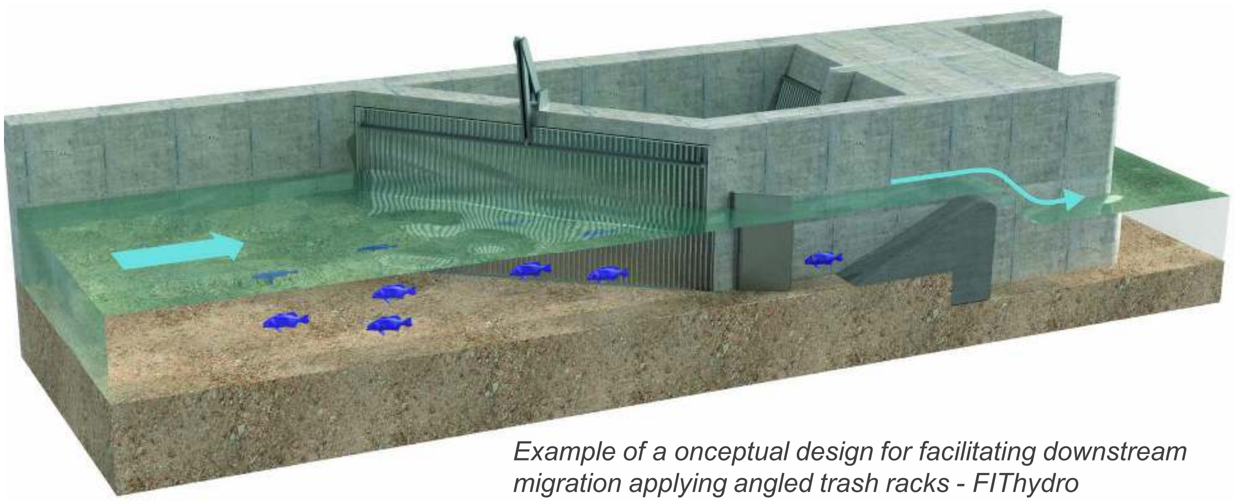
# Technology options

- Fully dependent on specific local conditions
  - environmental (species, seasonality, etc)
  - hydraulics: river flow, HP intake area (velocities, eddies, etc)
  - water quality
  - technical (intake design)
  - cost-effectiveness
  - Etc.

**Design considerations**

- Biological considerations
- Environmental considerations
- HP design considerations (existing or new facility)
- Hydrodynamic considerations
- Conceptual design and applicability
- Associated costs

Selected technologies are, regardless TRL (e.g. concept, fit-for-purpose, proven), subject to field testing under representative conditions prior to full field implementation.



*Example of a onceptual design for facilitating downstream migration applying angled trash racks - FIThydro (Illustration: VAW / ETH Zurich)*

# Key considerations for assessing best practices

- Species of concern, including
  - biology and physiology (swim capacity)
  - species specific behavioural responses to stimuli (light, acoustic, hydraulic cues)
  - spatial-temporal movement (e.g. route selection in river system/catchment, at bifurcations)
  - species behaviour in front of intakes
  - timing migration
- Conditions during (seasonal) migration periods of concern, including
  - hydraulic characteristics: insight by numerical modelling
  - water quality conditions at that time (e.g. turbidity, debris loads and types)
- Geometry/positioning intake area, relative to the river
  - lay out intake / trash rack design
  - bathymetry, depth, velocities in approach area
  - existing (alternative) routes for passage
- Space available for additional alternative routes, including
  - bypasses (which must be findable, functional and accessible!)
  - potential new alternatives
- HPP operation
  - position to river
  - flows and velocities
  - number of turbines in operation
  - turbine types + start/stop sequence

**Best Practices are site-specific**

Best Practices are not per definition technological solutions

Best Practice are approaches where a measure, or set of measures, dedicated to the conditions at a location, enable the best possible downstream migration of fish against proportional costs.

Best Practice is to be assessed for each site individually, where experiences / results / key learnings obtained elsewhere should carefully be reviewed and evaluated for their representativeness.

# Key message

Key considerations act as ‘Selection Criteria’ for assessing a cost-effective measure, or set of measures, by which the best possible facilitation of downstream fish migration can be achieved, attuned to the local situation (e.g. biology, hydraulics), whilst respecting the role, and associated operation of the HPP.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