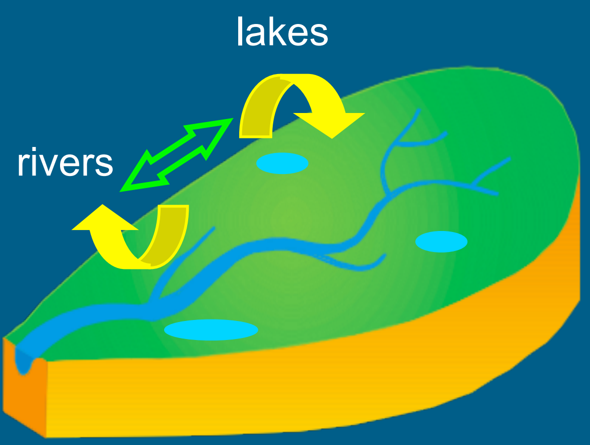
Response of species, habitats and ecosystems to impairment



Richard K. Johnson
SLU, Sweden

Landscape classification for multi-ecosystem management and conservation

A system to classify freshwater ecosystems for

Table 1. Common management and conservation goals and end points best suited for landscape-scale management and conservation of ecosystems.

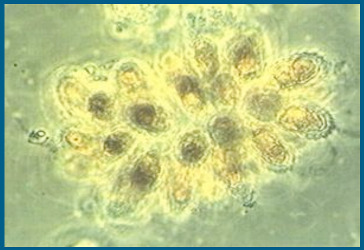
Goal	Example	Predictive classification model end point
Assess status	Conduct surveys to quantify ecosystem characteristics (i.e., physical, chemical, and biological features).	Homogeneous states
Set restoration or rehabilitation targets	Choose a minimally disturbed restoration goal using available data (e.g., nutrient levels, biological assemblages).	Homogeneous states or responses
Conserve biota and habitat	Identify ecosystems of special interest with regard to rare or endangered biota or habitats, or overall biodiversity.	Homogeneous states
Quantify response to stressors	Determine relationships between response variables and human activities.	Homogeneous responses
Detect temporal trends	Determine temporal responses to mitigation actions.	Homogeneous states or responses
Set policy	Designate standards for ecological integrity or human use.	Homogeneous states or responses

Soranno et al. 2010

Theory behind the use of multiple indicators

Different organism groups react differently to human-induced stress

- response times may be inversely related to generation times
- complementary early- and late-warning indicators may constitute a robust design

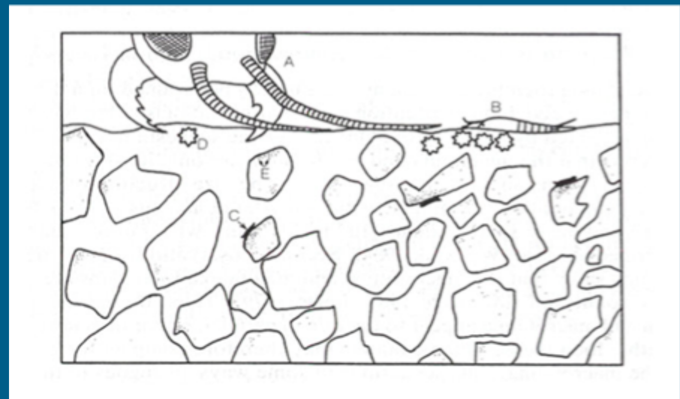


Responses to stress are scale dependent

- habitat/ecosystem/catchment

Bugs' (local) perspective

- individual particles are important
- spatial scales usually < 1 m^2, often cm^2 scale
- temporal scales of hours to years

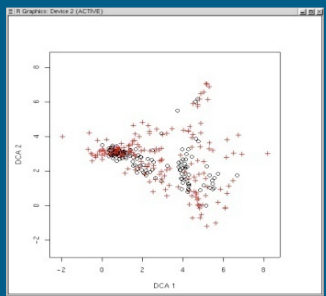


Picture taken from Lodge et al. 1988

Birds' (landscape) perspective

- large scale patterns in vegetation are evident
- spatial scales > 10 km^2
- temporal scales of usually > 10's of years

Background from **STAR to WISER**



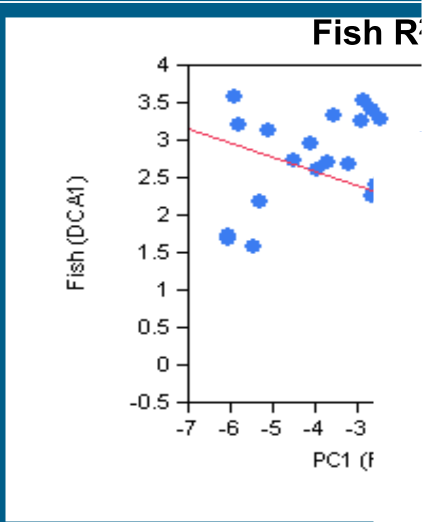
Main stress gradients

Land use

Eutrophication / organic pollution

Hydromorphology

Assemblage response to resource



Freshwater Biology (2006) **51**, 1757–1785 doi:10.1111/j.1365-2427.2006.01610.x

APPLIED ISSUES

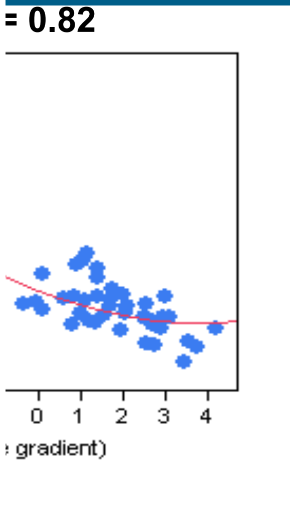
Assessment of European streams with diatoms, macrophytes, macroinvertebrates and fish: a comparative metric-based analysis of organism response to stress

DANIEL HERING,* RICHARD K. JOHNSON,† SANDRA KRAMM,* STEFAN SCHMUTZ,‡ KRZYSZTOF SZOSZKIEWICZ§ AND PIET F. M. VERDONSCHOT¶

*Department of Hydrobiology, University of Duisburg-Essen, Essen, Germany
†Department of Environmental Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden
‡Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Applied Life Sciences, Vienna, Austria
§Department of Ecology and Environmental Protection, Agricultural University of August Cieszkowski, Poznań, Poland
¶Alterra Green World Research, Freshwater Ecology, Wageningen, The Netherlands

SUMMARY

1. Periphytic diatoms, macrophytes, benthic macroinvertebrates and fish were sampled with standard methods in 185 streams in nine European countries to compare their response to degradation. Streams were classified into two main stream type groups (i.e. lowland, mountain streams); in addition, the lowland streams were grouped into four more specific stream types.
2. Principal components analysis with altogether 43 environmental parameters was used to construct complex stressor gradients for physical–chemical, hydromorphological and land use data. About 30 metrics were calculated for each sample and organism group. Metric responses to different stress types were analysed by Spearman Rank Correlation.
3. All four organism groups showed significant response to eutrophication/organic pollution gradients. Generally, diatom metrics were most strongly correlated to eutrophication gradients (85% and 89% of the diatom metrics tested correlated significantly in mountain and lowland streams, respectively), followed by invertebrate metrics (91% and 59%).
4. Responses of the four organism groups to other gradients were less strong; all organism groups responded to varying degrees to land use changes, hydromorphological degradation on the microhabitat scale and general degradation gradients, while the response to hydromorphological gradients on the reach scale was mainly limited to benthic macroinvertebrates (50% and 44% of the metrics tested correlated significantly in mountain and lowland streams, respectively) and fish (29% and 47%).
5. Fish and macrophyte metrics generally showed a poor response to degradation gradients in mountain streams and a strong response in lowland streams.
6. General recommendations on European bioassessment of streams were derived from the results.



- Responses
  - Diatom a… ates much higher.

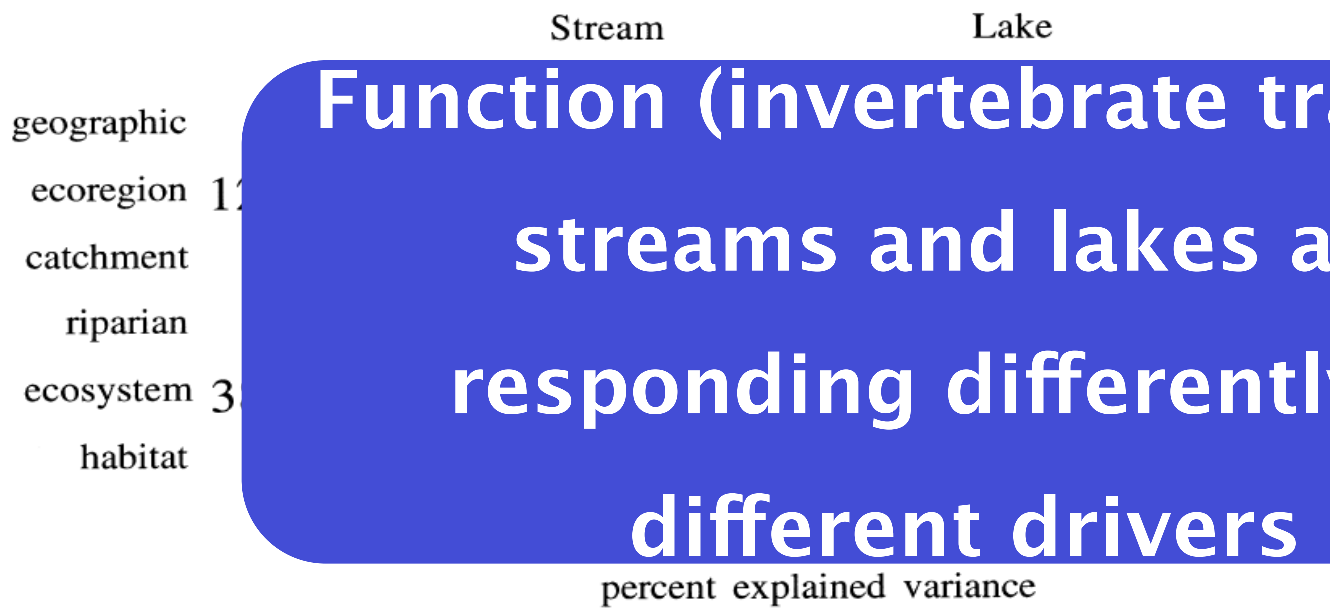
Johnson & Hering 2009

Putting within-system (habitat) and among-system (waterbody) knowledge of organism response to different stressors to work in catchment management.

To compare the response signatures of different organism groups <u>between habitats</u> within waterbodies and <u>among categories</u>.

It's all about the money…

Inherent differences between lentic & lotic systems



Function (invertebrate traits) of streams and lakes are responding differently to different drivers

of different levels
eographic posi-
l redundancy
mposition of lakes
d line shows the
of Efron's per-
ap randomisation test
with 1000 iterations.

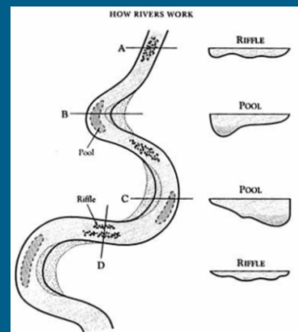
Johnson et al. 2004

© 2004 Blackwell Publishing Ltd, *Freshwater Biology*, 49, 1179–1194

Three main hypotheses

1) The taxonomic assemblages differ in their response to environmental stressors
2) Response signatures differ between systems (lakes and streams) and habitats within systems

- Response signatures (taxon and habitat) can be used to select complementary indicators and design more cost-effective management



WISER

Methods – Study site selection

- Harmonized taxon by site data for lakes and streams from previous EU projects and regional data bases (collated by WISER)
- Stratified to ecosystems where multiple taxonomic groups (n = 3-4) had been measured:
  - 67 stream sites (Germany): water quality, phytobenthos, macrophytes, benthic invertebrates and fish
  - 59 lake sites (UK – Nordic – Baltic): water quality, phytoplankton, macrophytes and fish
- Main environmental gradients: eutrophication, hydromorphological alteration

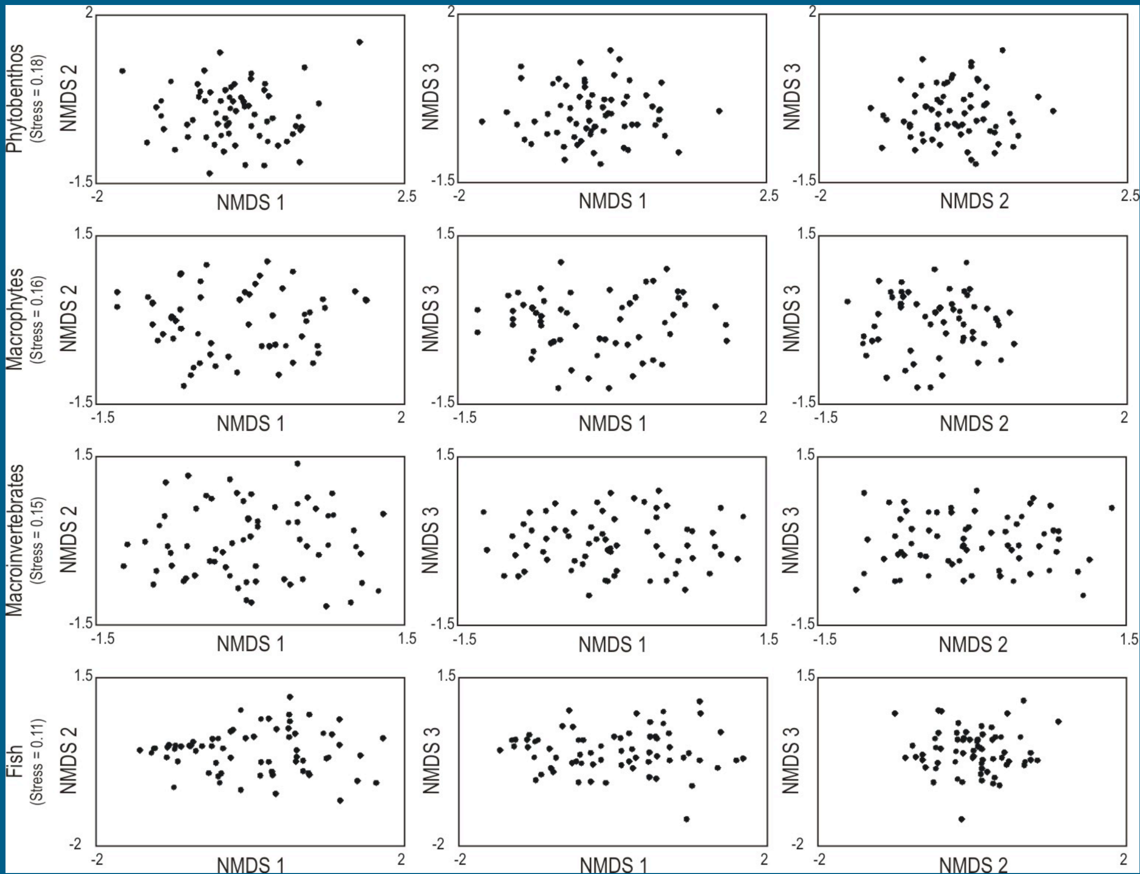
Methods – statistical analyses

- **NMDS** to determine the biological turnover and condense the species by site matrix into three indices (axes) of community composition
- **PCA** to assess the structure of the environmental data and to reduce the structure to a lower number of environmental gradients
- **Regression** analysis to determine response signatures (linear and second-order polynomial)
  - *Precision* as coefficient of determination (adjusted R^2)
  - *Sensitivity* as the magnitude of change (slope)

NMDS revealed different patterns of community dissimilarity among all taxonomic groups (1)

Streams

- main variance on 1st NMDS axis
- all taxonomic groups showed relatively homogenous distribution of sites in ordination space without aggregations into site clusters

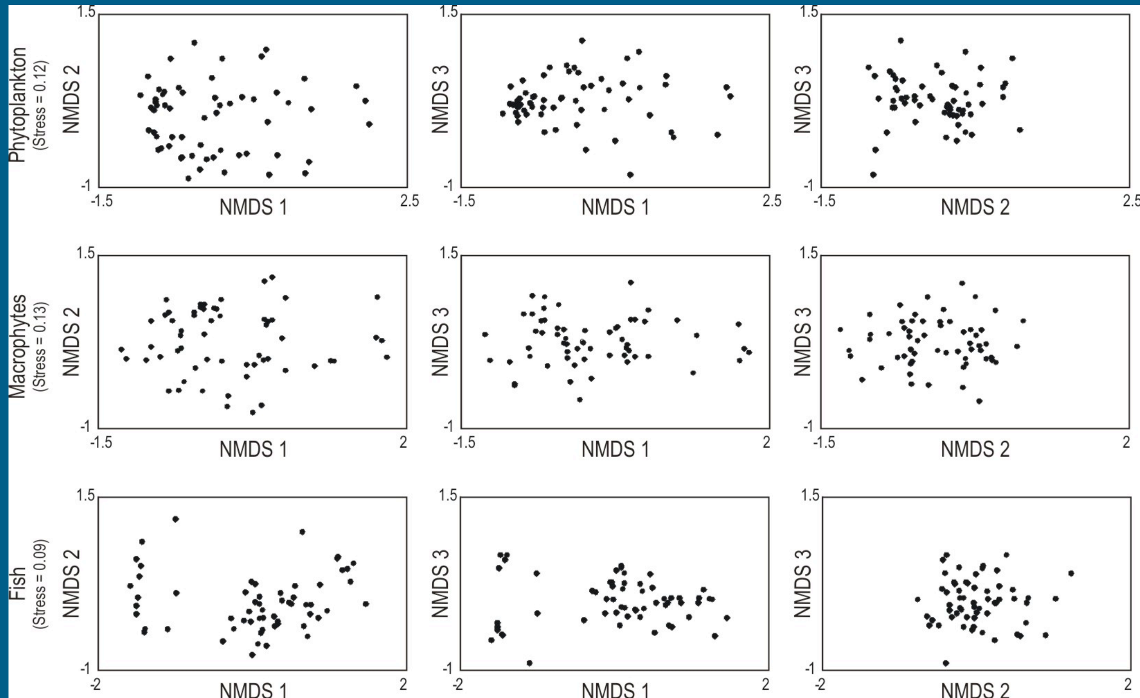


WISER

NMDS revealed different patterns of community dissimilarity among all taxonomic groups (2)

Lakes

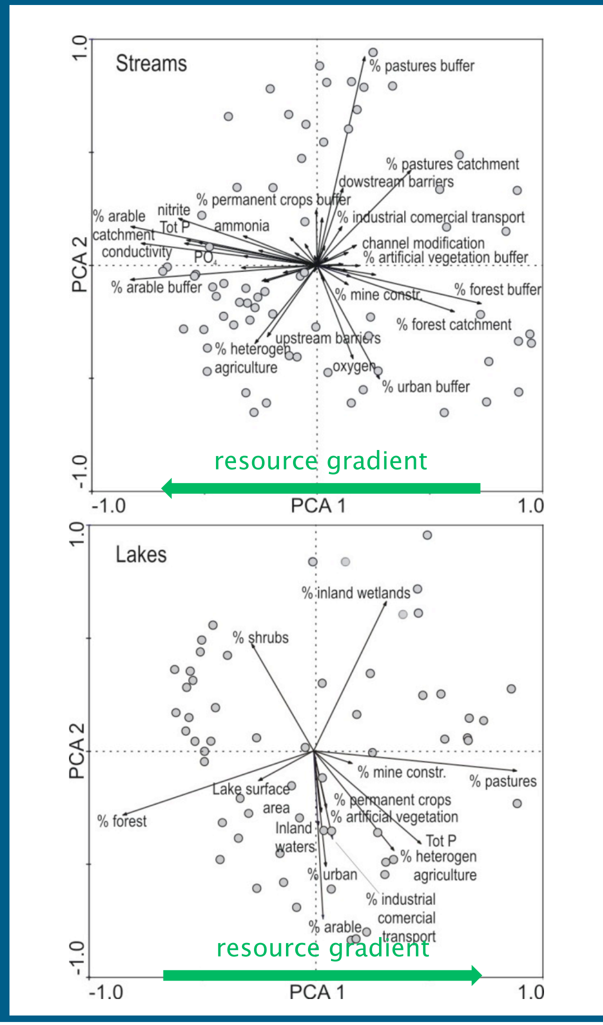
- main variance on 1st NMDS axis
- clustering of sites more heterogeneous, particularly for fish (sites split into two groups)



WISER

Environmental gradients (PCA)

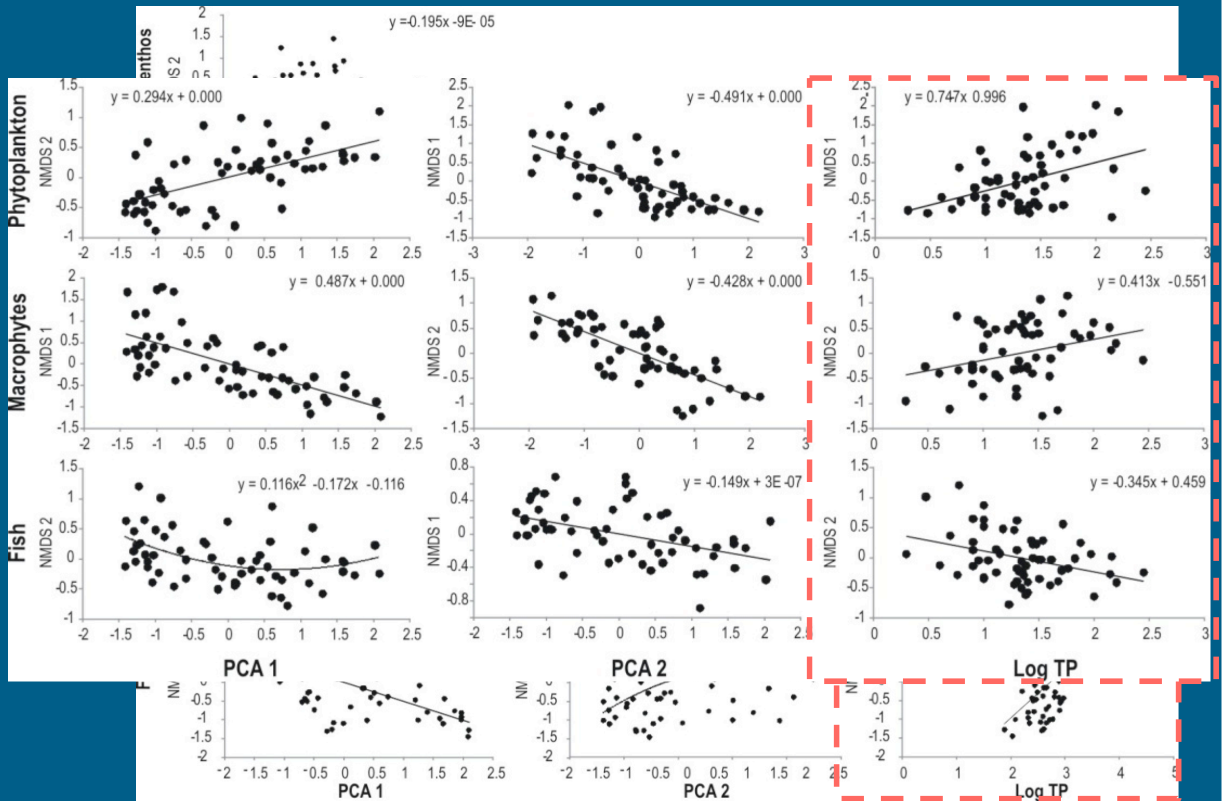
- **1st PCA** was related to resources (nutrients and agricultural land use): **streams (30%) and lakes (28%)**
-
- 2nd PCA related to land use: **streams (17%)**, e.g.% pastures (+) and urbanization (-); **lakes (21%)**, % wetlands (+),% arable and % urbanized land (-)



Across-taxon response to resources

Linear regression (NMDS 1-3)

- Two orthogonal complex gradients (PC1 & PC2) and TP
- Taxonomic group response differed both among groups and between habitat types (streams *vs* lakes)



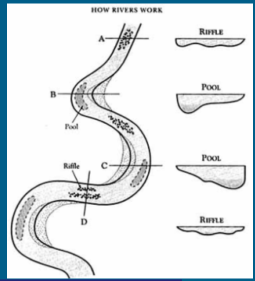
Across-taxon response to resources

Linear regression (NMDS 1-3)

- Few significant relationships
  - Streams: fish and invertebrates (NMDS 1)
  - Lakes: fish (NMDS 1 & 2) and phytoplankton (NMDS 1)

	Response	PC 1 Precision	PC 1 Sensitivity	PC 2 Precision	PC 2 Sensitivity
	NMDS	adj R2	|Slope|	adj R2	|Slope|
STREAMS					
Fish	1	0.470	0.5	**0.168**	**0.609**
	2				
	3				
Invertebrates	1	0.407	0.414	**0.200**	**0.463**
	2				
	3				
Macrophytes	1	0.233	0.345	0.170	0.052
	2				
	3				
Phytobenthos	1				
	2	0.110	0.195		
	3				
LAKES					
Fish	1	0.118	0.43	**0.535**	**0.702**
	2	**0.154**	**1.066**		
	3	0.189	1.361		
Macrophytes	1	0.460	0.963		
	2			0.561	1.325
	3				
Phytoplankton	1	**0.252**	**0.775**	0.411	0.856
	2	0.334	1.173		
	3				

Within-system (habitat) comparisons

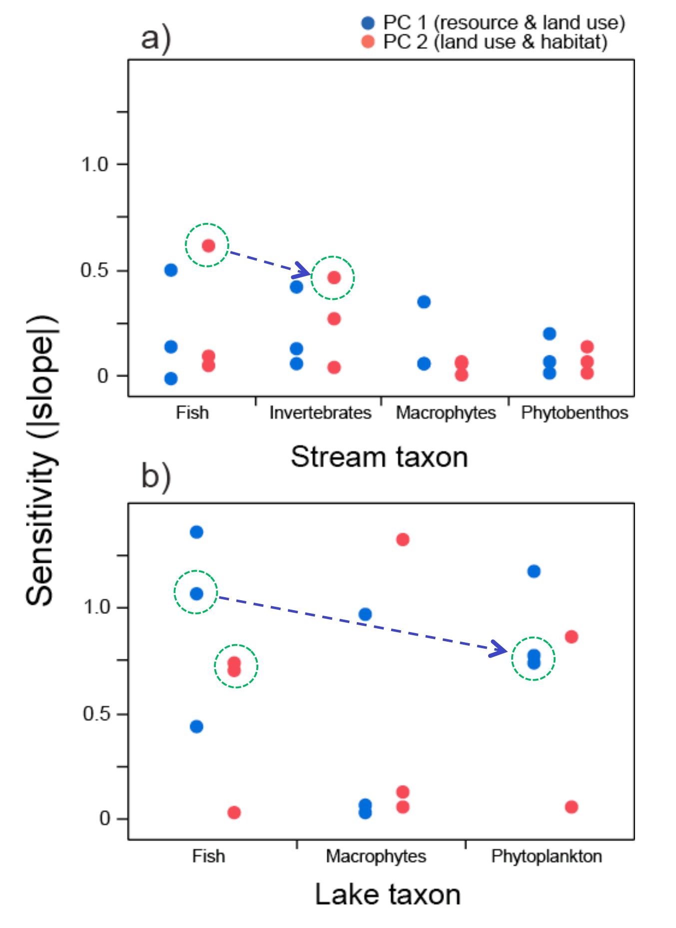


Expected response to elevated nutrients:

- **Lakes:** pelagic species respond > benthic species
- **Streams:** riffle species respond > pool species

Lake Pelagic vs Benthic –
NMDS 1-3 vs PC 1 & PC 2

- Sensitivity:
  - Streams PC1: ns; PC2: fish > invertebrates
  - Lakes PC1: fish > phytoplankton; PC2: fish



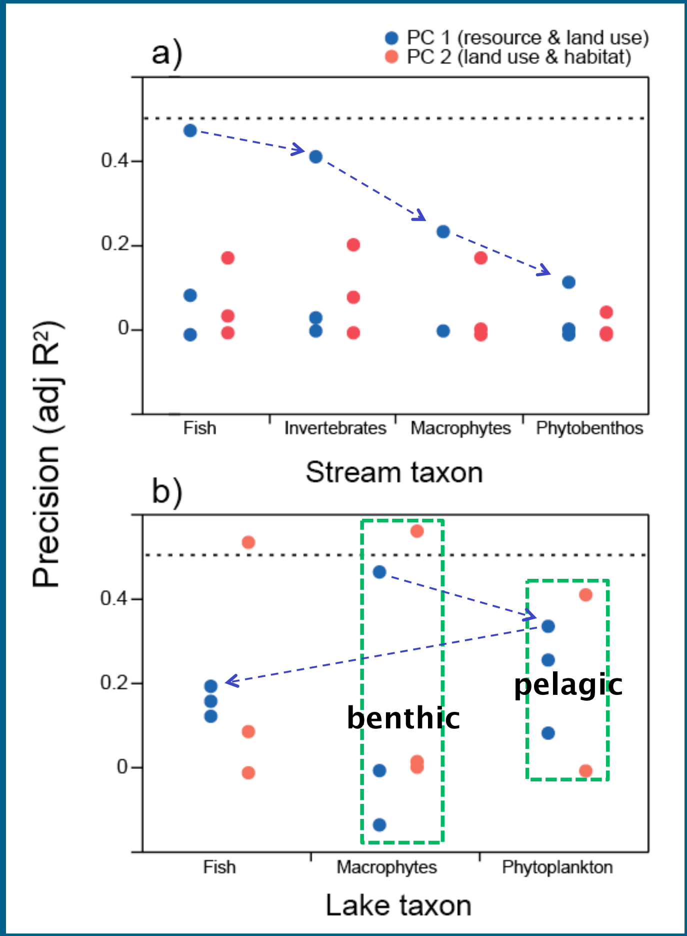
WISER

Lake Pelagic vs Benthic –
NMDS 1-3 vs PC 1 & PC 2

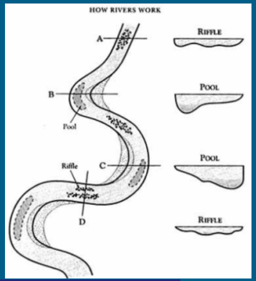
Precision:

Weak relationships often $R^2 < 0.50$

- Streams PC1: fish (0.47) ≥ invertebrates (0.41) > macrophytes (0.23) > phytobenthos (0.11)
- Lakes PC1: macrophytes (0.46) ≥ phytoplankton (0.41) > fish (0.19):PC2 macrophytes (0.56) ≥ fish (0.54) > phytoplankton (0.41)
- **H1: No support for pelagic > benthic response (but lake invertebrate data not available)**



Within-system (habitat) comparisons

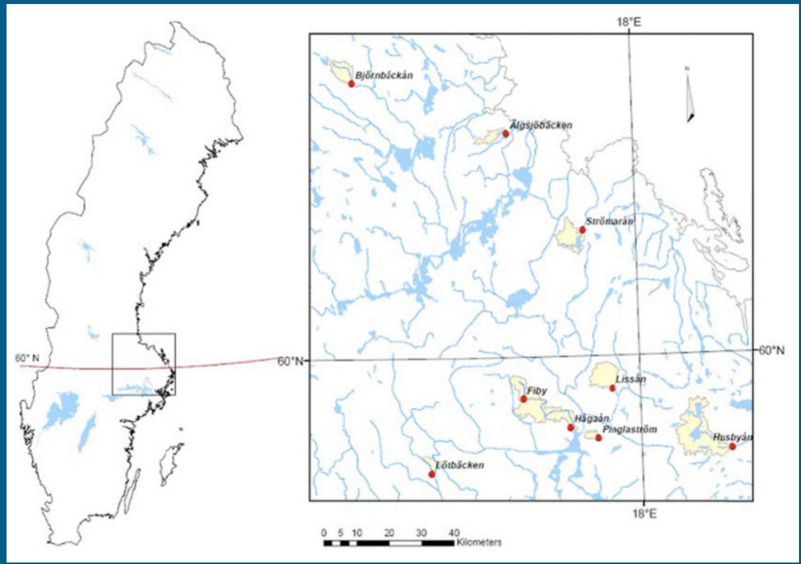


Expected response to <u>elevated nutrients</u>:

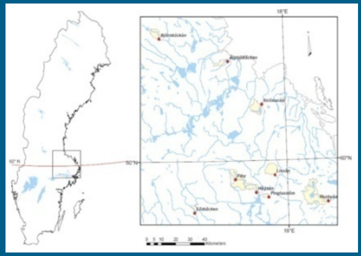
- **Lakes: pelagic species respond > benthic (littoral >> profundal) species**
- **Streams: riffle species respond > pool species**

Methods – Riffle vs Pool comparison

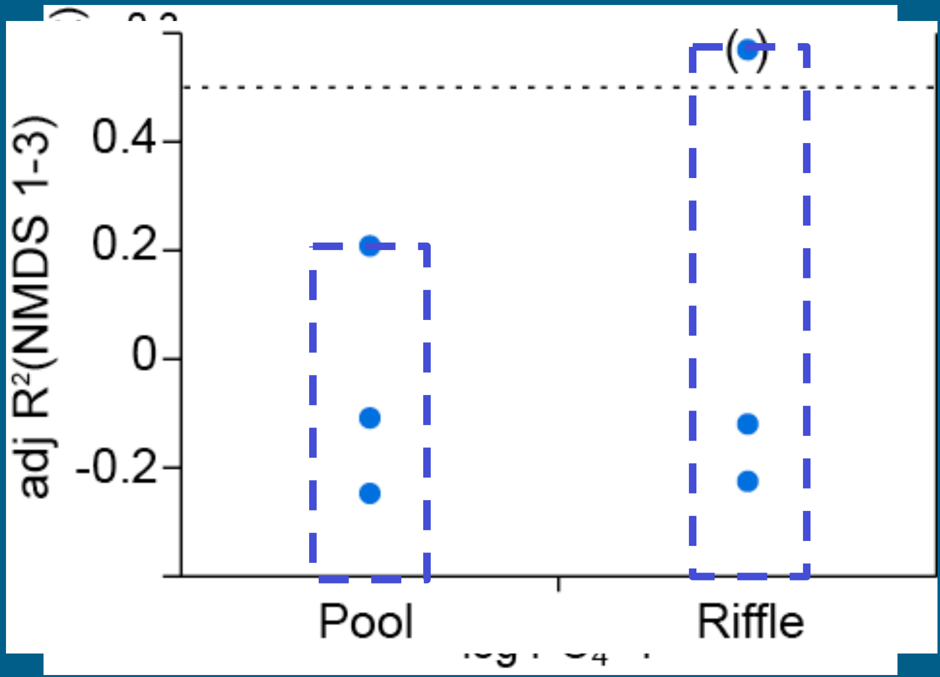
- Seasonal benthic invertebrate and environmental variables collected from 9 small to medium (orders 2-4), lowland (altitude 11 to 191 m a.s.l.) boreal streams in south-central Sweden.
- Main environmental gradients: forest to agriculture and elevated nutrients
  - 4 forested streams (73-98%); 5 agriculture (8.4-43% arable land/pastures)
  - width of undisturbed riparian vegetation (forested > 100m; agriculture 6 to 55 m)
- NMDS 1-3 used to test differences in pool and riffle sensitivity to disturbance



Stream Riffle vs Pool
– NMDS 1-3 vs log PO_4-P



- Precision:
  - Only one strong relationship (riffle NMDS2 $R^2 = 0.57$)
  - **H1: Partial support for riffle > pool response**



Among-system (category) comparisons

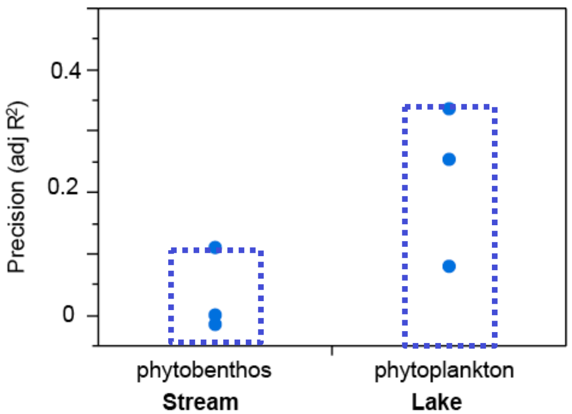
Expected response to land use (nutrients):

➢ **Stream** assemblages respond more rapidly to change than **lake** assemblages

✓ E.g. phytobenthos in streams >> phytoplankton in lakes

Across system assessment
(NMDS 1-3 for PB/P, MP, FI)

- Streams lower precision and sensitivity (highest fish) than lakes
- Lakes often higher precision and sensitivity for both PC1 ($p<0.05$) (e.g. fish) and PC2 (macrophytes)
- **H2: No support that stream assemblages respond > lake assemblages**
    - **BUT, resource gradient lengths**



Cross-system comparison of two primary producers. Expect "streams" to respond stronger than "lakes"

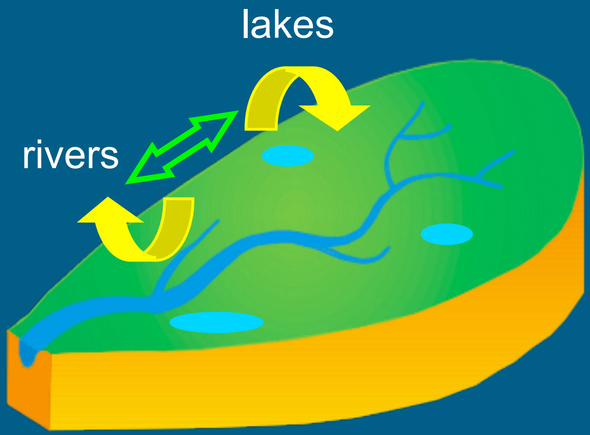
Summary - Within and among-system response of taxonomic assemblages to impairment

- Differences in stressor-response relationships
- Partial support for between-habitat differences
  - Lakes: No difference between pelagic vs benthic (but lake inverts not included)
  - Streams: Riffle > pool for nutrient enrichment
- No between-system differences (streams > lakes); (but gradient lengths differed [40-250 µg/LTP for lakes and > 200 µg/L TP for streams]

WISER

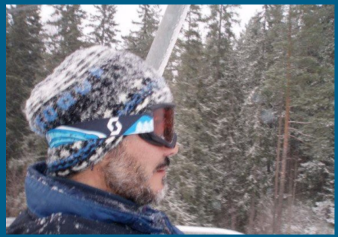
Incorporating science into management

- Use of robust stressor-response relationships
- Consider multiple spatial scales as drivers of change, acknowledging hierarchical structure and connectivity
- Select indicators considering both taxon and habitat-specific differences in response to degradation (and recovery)



Thanks

My co-authors



The WISER partners

The EU 7th Framework Programme for financial support

SEVENTH FRAMEWORK PROGRAMME