Multiscale modelling to assess the impact of regulated rivers in Scotland on the ecology of Atlantic salmon (*Salmo salar* L.)

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INTRODUCTION

- Hydropower generation is a key component for Scotland's aim of meeting all electricity demands from renewable sources by 2020.
- Conflict between energy demands (hydropower schemes) and ecological flow requirements in many regulated Scottish rivers (Water Framework Directive)
- Atlantic Salmon's (*Salmo salar* L) flow requirements are different for different life stages - these requirements strongly link to dynamics in spatio-temporal hydrological connectivity
- To inform sustainable management, there is a need for appropriate assessment of reference conditions and effects of current schemes, which are limited by data and decision support tools

Aims and Objectives

- The main aim is to provide a **cross-scaling modelling framework** to under- stand the **cumulative impacts** of existing and new hydropower schemes on **flows and ecological status** of Scottish rivers, as a basis for informing **sustain- able river management**.

- The objectives are to:

1. use a **generic rainfall-runoff model** to assess hydrological reference conditions at the **catchment scale** and effects of hydropower schemes on flows
2. use 2D-hydraulic models to assess the impacts of hydrological change (derived from (1)) on **habitat quality at the reach scale**
3. use output from (1) and (2) to investiga the role **hydrological connectivity** in determining the system's **resilience to hydrological changes**
4. use **scenario analyses** to project trade-offs between different river regulation **scales** in a way that can be **communicated to stakeholders**

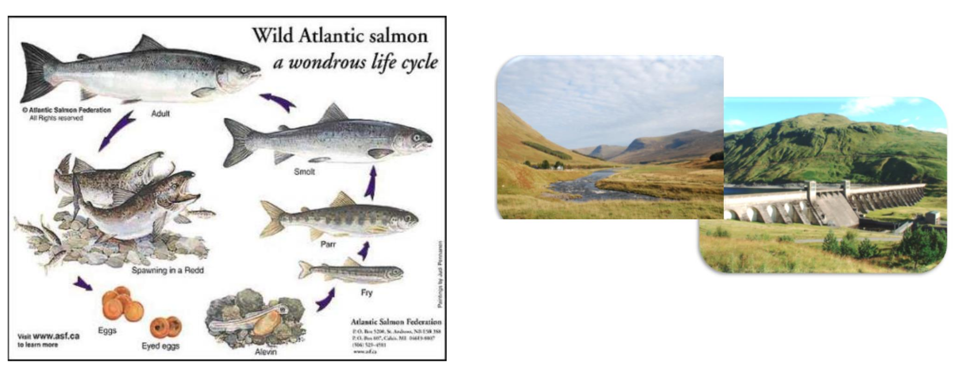

Fig 1: Overview of the life cycle of Atlantic salmon (left). Picture of the upper reaches of the River Lyon and the Loch Lyon Dam (right).

Study Catchments

Tay catchment
- Heavily regulated, large catchment, diverse hydrology

Main rivers of interest in Tay catchment:
- River Tay: 4970km^2; precipitation west -> east ~3000-750, evapotranspiration in lowland areas ~450 [mm a^{-1}]; average discharge at Ballathie 169m^3/s
- River Lyon: 390km^2; responsive soils; low permeable geology; heath and moor- land vegetation; precipitation ~2300, evapotranspiration ~400 [mm a^{-1}]; aver- age discharge 12.5m^3 s^{-1}; major tributary to River Tay

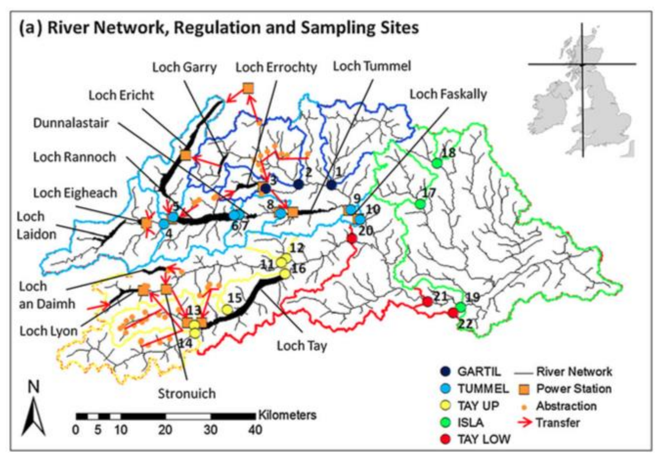

Fig. 2: Overview of the rivers of the Tay catchment and its regulation and sampling sites. Adapted from: Soulsby et al, 2014.

Girnock Burn Catchment
- Unregulated catchment, single river drains catchment

River of interest in Girnock Catchment
- Girnock Burn: 30km^2; precipitation ~1000mm, evapotranspiration ~400 [mm a^{-1}]; discharge ~0.52m^3 s^{-1}, granitic with glacial history

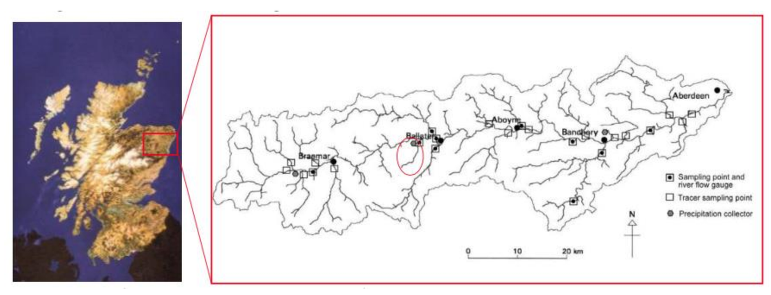

Fig 3: Location of the Girnock Burn catchment left and a detail with the Girnock Burn circled in red.

Methodology/Approach

- Integrate modelling and analyses for natural and regulated catchments

1. Collect empirical hydrometric data to determine reference condition for construction of a catchment-scale hydrological model (see Geris et al., 2014)
- Engage with stakeholders for input into model and to collect hydroscheme regulation data. Focus on hydropower schemes in heavily regulated rivers
- Study effects of hydroschemes on reference condition flows
2. Incorporate the outputs from the generic large-scale hydrological model into 2-D reach-specific hydraulic models
- Impacts on habitat quality of selected life-stages of Atlantic salmon will be as- sessed by comparing output of reference conditions to regulated conditions and available or collected field data
3. Study how hydroschemes affect the connectivity in the hydrological systems compared to a non-regulated reference state. Determine impacts on resilience and vulnerability to change

- Spatial connectivity
- Temporal connectivity

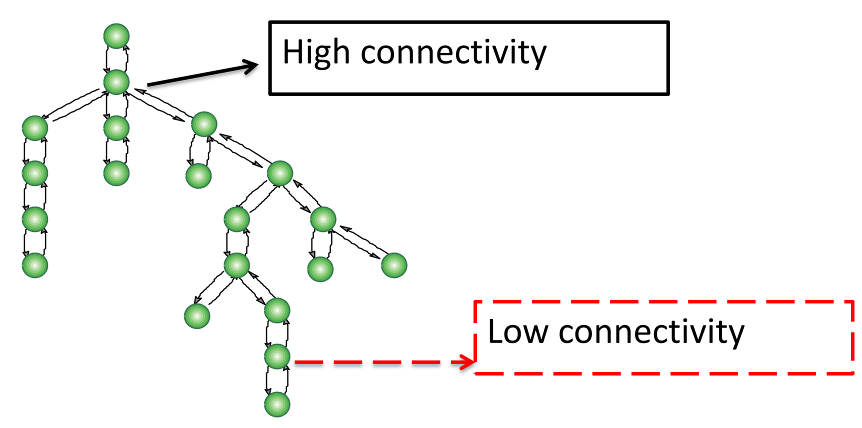

Fig. 4: Depending on the position of a node within a network, it can have a high or a low connectivity. The higher the connectivity, the more stable a node is.

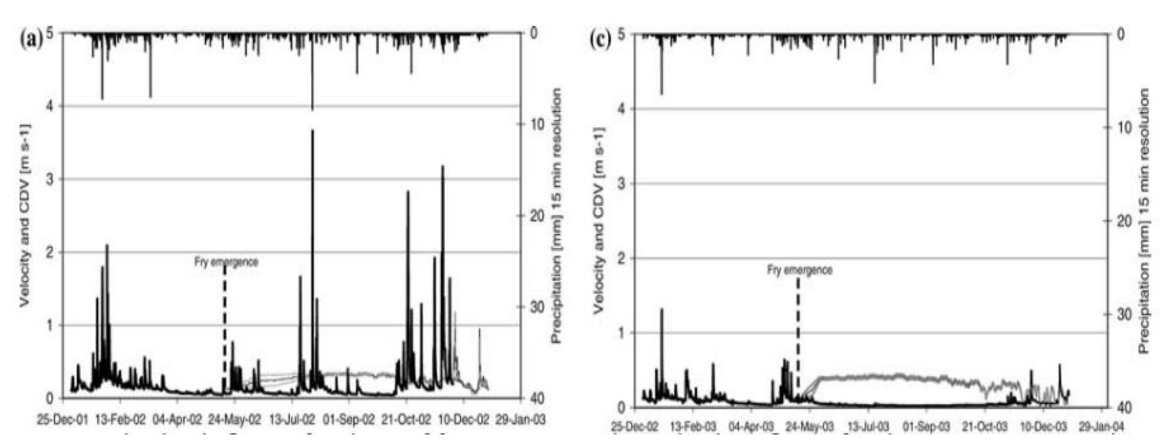

Fig. 5: Under high flows, feeding of fry is restricted. Under low flows feeding is unrestricted. Adapted from Tetzlaff et al., 2005.

4. Develop relevant scenarios based on input from stakeholders
- Run scenarios and use statistical methods (e.g., Monte Carlo methods) to project the effects of the different scenarios on different salmon life-stages taking into account different scales
- Analyse output from scenarios in terms of effects on different salmon life-stages

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Acknowledgements
Special thanks go to

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