dam logic: qualitative reasoning about benthic macroinvertebrate responses to dam removal

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my damned logic

performance evaluation that moves beyond case studied through:

• testing hypotheses about predictability of geomorphic and biological responses

• evaluating reliability of biotic and abiotic indicators (e.g. responsiveness to dam removal, detectability, feasibility of measurement)

• satisfying permit requirements, scientific interest, and stakeholder outcomes
overall goal - to understand the major information gaps and to frame our performance evaluations around testable hypotheses.
predicting outcomes and recovery

- how long does it take?
- is it measurable?
- how does it vary with space? with time?
response mechanisms?

Fig. 1. Non-parametric multi-dimensional scaling ordination of benthic invertebrates in Kennebec River, Maine (USA). Relationships are based on a Bray-Curtis dissimilarity matrix using relative abundance at all sites (ci = continuously impounded, rr = restored reach,cff = continuously free-flowing) and all sampling dates: June 1999 (prior to removal of the Edwards dam), September 1999, June 2000, and September 2000 (post-removal). Circles indicate samples from the same sample dates.
a need for causal relationships

“there appears to be a wide range of ecological responses to dam removal. It is therefore difficult to predict responses…it is currently difficult to identify the causal factors that account for observed variation in dam removal responses. Because it may take many years to obtain a large set of comparable studies, other approaches probably also are needed to help explain potential variation in ecological responses to dam removal” (Heinz 2002)
what is QR?

Qualitative Reasoning (QR) - logic-based simulation used for hypothesis development, pattern identification, and prediction of management outcomes.
Figure 4. The Reference Process, One Iteration of the Inner Design Loop.
QR and ecosystems

- offers mechanistic explanations for observed changes
- analysis of nonlinear processes and threshold responses

View to West from RM 70, Confluence with the Sycan River is visible at the top
QR modeling software tool

GARP 3.0.4 - user interface
(hcs.science.uva.nl)
modeling objectives

1. identify of information gaps
2. develop hypotheses related to predictability and patterns in biotic and abiotic responses as related to:
   - removal strategy
   - dam operation
the process of QR modeling building

1. delineate knowledge “fragment”
2. document assumptions and logic
3. concept map - quantities and relationships
4. conform conceptual map to ontology
5. define relationships between knowledge fragments
6. build scenario of fragments and simulate
Figure 4. Flow chart illustrating how attributes of dam–reservoir systems, especially dam size and operations, modify fundamental riverine biophysical processes to cause alterations with local and landscape environmental effects.
references for model building


domains
• dam removal
• dam construction and operation
• basic benthic ecology
  • debris flows
some general principles...

organisms with short generation times are able to recover quickly from sediment releases

long-lived species are more vulnerable
but...the dam bugs

- declines in densities and shifts in species composition of macroinvertebrate communities observed with sediment flushing of reservoirs (Zuellig et al. 2002, Doeg and Koehn (1994))

- downstream deposition does not always produce detectable changes in invertebrate communities (Stanley et al. 2002, Bushaw-Newton et al. 2002)
<table>
<thead>
<tr>
<th>quantity</th>
<th>relationship</th>
<th>quantity</th>
<th>logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse sediment supply</td>
<td>+I</td>
<td>river - grain size</td>
<td>continuous supply of coarse sediment from upstream</td>
</tr>
<tr>
<td>fine sediment transport</td>
<td>-I</td>
<td>river - grain size</td>
<td>transport of fines out of downstream reach</td>
</tr>
<tr>
<td>hydropeaking</td>
<td>+P</td>
<td>BM mobility</td>
<td>the more hydropeaking the greater the mobility will be required for taxa to survive downstream</td>
</tr>
<tr>
<td>outlet elevation</td>
<td>+P</td>
<td>water temperature</td>
<td>the higher the elevation of the outlet, the warmer the temperature</td>
</tr>
<tr>
<td>water temperature</td>
<td>+P</td>
<td>BM thermal preference</td>
<td>water temp acts as filter for sensitive inverts</td>
</tr>
<tr>
<td>removal strategy rate</td>
<td>+P</td>
<td>sediment release rate</td>
<td>instantaneous release encourages faster release of sediment</td>
</tr>
<tr>
<td>reservoir - stored</td>
<td>-P</td>
<td>river - depth of fines</td>
<td>the less sediment stored in the reservoir, the more sediment depositied downstream</td>
</tr>
<tr>
<td>sediment volume</td>
<td></td>
<td>BM reophily, BM abundance</td>
<td>DS deposition causes short-term, local declines in the abundance of riffle benthos</td>
</tr>
<tr>
<td>river - depth of fines</td>
<td>+P</td>
<td>BM reophily</td>
<td>as the reservoir drains, the lentic taxa (oligochaete worms, chironomid midges, and caenid mayflies) will be replaced by lotic (mayfly, stonefly, and caddisfly genera) taxa</td>
</tr>
<tr>
<td>reservoir - stored</td>
<td>+P</td>
<td>BM reophily</td>
<td>particle sizes released from the reservoir following removal will influence downstream grain size as particles are flushed from reservoir</td>
</tr>
<tr>
<td>water volume</td>
<td></td>
<td>BM reophily</td>
<td>DS deposition causes short-term, local declines in the abundance of riffle benthos</td>
</tr>
<tr>
<td>reservoir - median</td>
<td>+P</td>
<td>river - grain size</td>
<td></td>
</tr>
<tr>
<td>stored grain size</td>
<td></td>
<td>BM reophily, BM abundance</td>
<td></td>
</tr>
<tr>
<td>reservoir - hydraulic</td>
<td>+I</td>
<td>reservoir - stored sediment volume</td>
<td>longer HRT allows greater deposition</td>
</tr>
<tr>
<td>residence time</td>
<td></td>
<td>BM abundance</td>
<td></td>
</tr>
</tbody>
</table>
conceptual model
(according to wikipedia)

“...the model may make explicit assumptions that are known to be false (or incomplete) in some detail. Such assumptions may be justified on the grounds that they simplify the model while, at the same time, allowing the production of acceptably accurate solutions.”
SIMPLE PROCESSES

• focused on sediment

• other processes omitted (predation, vegetation, food web and nutrient cycles, temperature)

SIMPLE COMMUNITIES

• focused on invert abundance, richness, and mobility

• other metrics omitted (functional richness, life history, life span, morphology, feeding, thermal preference)
concept map – quantities and relationships

- RIVER
  - rate: transport of fines
  - rate: flood frequency
  - rate: supply of coarse material
    - median grain size
    - habitat quality
    - bar: pool

- RESERVOIR
  - rate: transport of stored sediment
    - stored sediment grain size
  - rate: hydraulic residence time

- DAM
  - rate: regulation by dam

Other:
- benthic macroinvertebrates
  - richness
  - abundance
  - mobility
concept map – quantities and relationships
concept map – quantities and relationships
scenarios

(1) set initiation conditions
(2) simulate invertebrate response to:
  • removal strategy (staged breaching, blow and go)
  • dam operation (hydropeaking vs. irrigation)
scenarios - dependencies and initial values
state transitions
documenting assumptions - reducing ambiguity
scenario 1 – dam operation

- Hydropeaking
- Irrigation diversion
scenario 2 – removal strategy

“blow and go”

staged breaching
interpretations

dam removal - disturbance as described by a “discrete event in time that disrupts ecosystem, community, or population structure, and changes resources, substrate availability, or the physical environment” (White and Pickett 1985).
model interpretations – “classes” of responses

- instantaneous (e.g. fish migration up following removal, HRT)
- episodic (e.g. storm-based erosion)
- cascading/threshold (e.g. nonmigratory fish and benthos; vegetation)

what are the mechanisms for these, how do we monitor them, and how can we influence them?
mechanisms?

- effect size (e.g. HRT, classification (Brandt 2000), T*, S* (Grant et al. 2003))
- “interventions”
- historical and landscape conditions
towards hypotheses

• response classes are consistent across sites

• distinct responses of bioindicators (abundance, richness, traits) over:
  – time
  – site characteristics
  – space!? 

• other site characteristics (e.g. HRT, Qs/Vs) are reliable indicators of response “magnitude/presence”
QR challenges: parameterization

The quality of model predictions is critically related to the parameterization of the qualitative model:

**Challenges:**

- converting qualitative values to measurable and meaningful field measurements

**Solutions:**

- sensitivity analysis to identify how quantity spaces can be defined operationally
- ecologically-relevant definitions of normal/undisturbed/equilibrium as a landmark point for QS
model testing and application

- Chiloquin Dam (Sprague River 2008)
- Brownsville Dam (Calapooia River 2007)
- Sodom Dam (Calapooia River 2009)
- Coal Creek Dam (Coal Creek 2007)
- Savage Rapids dam (Rogue River 2008)
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