Response of taxonomic groups in streams to gradients in resource and habitat characteristics

Richard K. Johnson
Dept. of Aquatic Sciences and Assessment
SLU, Uppsala
What it’s about

• Ecological drivers & scales
• Land use & hydro-morphology
• Response of stream assemblages to resource and habitat gradients
• Multiple-stressor effects on stream invertebrates (special thanks to Colin Townsend)
Geographically distinct regions often have their own distinct flora and fauna…

**Regional diversity** is the result of evolutionary history (rates of speciation and extinction), and sets the upper limit of local diversity.

**Local diversity** is constrained by the size of the regional species pool, but often also the size and heterogeneity of the habitat, and the outcome of interactions.
Conceptual models of biological change

adapted after Frissell et al. 1986, Poff 1997 and others

Adapted from P. Verdonschot
Birds’ (landscape) perspective

- large scale patterns in vegetation are evident
- spatial scales > 10 km²
- temporal scales of usually > 10’s of years
Bugs’ (local) perspective

- individual particles are important
- spatial scales usually < 1 m$^2$, often cm$^2$ scale
- temporal scales of hours to years
Predictors of stream assemblages (pCCA)

- **VE** - 42% (macrophytes) to 58% (diatoms) in lowland streams
- **Unique effects:**
  - **Geo:** 5% (inverts) to 7% (fish)
  - **Regional:** 12% (diatoms) to 14% (inverts)
  - **Local:** 16% (macrophytes) to 29% (inverts)
- **Shared variance:** 1% (inverts) to 22% (diatoms)
Effects of global change on streams

CC predicts – greater & more intense precipitation

more spates & droughts

- intensification agriculture
- abandoning agriculture

siltation, scouring

- deteriorating morphology
- deteriorating biodiversity

- improving morphology
- improving biodiversity

Adapted from P. Verdonschot
Change, Yes we can: Climate $\leftrightarrow$ hydrology $\leftrightarrow$ species

- Climate model: PRUDENCE B2 med-low (RCAO HadAM3H model)
- Catchment rainfall-runoff model: IHACRES

- Catchment model explained 69% of discharge variation
- UK chalk geology: higher winter discharges

(data CEH)

Adapted from P. Verdonschot
Change, Yes we can: **Land-use ↔ Habitat ↔ species**

- Siltation at the disturbed site due to land-use change (drainage)
- Most habitats present at disturbed site, though many < 5%

*(Adapted from P. Verdonschot)*
Land-use and hydromorphology - predictors of fish assemblages

46 Fish taxa
- 11 spp selected

- Clustering by SOM (Self Organising Map)
- Prediction by MLP-BP (Multi-Layer Perceptron with backpropagation algorithm)

• Land-use and hydromorphology were good predictors of fish assemblages
• Climate, land-use and local physical descriptors were species-specific

Adapted from P. Verdonschot
STAR - streams types across Europe
STAR stream types

Lowland streams
Main stress gradients

- Land use
- Eutrophication / organic pollution
- Hydromorphology
Sampling

Standardized sampling:

- **Fish** (electrofishing, 2 runs, 10 x width)
- **Inverts** (multihabitat, n = 20, composite)
- **Macrophytes** (100-m stream stretch)
- **Diatoms** (5 cobbles)
Environmental gradients - lowland streams

48% of variance explained by PC1 and PC2.

1st PC: % forest (+); % pasture (-), nutrients (-).

2nd PC: CPOM (+); stream order (-), cobble (-).

Studied biological response to these two orthogonal gradients.
Analyses

• Regressed measures of diversity (5) and assemblage composition (2) to two gradients (n = 66 streams)

• Three metrics of response models:
  • Precision (coefficient of determination),
  • Sensitivity (magnitude of change, slope),
  • Error (RMSEP)
Fig. 4. Coefficients of determination ($R^2$ values) of diversity and assemblage composition of four taxonomic groups in lowland ($n = 66$) and mountain ($n = 77$) streams against two environmental gradient extracted using principal component analysis. Circles show lowland and triangles show mountain streams.
Assemblage response to resource gradient

- Responses were species-specific
- Diatom assemblages collapsed at ca 50 µg P/L, invertebrates much higher

Johnson & Hering 2009 (J. Applied Ecology)
Assemblage response to habitat gradient

- All groups showed very weak responses to habitat gradient

*Johnson & Hering 2009 (J. Applied Ecology)*
Not giving up; another approach

PCA used to isolate high & low resource & habitat groups

Johnson unpubl.
• All four groups showed clear differences between H and L resource groups

• ANOSIM – R values between 0.36 (macrophytes) and 0.81 (invertebrates)

Johnson unpubl.
Response to Habitat
(blue = H, red = L)

- All four groups showed considerable overlap between H and L habitat quality

- ANOSIM – only fish and invertebrates differed, but R values were low (< 0.20)

Johnson unpubl.
Local factors more important than regional

Response to resource gradient: diatoms $\geq$ macrophytes $> \text{fish} \approx \text{invertebrates}$

Response to habitat gradient: macrophytes $\approx$ diatoms $> \text{fish} \approx \text{invertebrates}$

Response trajectories differed between taxonomic group and stressor (nutrients – moderate to strong; hydromorphology – weak)

BUT...multiple stressors at work?
Multiple stressors the norm not the exception!

- **Simple outcome**: additive or multiplicative effect of all stressors combined equal to sum or product of individual effects.

- **Complex outcome**: synergistic or antagonistic combined effect larger or smaller than predicted from single effects.

*Adapted from Townsend et al. 2008 (J. Applied Ecology)*
Understanding effects of multiple stressors

- **Field survey** - realistic but lacks control
- **Channel experiment** - controlled but realism in question (i.e. appropriate temporal and spatial scale)
- **Reach-scale experiment** - reasonably controlled and reasonably realistic

*Adapted from Townsend et al. 2008 (J. Applied Ecology)*
The survey

- 32 grassland streams in summer
- 2nd order, homogeneous land-use (e.g. tussock grass (least impaired) or pasture with sheep [impaired])
  - % sediment cover (S)
  - $\log_{10}\text{DIN} + \log_{10}\text{SRP}$ (N)
- All variables normalized and scaled 0-1
- Multivariate models to quantify individual stressor effects and interaction $Y = b_1S + b_2N + b_3SN + b_0$

Adapted from Townsend et al. 2008 (J. Applied Ecology)
The reach-scale experiment

- Nine relatively unimpacted streams (50 m reaches, 5 week experiment)
- Complete factorial design - ambient, intermediate and high levels of both nutrients and sediment
- Repeated measures ANOVA

Adapted from Townsend et al. 2008 (J. Applied Ecology)
The channel experiment

- Eighteen channels (18 d experiment)
- Complete factorial design - nutrients and sediment, also normal and 85% reduced discharge
- ANOVA: important terms are sediment and nutrients and the interactions:
  - Sediment * Nutrients
  - Sediment * Discharge
  - Nutrients * Discharge

Adapted from Townsend et al. 2008 (J. Applied Ecology)
EPT taxon richness

<table>
<thead>
<tr>
<th>Survey</th>
<th>Reach</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPT richness</td>
<td>EPT richness</td>
<td>EPT taxon richness</td>
</tr>
</tbody>
</table>

- **single stressor:** sediment
- **multiple stressors:** sediment*nutrient antagonism
- **multiple stressors:** sediment*discharge antagonism

Adapted from Townsend et al. 2008 (J. Applied Ecology)
<table>
<thead>
<tr>
<th>Survey</th>
<th>Reach</th>
<th>Channel</th>
</tr>
</thead>
</table>

- **Survey:** Multiple stressors: nutrient*sediment antagonism
- **Reach:** Multiple stressors: sed and nutrients multiplicative
- **Channel:** Multiple stressors: sediment*discharge antagonism

*Adapted from Townsend et al. 2008 (J. Applied Ecology)*
Relative importance of nutrients, sediment and discharge?

<table>
<thead>
<tr>
<th></th>
<th>Nutrient effects</th>
<th>Sediment effects</th>
<th>Discharge effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survey</strong></td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>Reach experiment</strong></td>
<td>5</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
| **Channel experiment** | 8               | 13               | 16               | Adapted from Townsend et al. 2008 (J. Applied Ecology)
Summary - multiple stressors

- Sediment often more influential than nutrients
  - Abstraction perhaps more important than both

- Surveys and experiments both offer something (not always the same result)
  - Survey - responses confounded by uncontrolled influences?
  - Experiments - scale appropriate?

- Survey and, especially, experiments revealed many complex interactions
  - Managers may get it wrong if multiple stressors act in complex ways

Adapted from Townsend et al. 2008 (J. Applied Ecology)
Focus on nutrients vs hydromorphology

**Web of Science®**
1980-2009 (22/2)

Databases=SCI-EXPANDED.  
stream* and nutrient* = **3839**  
stream* and hydromorpho* = **68**

**Since acceptance of WFD**
Databases=SCI-EXPANDED.  
stream* & nutrient* = **2661**  
stream* & hydromorpho* = **61**
Hydromorphology alterations of streams

Is there a problem? Yes

Is the problem easy to measure? Not really

Do we know what to measure? Nope
Some questions

- How do we best establish the **reference condition** of streams where present-day analogues are lacking or too few (e.g. lowland streams)?

- Without drastically altering the landscape, is it possible to reconstruct the natural or near natural hydro-geo-morphology and structure and function of streams? How important is **spatial configuration in stream restoration**, e.g. for hydrology, for dispersal and colonization, etc?

- How important are **terra-aquatic linkages** for stream structure and function? Can use of large woody debris in stream restoration replace the function of mature riparian habitats?

- Many streams are affected by **multiple stressors**. Is it possible to separate the effects of multiples stressors on stream systems to best design and recommend management programs?
“Landscape where the richness element is a little sunshine innocent..”

Thoreau “Walden or life in the woods”