Towards a mechanistic river model for the benthic community and biogeochemical cycles

Nele Schuwirth, Martin Kühni, Steffen Schweizer, Urs Uehlinger, Peter Reichert
Goals

Develop a **mechanistic** model for a **river benthos** ecosystem

- to get a better **understanding** of main processes and influencing driving forces
- to make a (small) step forward to the prediction of the **future development** of an river ecosystem under changing environmental conditions
Requirements

- consider **uncertainty** of model parameters and results
- include all important processes to close **mass balances**
- use the **chemical composition** of substances and organisms to confine stoichiometric relationships
- complex interactions lead to overparameterized-models: overcome the problem with **poor-identifiable** calibration parameters:
  - formulation of process kinetics as **simple** and as universal as possible
  - **include prior knowledge** to estimate parameters

→ **Use of Bayesian inference**
Strategy for Model Development

1. **Definition of Model Structure and Parameters**
2. **Definition of Prior Parameter Distributions**
3. **Sensitivity Analysis**
4. **Preliminary Calibration**
5. **Bayesian Inference for All Parameters**
6. **Analysis of Results:**
   - Sensitivity
   - Correlation/Identifiability
   - Prior-posterior
   - Residuals (bias, error model)
   - Interpretation of results

Implementation in AQUASIM (Version 2.1f), (www.aquasim.eawag.ch), Bayesian Inference, Identifiability analysis: UNCSIM (www.uncsim.eawag.ch)
Model Structure - Process Kinetics

- **Growth**
  \[
  r_{\text{Pred}} = k_{\text{gro}} \cdot e^{\beta(T-T_0)} \cdot X_{\text{Pred}} \cdot \frac{X_{\text{Prey}}}{K + X_{\text{Prey}}}
  \]

- **Colonization**
  \[r = c_{\text{col}}\]

- **Death**
  \[r = k_{\text{death}} \cdot X\]

- **Detachment**
  \[
  r = \begin{cases} 
  0 & \text{for } Q < Q_{\text{crit}} \\
  c_{\text{det}} \cdot X \cdot (Q - Q_{\text{crit}})^2 & \text{for } Q \geq Q_{\text{crit}}
  \end{cases}
  \]

---

- $r$: process rate [gDM m$^{-2}$ d$^{-1}$]
- $X$: organism/substance density [gDM m$^{-2}$]
- $k_{\text{gro}}$: specific maximum growth rate at $T_0$ [d$^{-1}$]
- $\beta$: temperature coefficient [$^\circ$C$^{-1}$]
- $K$: halfsaturation constant [gDM m$^{-2}$]
- $c_{\text{col}}$: colonization coefficient [gDM m$^{-2}$ d$^{-1}$]
- $k_{\text{death}}$: specific death rate [d$^{-1}$]
- $Q$: discharge [m$^3$ s$^{-1}$]
- $Q_{\text{crit}}$: critical level of discharge [m$^3$ s$^{-1}$]
- $c_{\text{det}}$: detachment constant [s$^2$ m$^{-6}$ d$^{-1}$]
Application to the River Sihl (CH)

River characteristics:

- 30-40 m width, 0.2-0.7 m depth
- Hydropower plant
- residual flow reach without natural discharge regime
- 2.5 m$^3$/s minimum discharge
- artificial floods up to 95 m$^3$/s 5-8 times per year

Data availability:

- periphyton and invertebrates [DM m$^{-2}$], 44 points in time during 2 years
- external influence factors Q, T, I, nutrients
Application to the River Sihl (CH)

Background
Strategy
Model structure
Application
Analysis
Conclusions

Diagram:
- Predators
- Scrapers
- Collector-gatherers
- Filamentous algae
- Crusty algae
- Organic detritus

N, P
Results: Simulations

**measured data** (red markers), **simulation results** (solid lines) with 2.5% and 97.5% **quantiles** (dashed lines) at maximum of the joint posterior distribution, \((g_{AFDM} \text{ m}^{-2} \text{ for algae and } g_{DM} \text{ m}^{-2} \text{ for invertebrates and OM})\)
Results: Bayesian Inference

Comparison marginal prior and posterior distribution

- *k*$_{groScra}$
- *k*$_{groPred}$

**Reduction in width** of the posterior indicates a reduction of the uncertainty
Results: Bayesian Inference

Comparison marginal prior and posterior distribution

_shift_ of the _mode_ of the posterior indicates the need for an adjustment of the parameter value
Results: Bayesian Inference

Comparison marginal prior and posterior distribution

no differences indicate no gain of information from data (low sensitivity or high correlation with other parameters)
Conclusions

- Mechanistic model useful for evaluation of processes and influence of external input factors.
- Good simulation of Sihl data possible.
- Assessment of process rates.
- Complex interactions lead to overparameterized model.
- Consideration of sensitivity and correlation is necessary to evaluate identifiability.
- Prior-posterior analysis of Bayesian inference indicates what we can learn about parameter values from the data.
- Quantification of uncertainty of model results.
- Reasonable choice of parameter values and prior probability distribution requires hydrobiological expert knowledge.
Outlook

- coupling of the benthos-submodel to submodels for nutrient, bacteria and organic matter dynamics based on the RWQM 1
  (Vanrolleghem et al., 2001, Reichert et al., 2001, Shanahan et al., 2001)

- application to other rivers:
  - to assess differences in functionality
  - to improve universality
Thank you!

Acknowledgements:

- Andreas Frutiger, Klement Tockner (EAWAG), Christopher Rutherford (NIWA, Hamilton, New Zealand) (helpful comments and discussions)
- Joachim Hürliman (AquaPlus) Horst-Luc Morf (AWEL) (hydropeaking data Sihl)
- Peter Nosari, Barbara Kaenel (AWEL) (water quality and hydrology data Sihl)
- Christopher Robinson (EAWAG), Peter Burgherr (PSI), Elisabeth Meyer (University of Muenster, Germany) (evaluation of the mean specific body mass of the invertebrates)