Master Thesis

Modelling Larval Dispersal in Rivers: The Role of Hydromorphology

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Fig. 1: Example of contrasting morphologies on the Inn River (Bavaria, Germany): bypass channel around hydropower dam (left) and main river channel (right).

Motivation

Functional connectivity describes how habitat spatial arrangement, quality, and accessibility enable aquatic organisms to move between essential habitat patches (Torgersen, 2022).
For gravel-spawning species, such as brown trout, grayling or nase, functional connectivity between spawning and larval nursery habitats is especially critical. After successful spawning in gravel spawning sites, emerging larvae enter the flow and disperse downstream. During their drift, they must reach suitable nursery habitats to survive and grow. This drift-driven dispersal is characterized as active-passive: transport is largely flow-driven (passive) because larvae, due to their small sizes (~ 5-30 mm) cannot swim against the current, yet they can still influence drift timing and orientation (active) (Lechner et al, 2016).
Larval drift and resulting spawning-to-nursery connectivity are strongly influenced by river hydromorphology: greater morphological complexity increases habitat diversity and shortens distances between key habitats, while discharge magnitude and variability affect drift duration and transport distance (Sukhodolov and Wolter, 2009; Farò & Wolter, 2024). However, knowledge of larval dispersal and its hydromorphological controls remains limited, largely due to the high effort required for field-based drift measurements. Larval drift models based on

Lagrangian particle-tracking models provide a promising alternative to quantify larval dispersal and improve understanding of how hydromorphology shapes functional connectivity.
Larval drift model assumes larvae are small and have a density close to that of water, and hence move through the flow like parcels of water. Their path ($\vec{r}$) can be described by the following equation, which includes active and passive movement components:

$$\vec{r}(t+\Delta t) = \vec{r}(t) + \vec{v}\Delta t + \vec{v}_L \Delta t + \vec{L}\sqrt{2K\Delta t}$$

Passive drift includes advection by the ambient flow velocity ($\vec{v}$) and dispersion due to turbulence, modelled as a random walk with Gaussian-distributed step lengths $\vec{L}$ (mean zero, standard deviation one) scaled by $\sqrt{2K\Delta t}$, where K is the turbulent diffusivity. Active drift is added through a larval velocity term $\vec{v}_L$, which can represent behaviours such as swimming, settling, or other directed movements.
Due to the stochasticity involved in the description of the drift, and the variability of flow conditions that can incur depending on the emergence location, a large number of simulations is necessary (typically in the range 5-10'000) to simulate the drift.

Research objective

The main objective of this thesis is to investigate how hydro-morphological characteristics shape the spatial distribution of key habitats and larval drift pathways, and hence spawning-to-nursery functional connectivity.
The study will be carried out on river reaches with contrasting morphological characteristics, based on laboratory-derived DTMs and/or real-world case studies.

Specifically, the student will:
1. Set-up and execute 2D (depth-averaged) steady hydraulic simulations (i.e. water depth and flow velocity) for a range of discharges.
2. Describe spawning and larval habitats using available suitability curves from the literature
3. Set-up and test a larval drift model using existing Lagrangian particle tracking models (e.g. fluvial-particle[1])
4. Quantify and compare spawning-to-nursery functional connectivity across reaches and hydromorphological conditions

Methods

The thesis involves hydraulic and habitat modelling using 2D hydraulic modelling (e.g. Basement, HecRas2D) and habitat suitability modelling at the micro-scale (Farò and Wolter, 2024). Larval drift and spawning-to-nursery functional connectivity are modelled using a Lagrangian particle tracking model (McDonald and Nelson, 2020; Nelson et al. 2023).

Remarks

Meetings and final thesis report will be conducted in English. The thesis will be developed in collaboration with the Leibniz Institute of Freshwater Ecology and Inland Fisheries IGB, Berlin (Dr. David Farò). The project requires interest in setting up and running numerical simulations, as well as performing data analysis. Experience with 2D hydraulic modelling and the programming language Python (or willingness to learn) are an advantage.

[1] https://code.usgs.gov/wma/nhgf/fluvparticle

References

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