Linkages between aquatic ecosystem health and human activities in the surrounding landscape: The case of North Saskatchewan River Watershed

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NSWA
NORTH SASKATCHEWAN WATERSHED ALLIANCE

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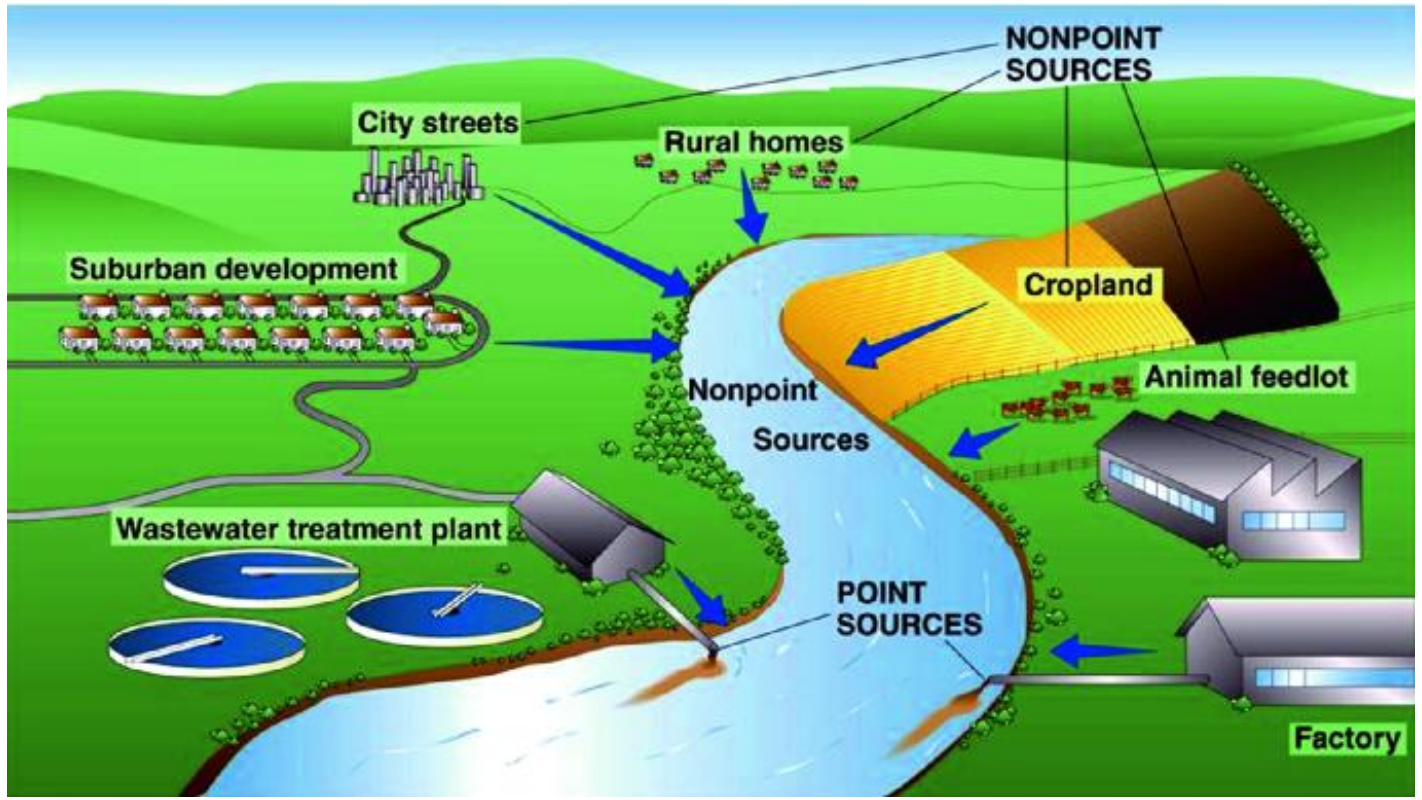
Landscape Influences of Stream Ecosystems



Source: Breaban and Breaban (2019)

Streams receive water and material from the surrounding landscape

↓ **Human activities**

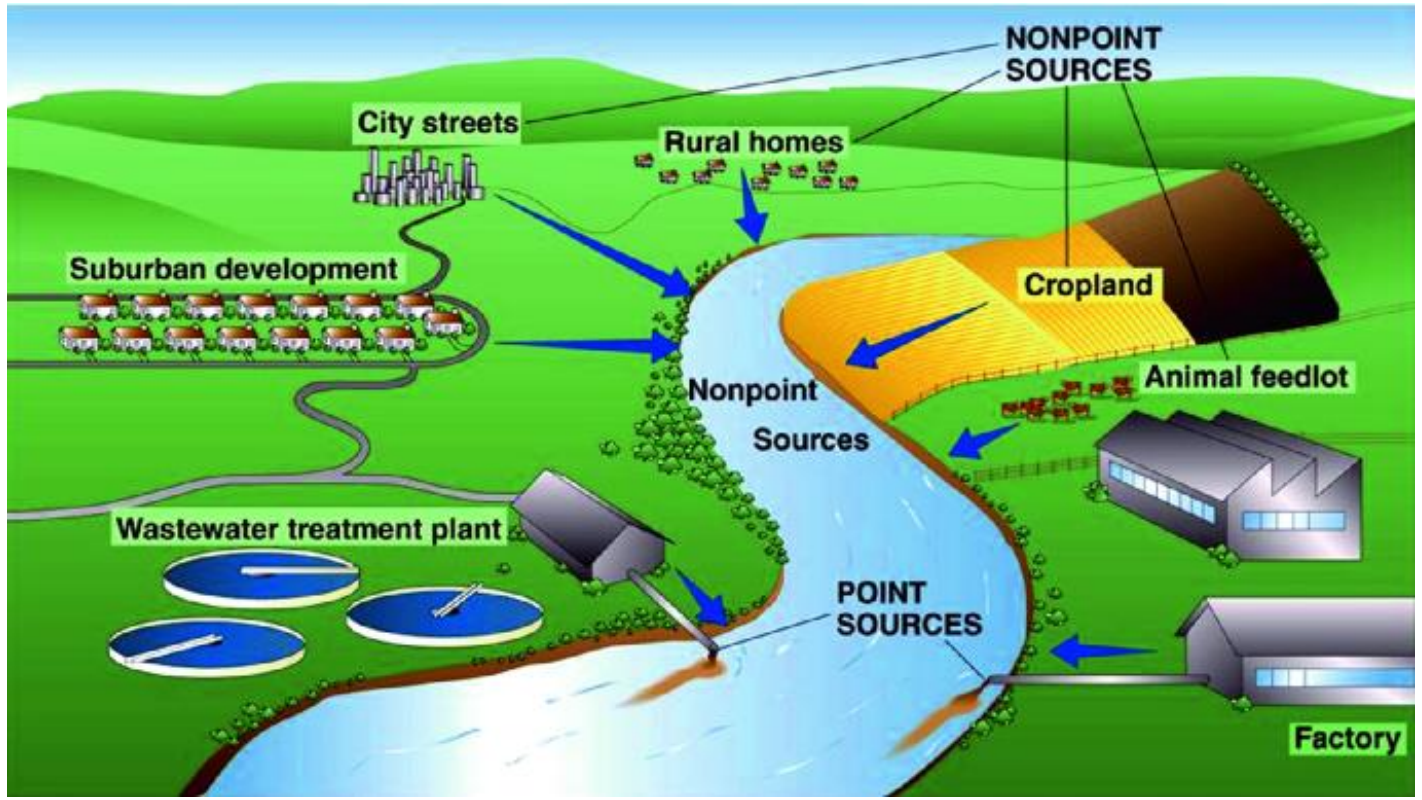
Alterations in flow and material fluxes from the landscape

Cumulative Effects

"Cumulative effects is a change in the environment caused by multiple interactions among human activities and natural processes that accumulate across space and time."

Canadian Council on Environmental Quality (2014)

Landscape Influences of Stream Ecosystems



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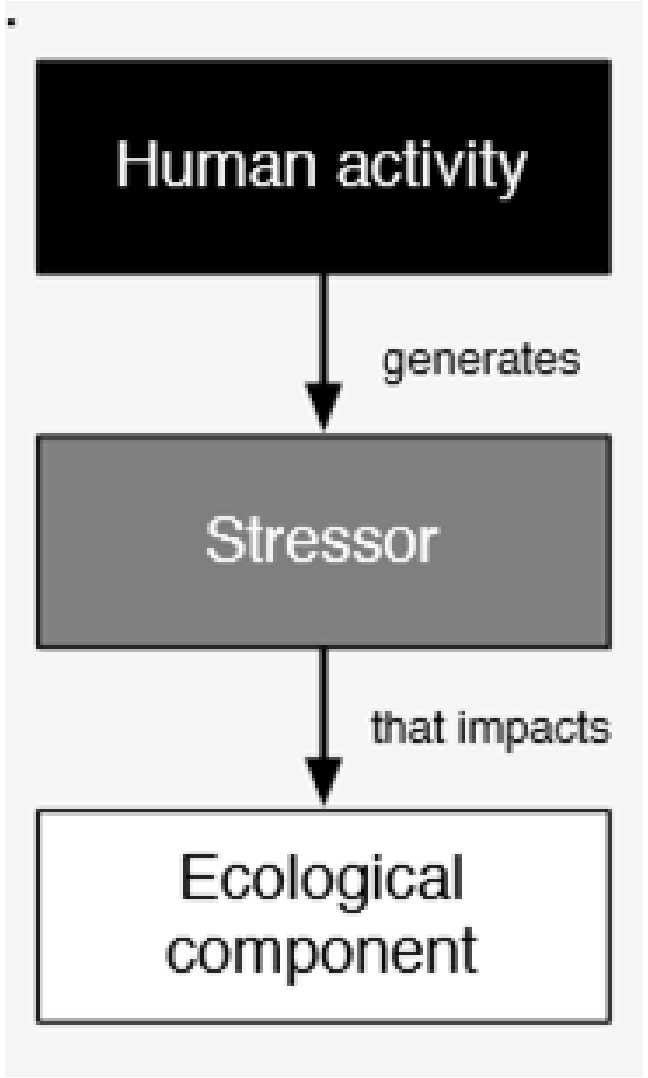
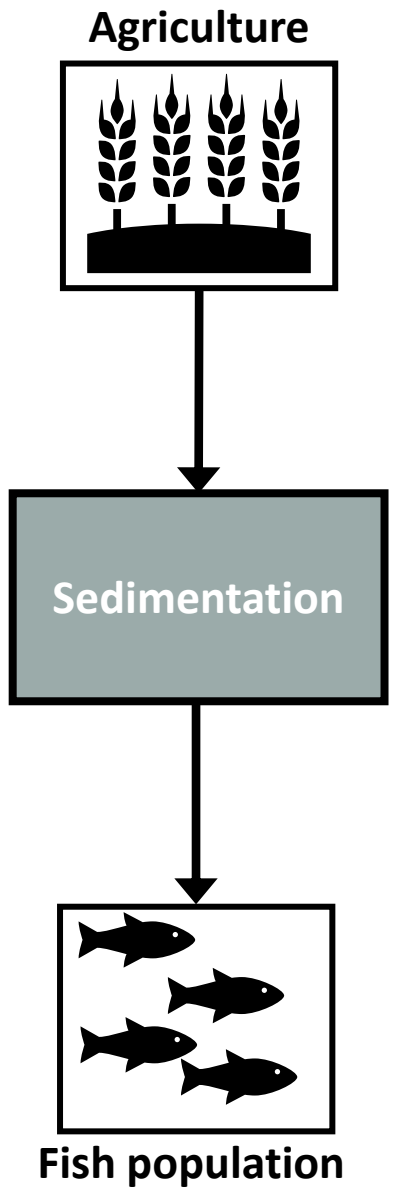
Alterations in flow and material fluxes from the landscape

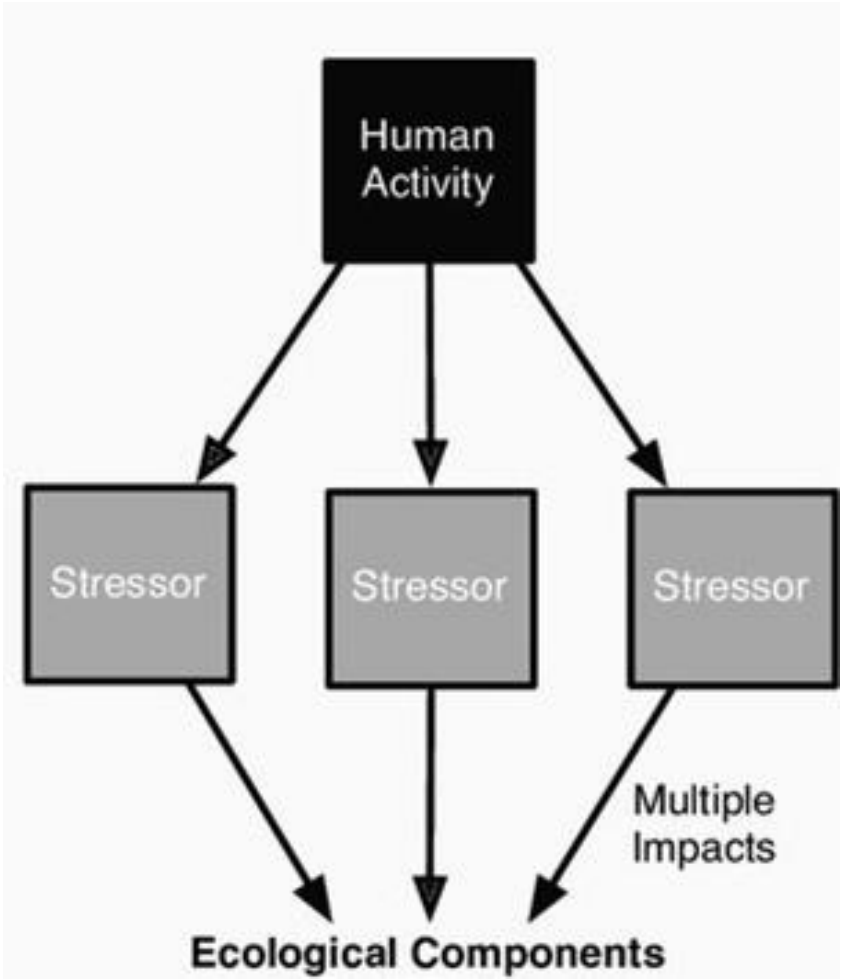
Pathway of Effect



Source: Clarke Murray et al. (2014)



Single Activity → Multiple Stressors



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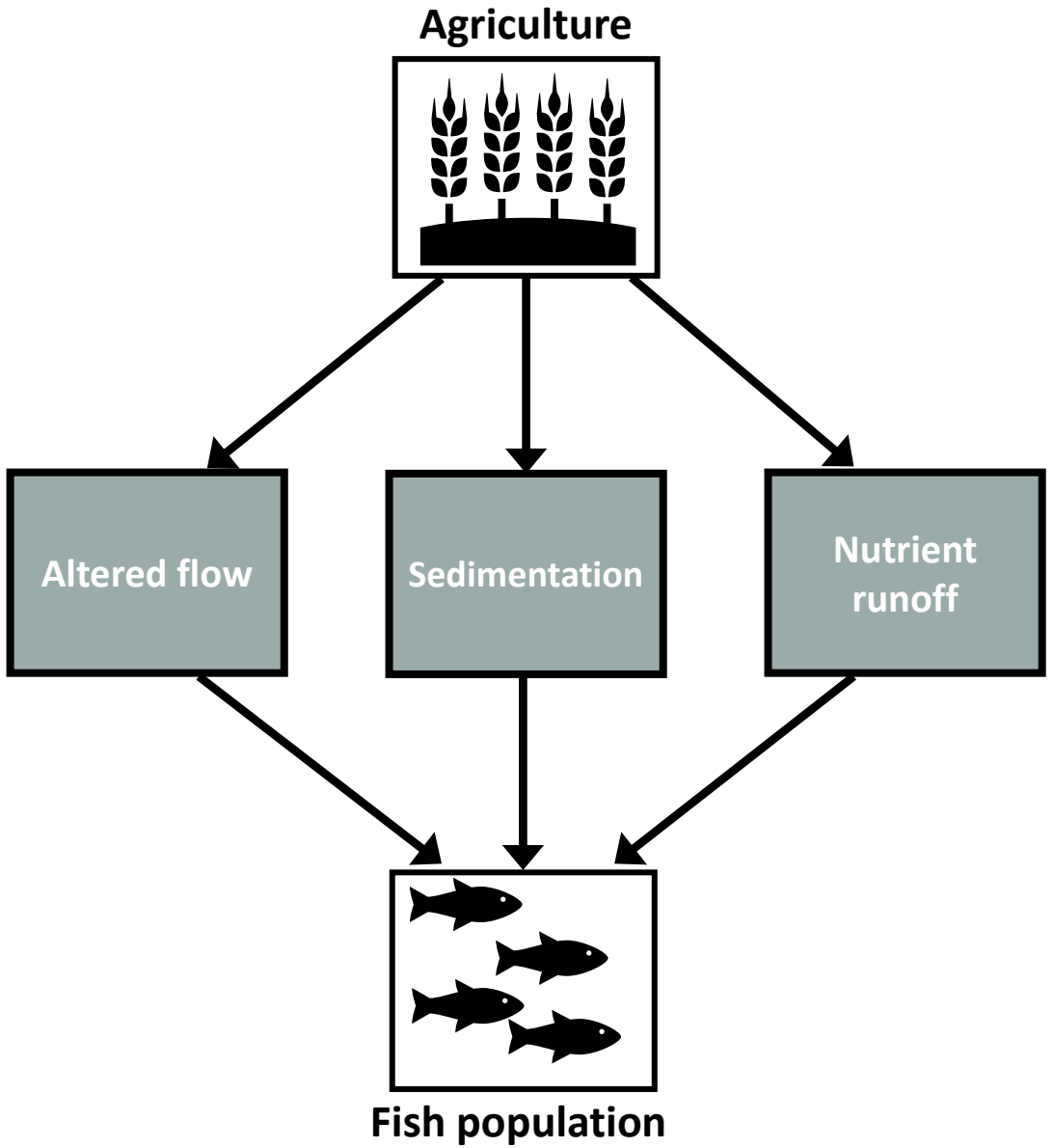
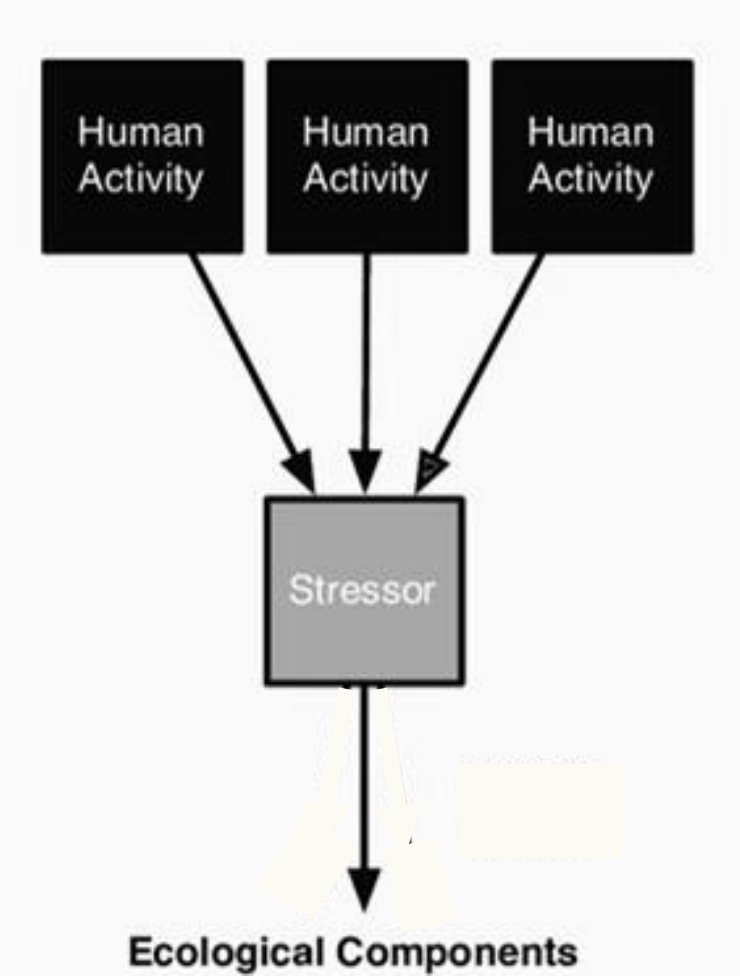


Multiple Activities → Single Stressor



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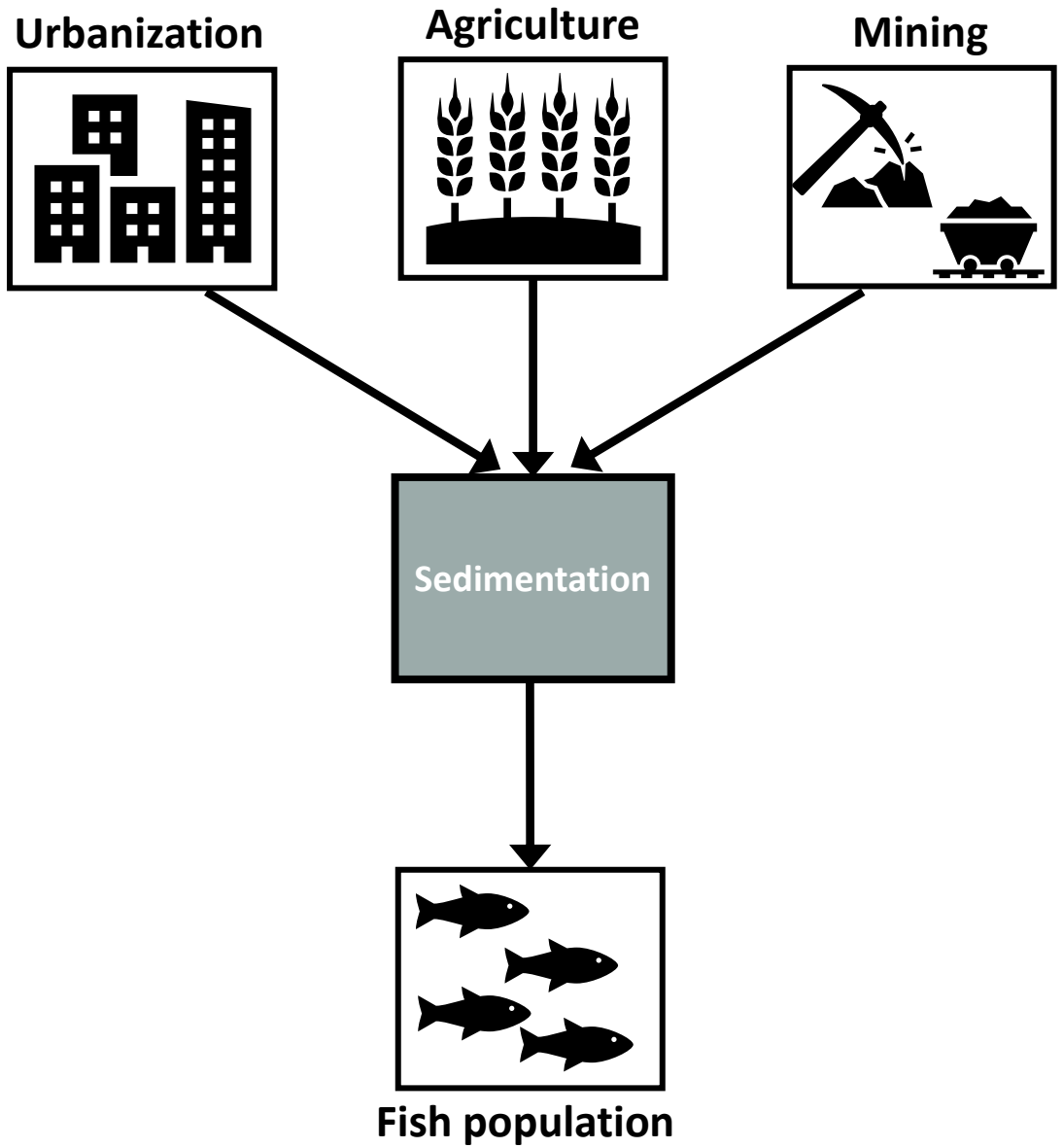
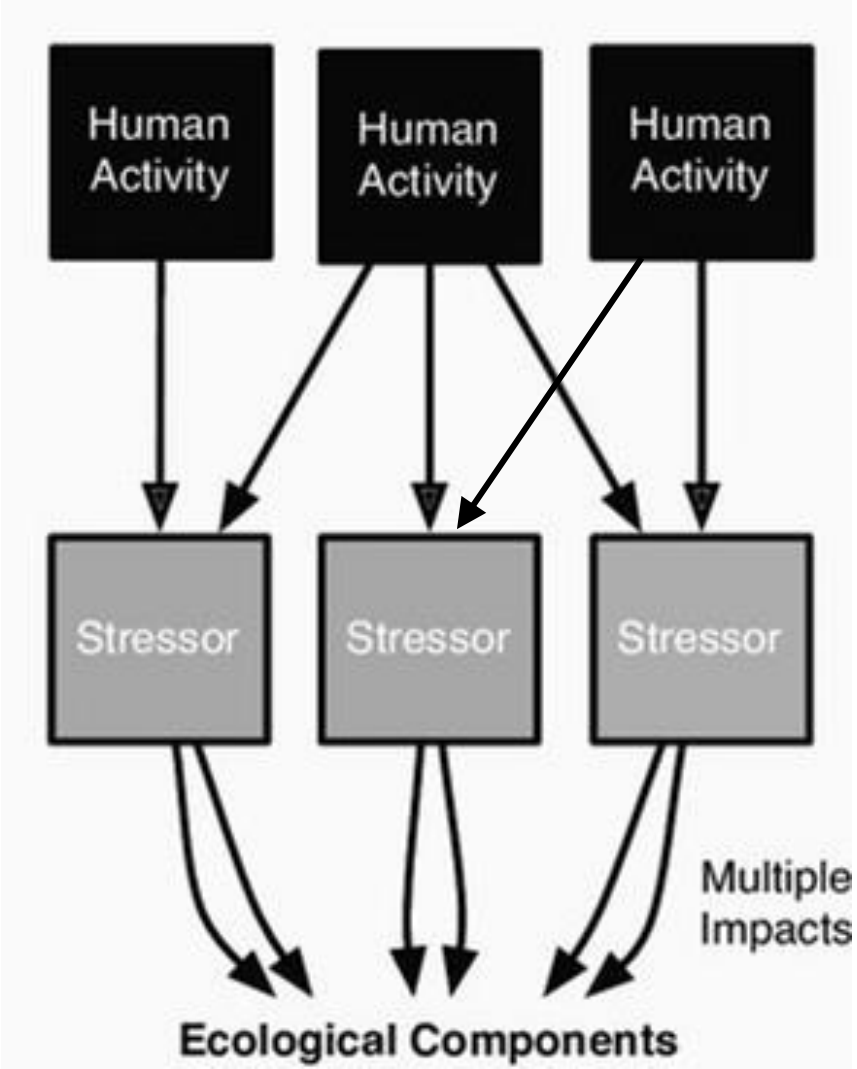


Cumulative Effects



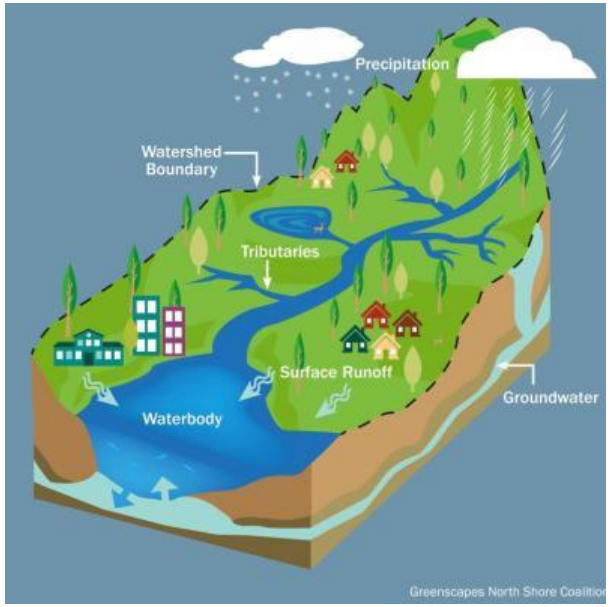
Source: Clarke Murray et al. (2014)

Cumulative Effects at the Watershed Scale

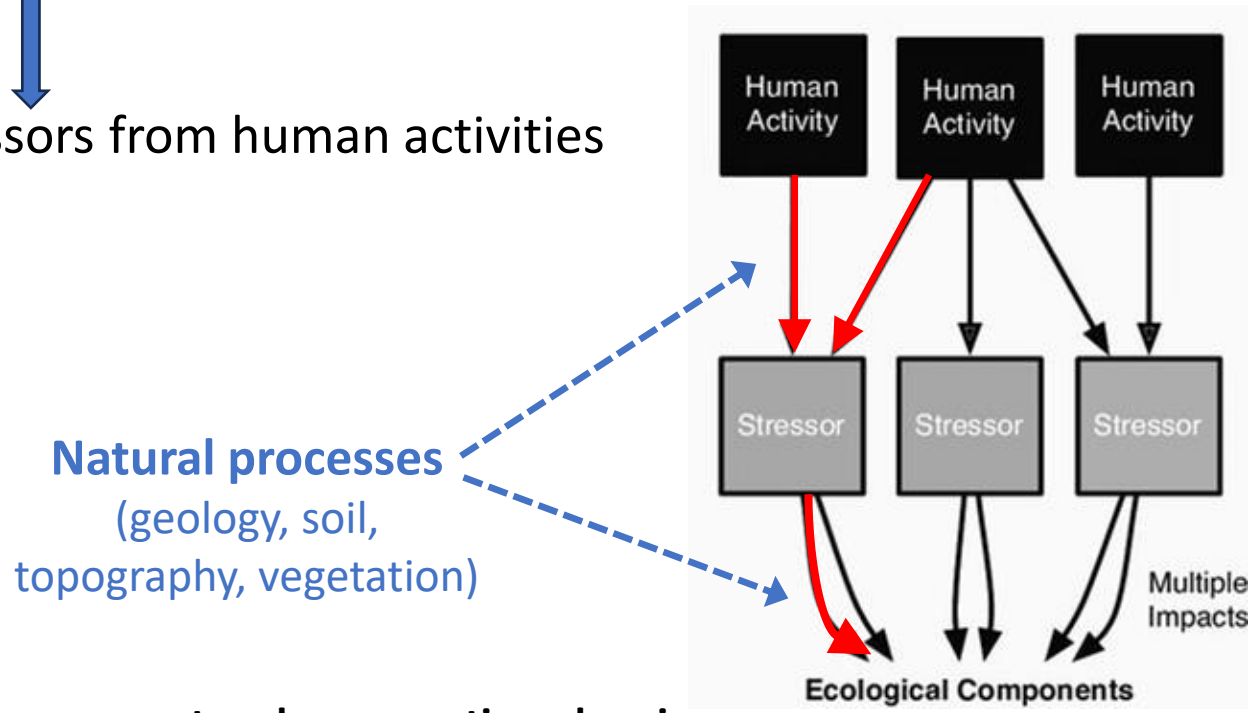
Cumulative effects on freshwater ecosystems should be considered within a watershed context.

River network act as a connector between distance points in space

Transport/mediate stressors from human activities



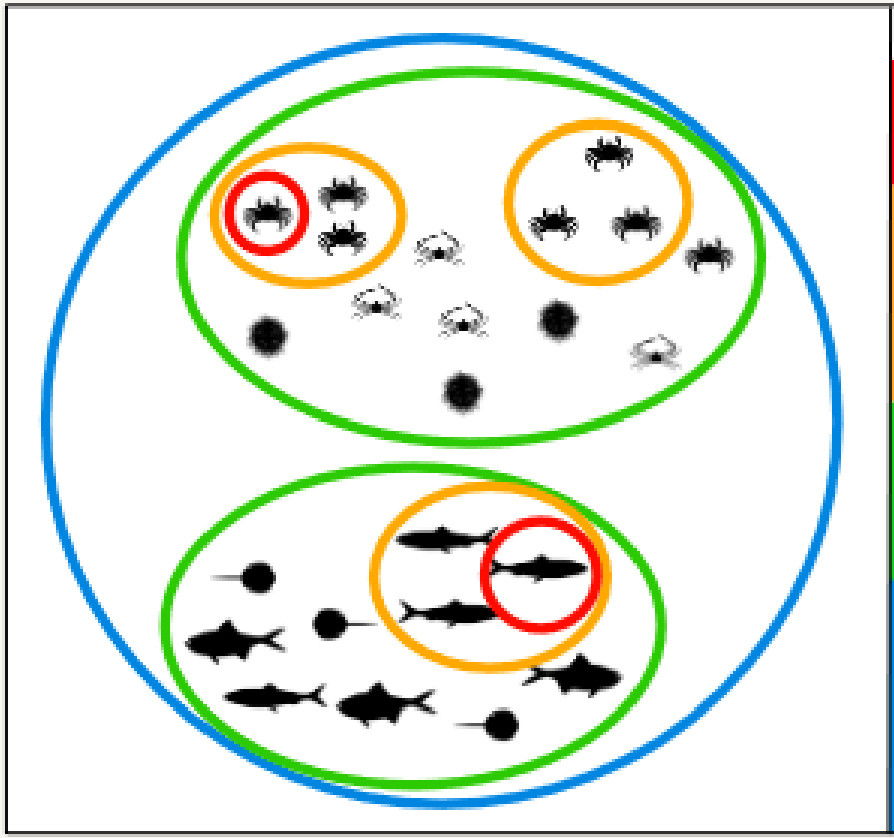
Credit: Greenscapes North Shore Coalition



Important for watershed management and conservation planning

Source: Clarke Murray et al. (2014)

Ecological Responses



Ecological Components	
Individual	Single organism. One individual of a single species.
Population	Grouping of individuals of a single species or taxa. Populations are considered separate when they form genetically distinct groupings either through behavioural or geographic isolation.
Community	Grouping of species within a single habitat. For example, urchin and crab populations living in the same habitat would be members of the benthic community.
Ecosystem	Grouping of communities into an ecosystem. For example, a kelp forest ecosystem includes all the resident populations of kelp, fish, invertebrate and other species. Communities interact through biophysical processes like nutrient flows.

Examples of responses

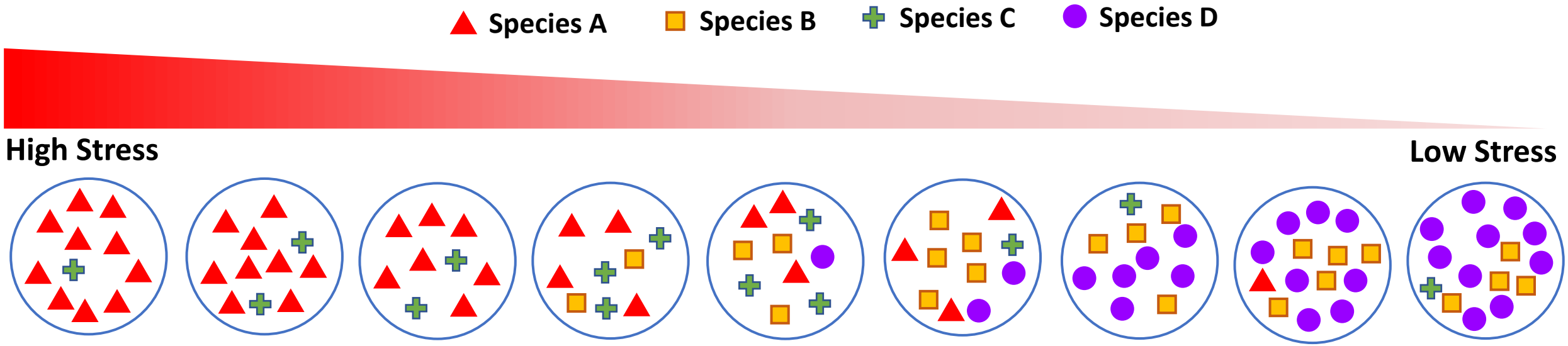
Decrease in body Size

Decrease in Population Size

Change in Species composition

Source: Clarke Murray et al. (2014)

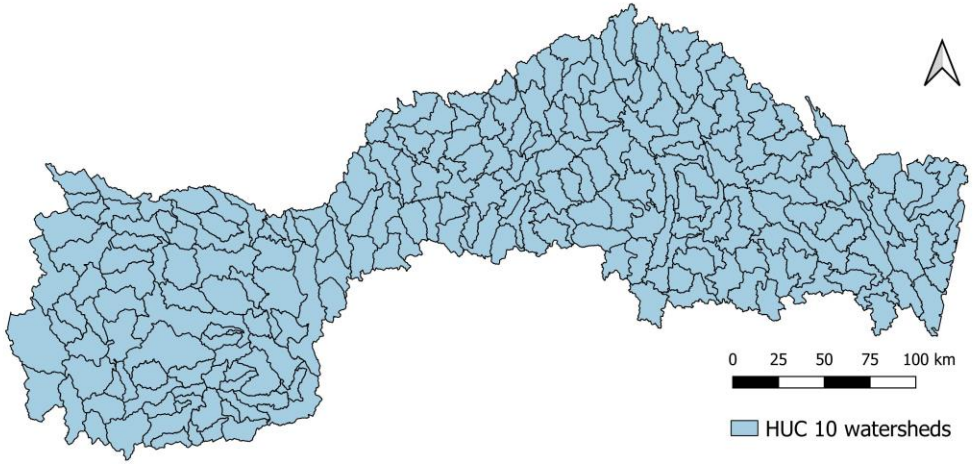
Community Responses



Objective of the Present Study

- Identify the pathways linking the human activities in the watershed to condition of biological communities in streams

- Estimate the relative importance of different human activities to stream ecological health

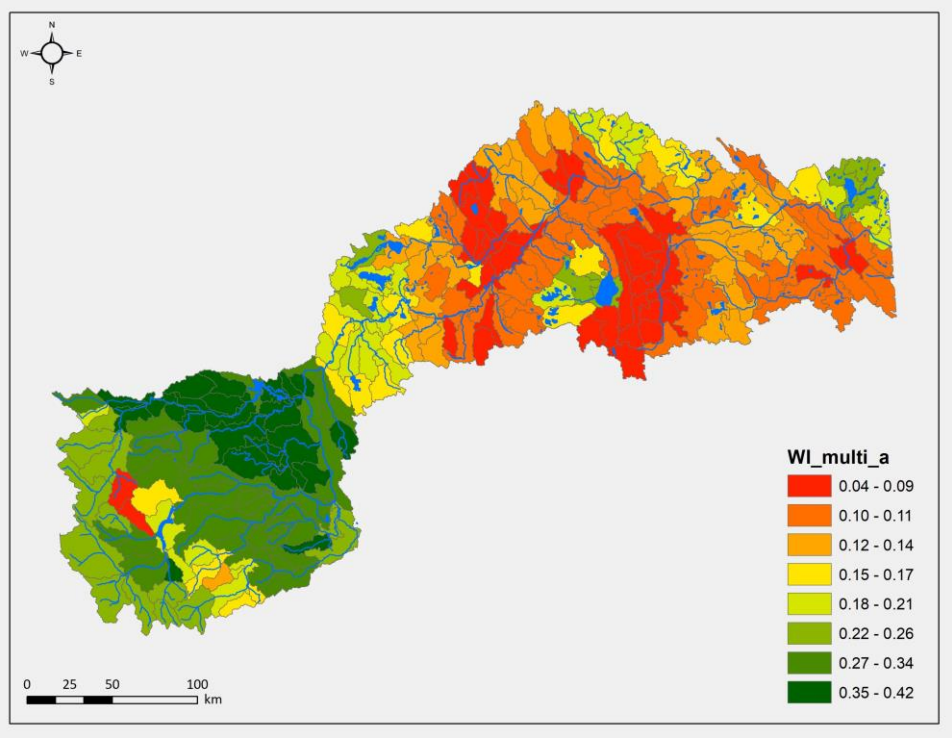


North Saskatchewan River Watershed

NSR Basin Watershed Integrity Project

Development of a comprehensive geospatial tool for assessing watershed integrity and aquatic ecosystem health in the North Saskatchewan River basin

Watershed integrity (geospatial)



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Geospatial data

Natural variables

Daily maximum air temperature
Mead daily precipitation
Mean daily windspeed
Mixed canopy-Dominant coniferous density
Coniferous canopy density
Deciduous canopy density
Mixed canopy-Dominant deciduous density
Bog density
Swamp density
Fen density
Marsh density
Open water density
Parks and protected area density
Maximum elevation
Minimum elevation
Mean elevation
Maximum slope
Minimum slope
Riparian density
Riparian coniferous canopy density
Riparian deciduous canopy density
Riparian Mixed canopy density
Moraine density
Stagnant ice moraine density
Ice-thrust moraine density
Organic depositional density
Glaciolacustrine density
Lacustrine density
Bedrock/glaciers density
Fluvial/glaciofluvial density
Eolian density
Colluvial density

Climate
Hydrology
Topography
Surficial geology
Vegetation

Anthropogenic variables

Road density
Rail density
Road and rail density (combined)
Seismic, pipelines and power lines density (combined)
Areal cover of rural industrial footprint
Areal cover of residential footprint
Areal cover of Industrial, residential, road, rail, and pipeline
Areal coverof agricultural footprint
Sum of fertilizer application rate
Livestock density
Areal cover of mining sites
Areal cover of oil and gas well sites
Density of wastewater facilities
Surface water consumptive losses
Sum of groundwater consumptive losses
Areal cover of canals and ditches
Areal cover of reservoirs
Dams density
Watercourse road crossing density
Population density
Area cover of harvested area
Percent cover of burned area
Riparian areal cover
Riparian Road density
Riparian residential footprint
Riparian agricultural footprint

Urbanization
Agriculture
Waste disposal
Resource extraction
Man-made water features
Water consumption

Field data

Physical habitat
Water quality

- Substrate, river flow
- Gen chemistry, nutrients, metals

Microbial communities

- ASV composition (Abundance)

Benthic algae/ phytoplankton

- Species composition (Abundance)
- Pigment concentrations

Benthic invertebrates

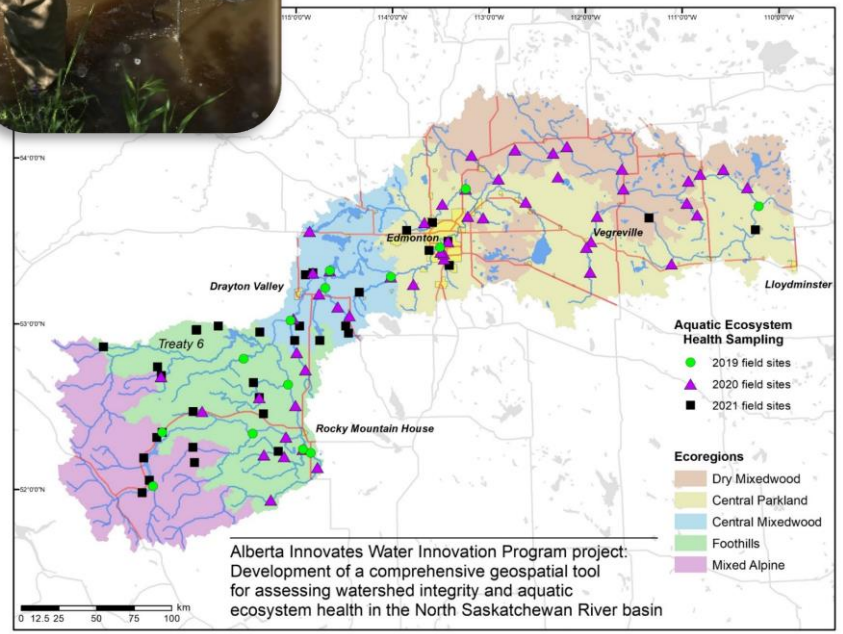
- Species composition (Abundance)

Fish

- Species composition (Incidence)
- Biometrics
- Stable Isotopes

Crayfish

- Species composition (Abundance)
- Biometrics
- Stable Isotopes



Multi-taxon Indicator Approach

Immobility/limited mobility

↓

Can better reflect the changes in their immediate surroundings

Benthic algae have shorter generation times and recolonization rates

↓

Reflect short-term environmental changes

Benthic invertebrates live longer

↓

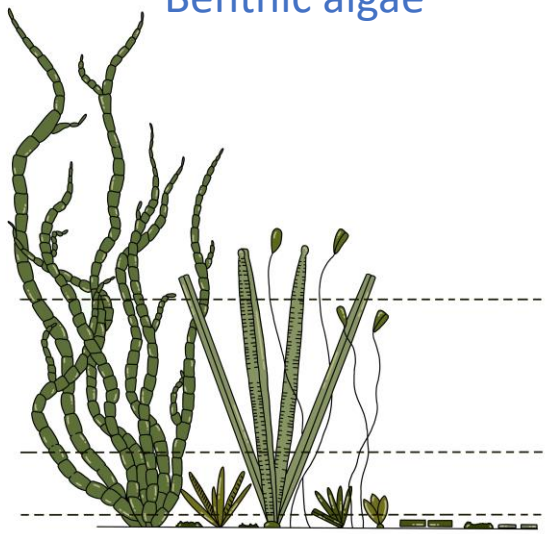
Integrate the effects of stressors over time

Two groups may have varying sensitivities to different stressors

↓

More comprehensive and robust assessment

Benthic algae



rock's surface

Modified from Hoagland et al. 1982

Benthic invertebrates

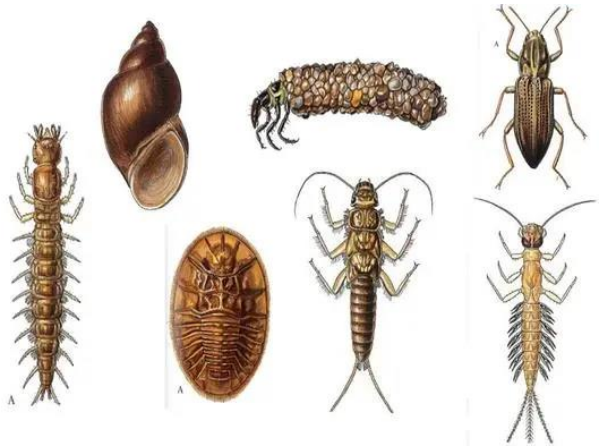
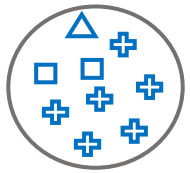


Photo credit: cmwaterqualityproject.weebly.com

Indicator Metrics

Principal Curve Scores

- A simplified and meaningful representation of complex data.
- Represents **differences** in species composition between sites.



Site	Species 1 △	Species 2 □	Species 3 ○	Species 4 ✣
Site 1	4	3	3	1
Site 2	3	2	4	1
Site …	….	…	…	…
Site …	….	…	…	…
Site n	1	2	0	6

Multivariate (Principal Curve) Analysis

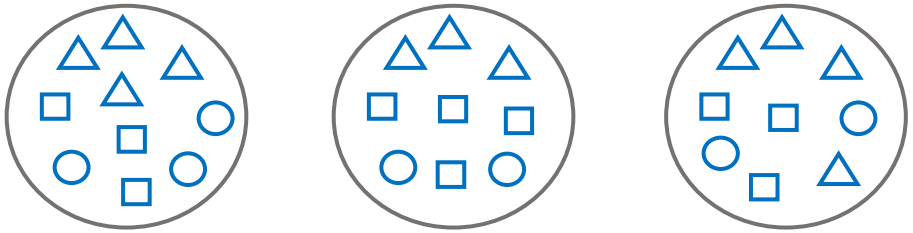
PC score
0.3
0.4
….
….
0.9

Indicator Metrics

Local Contribution to Beta Diversity based on Taxonomic Composition (LCBD)

- A simplified and meaningful representation of complex data
- A measure of **uniqueness** of sites based on *taxonomic composition*

Average community



Site 1 **Site 2** **Site 3**

LCBD ≈ 0

Unique community

Site 4

More species - High diversity

Site 5

Dominated by a single species

LCBD ≈ 1

Indicator Metrics

Local Contribution to Beta Diversity based on Functional Traits (LCBD_f)

- A measure of **uniqueness** of sites based on *taxonomic composition*

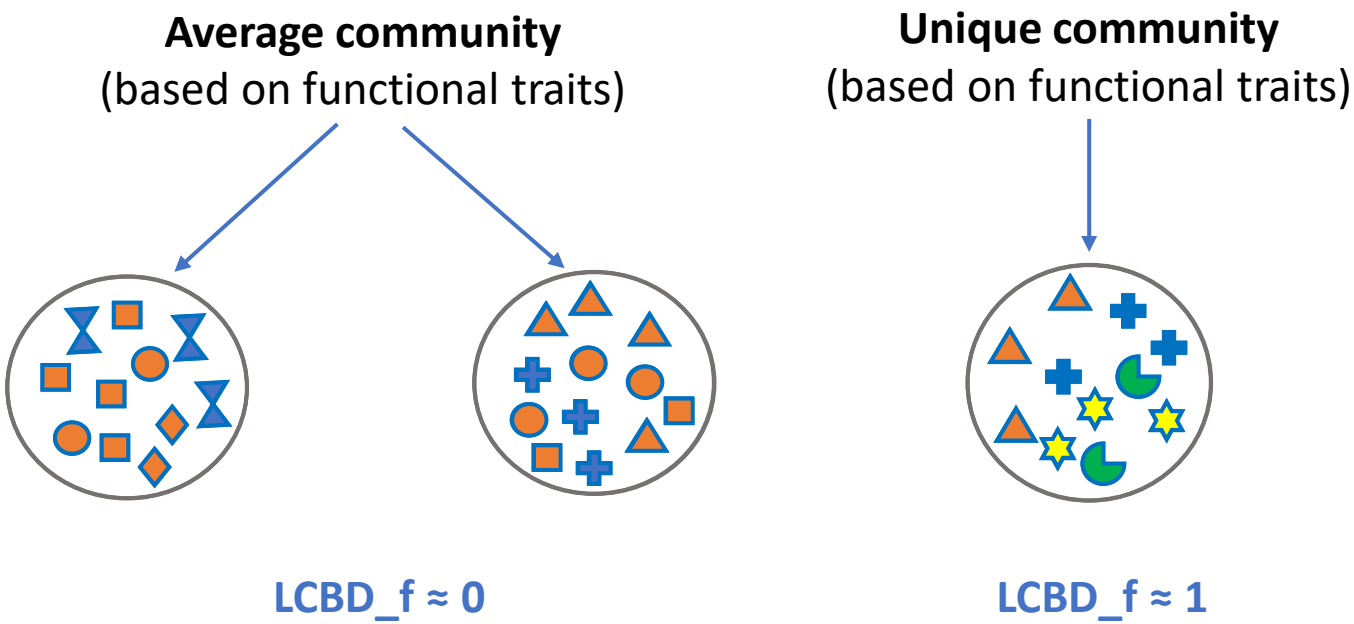
Functional traits = Characteristics that living organisms possess to survive, thrive, and interact with their surroundings.

Example: Functional traits of benthic invertebrates

- **Feeding mode** – grazer, filter feeder, predator
- **Body size** – large, medium, small
- **Morphology** – hard shell, irregular, fragile
- **Living habit** – free living, sessile, burrower

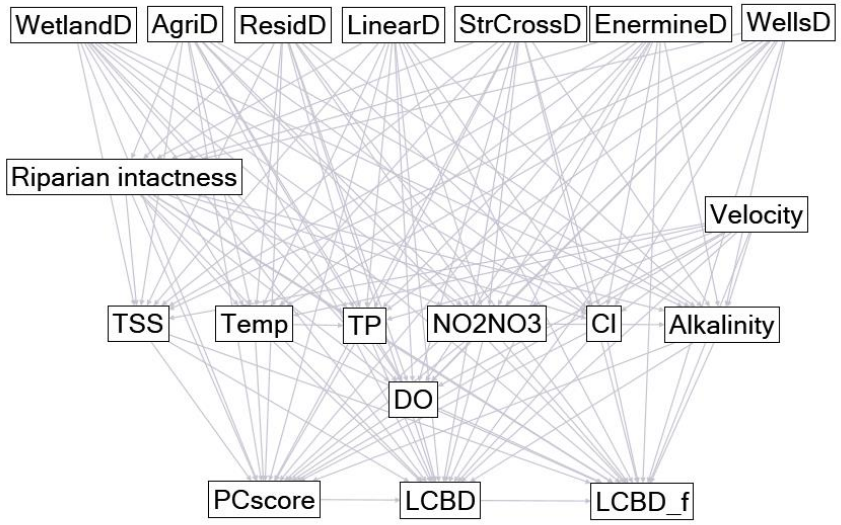
Indicator Metrics

Local Contribution to Beta Diversity based on Functional Traits (LCBD_f)



Data Analysis

Conceptual model

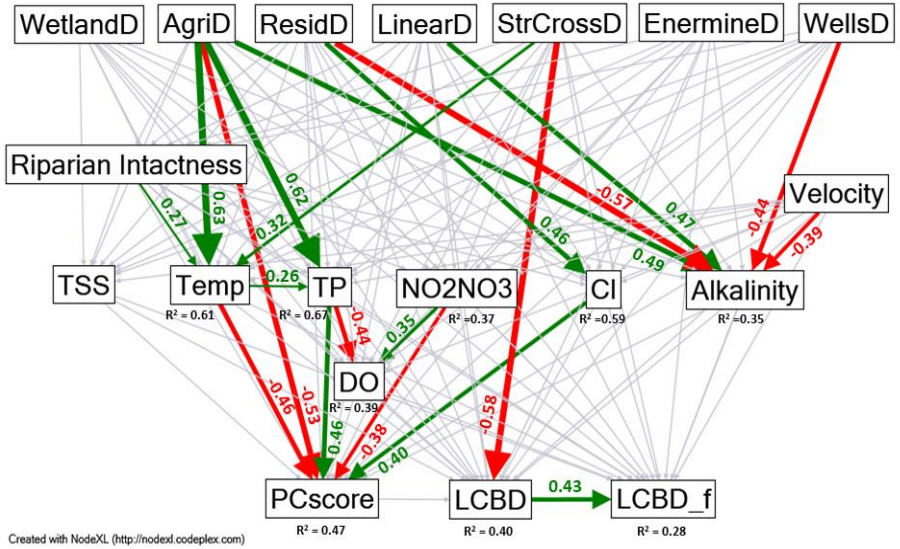


Structural Equation Modeling (SEM)

Statistical Testing

Empirical Data from NSR Basin

Output model

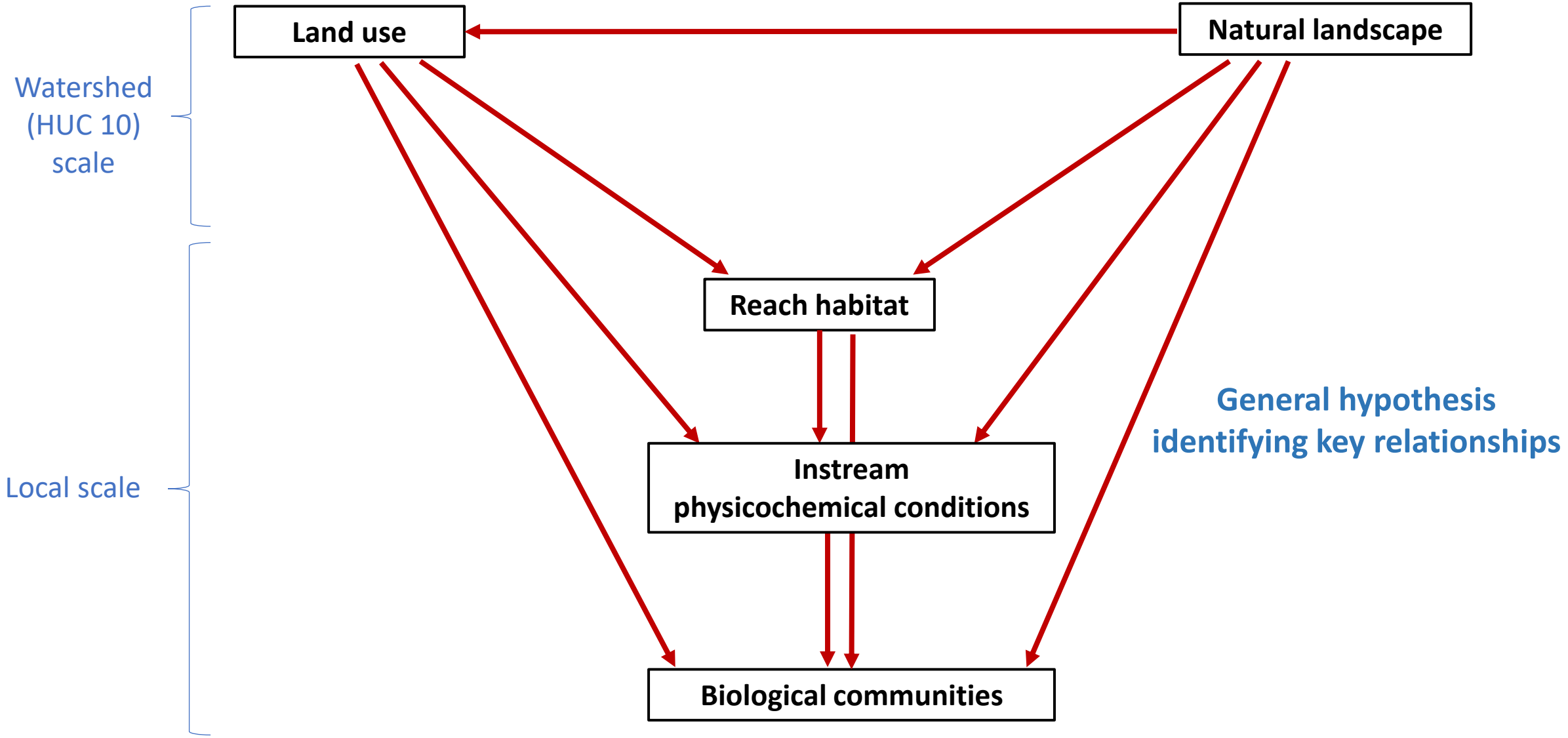


Hypothesized causal relationships
between land use/land cover factors, reach habitat, instream physical and chemical conditions and biological communities

→ Significant ($p < 0.05$), positive relationship

→ Significant ($p < 0.05$), negative relationship

Meta (Conceptual) Model



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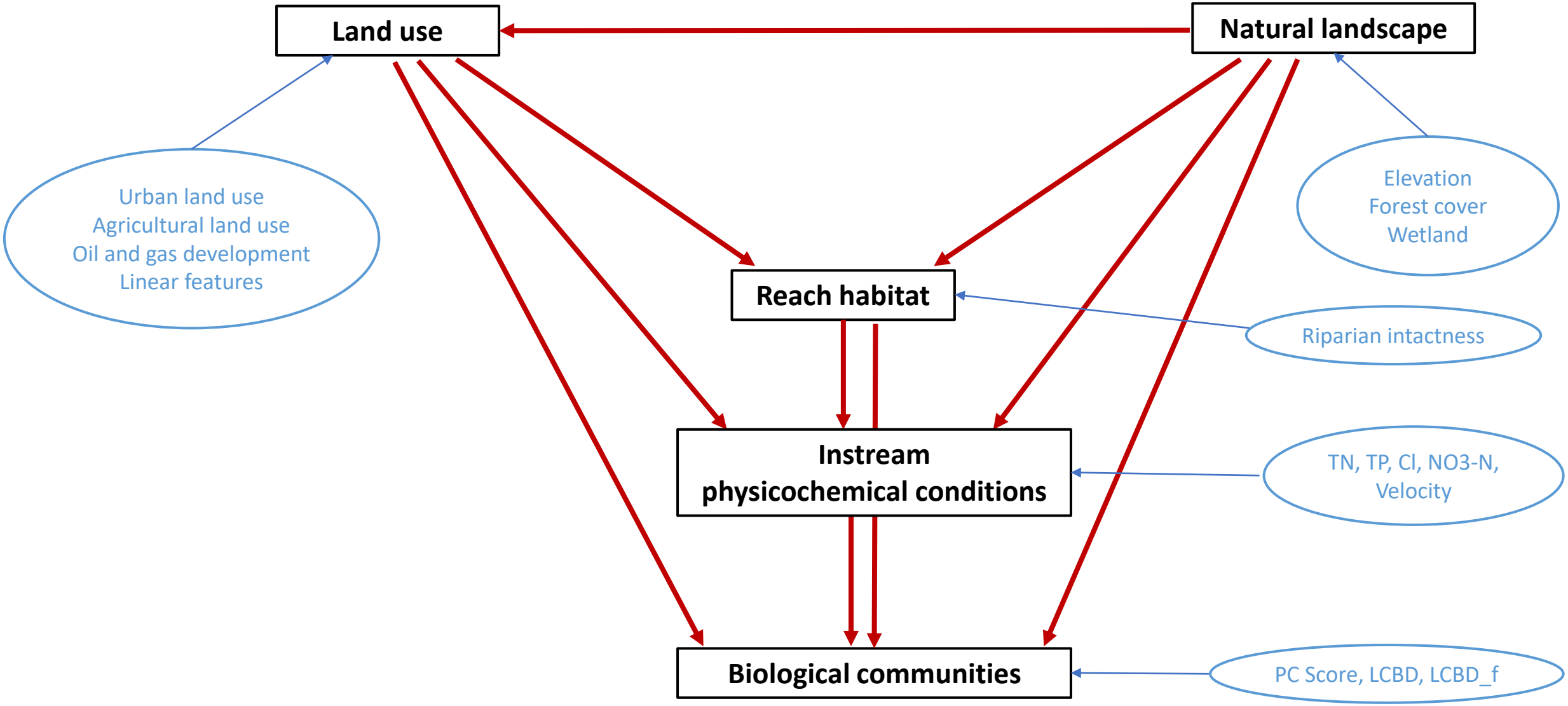
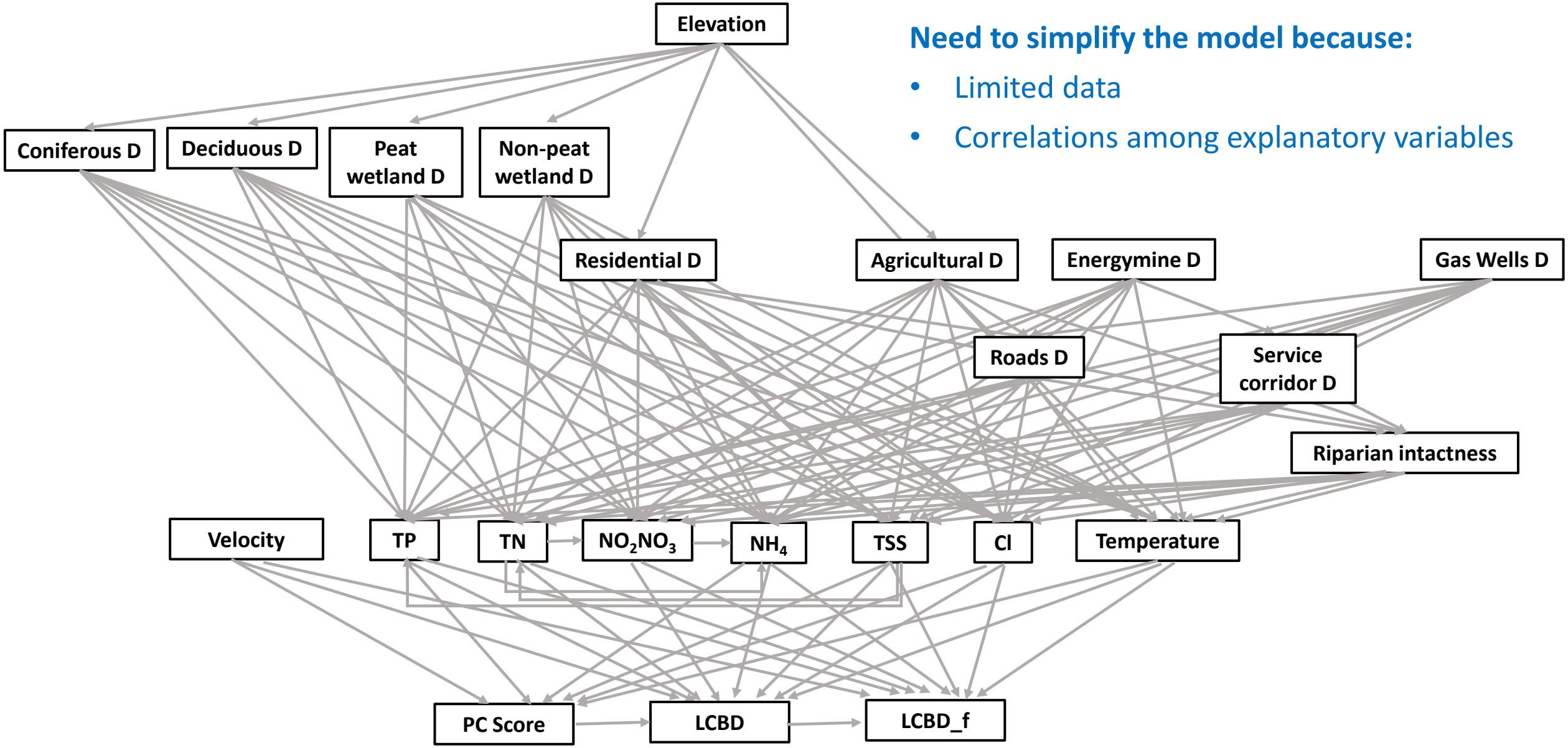


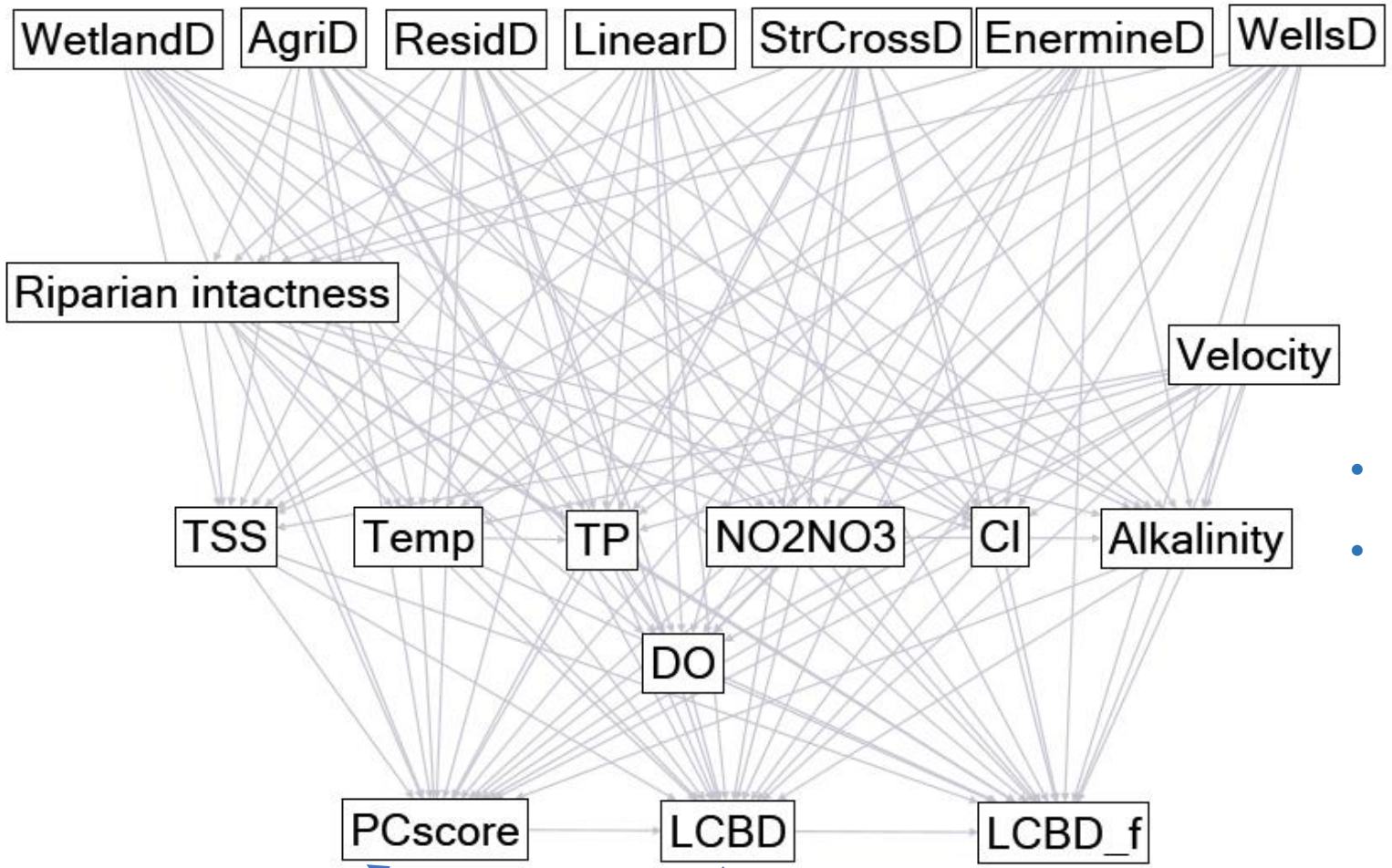
Conceptual Model



Need to simplify the model because:

- Limited data
- Correlations among explanatory variables

Simplified Conceptual Model



- Be cautious with interpreting the results
- Need to consider excluded variables

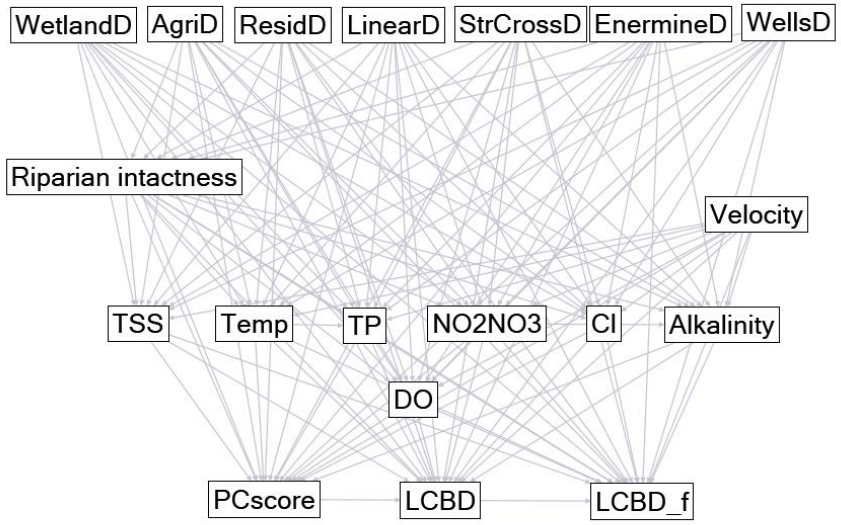
Differences bw sites based on taxonomic composition

Uniqueness of sites based on taxonomic composition

Uniqueness of sites based on functional traits

Data Analysis

Conceptual model



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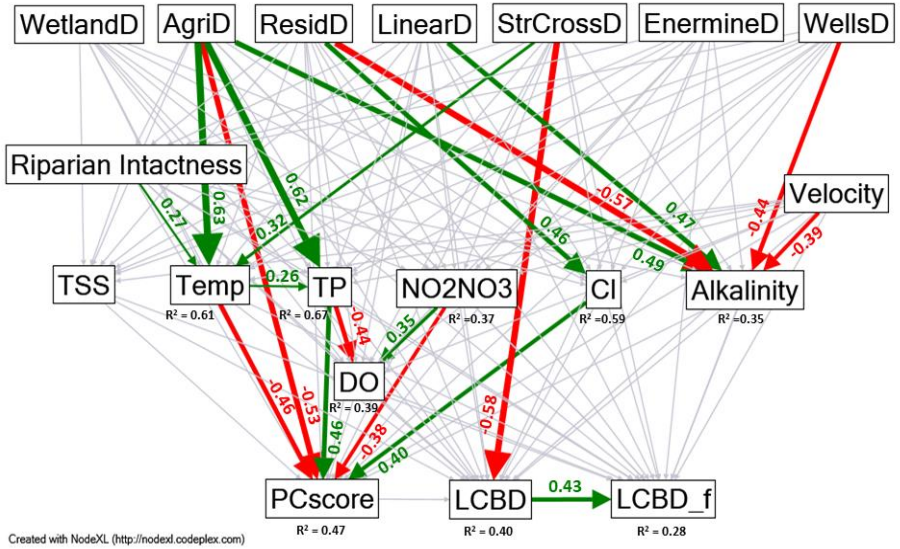

Hypothesized causal relationships
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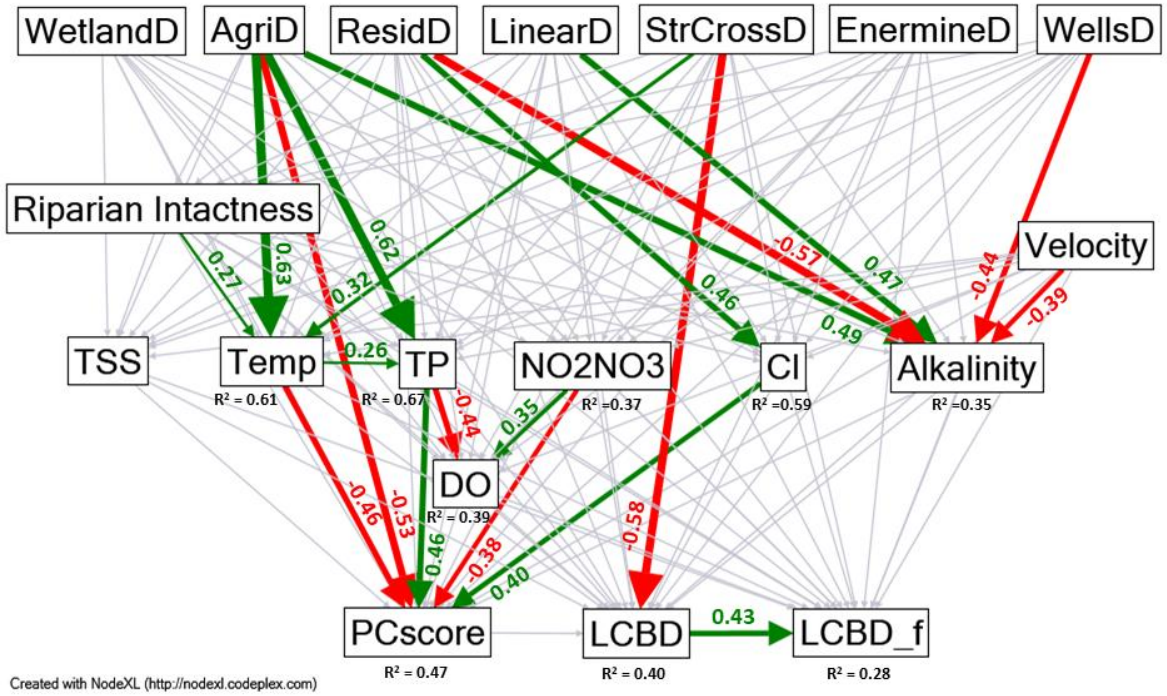
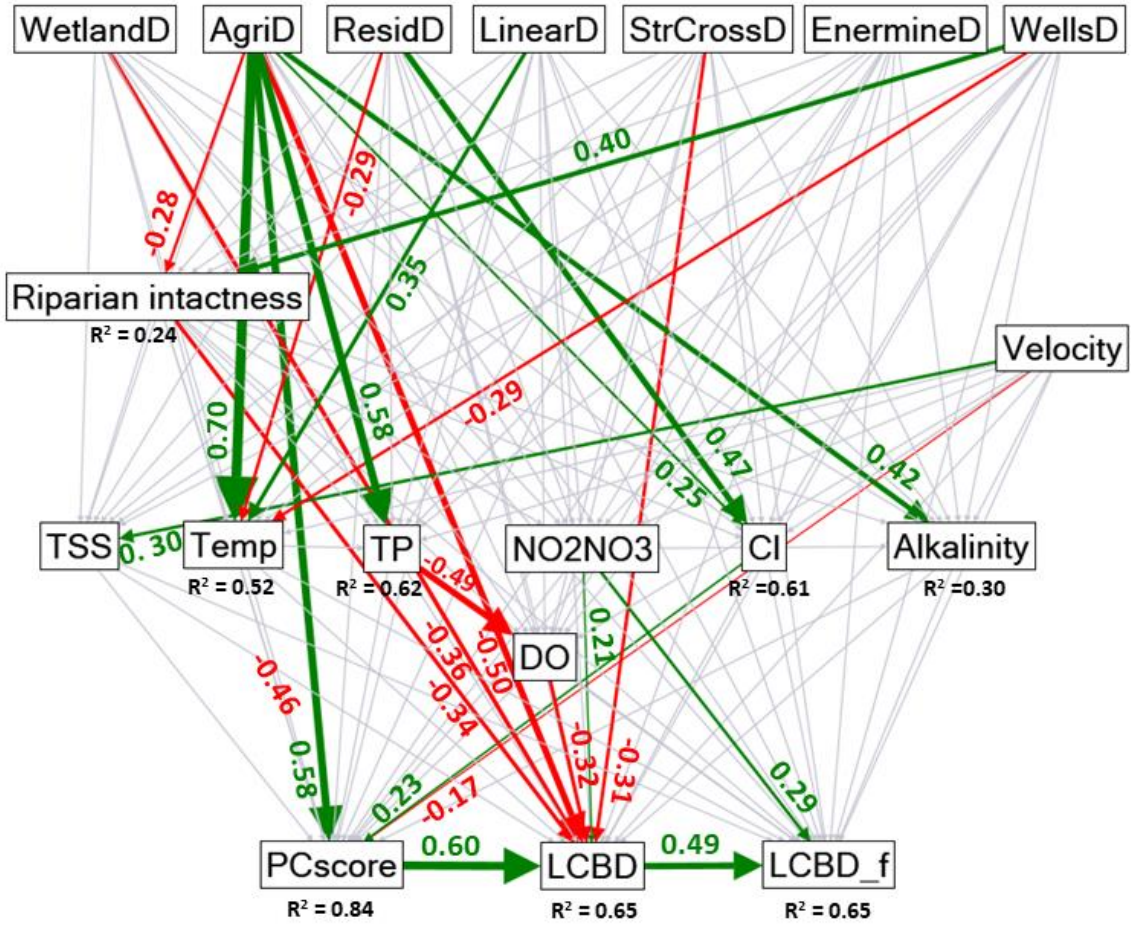
Output Models

Benthic Algae



Benthic Invertebrates



Significant ($p < 0.05$), positive relationship

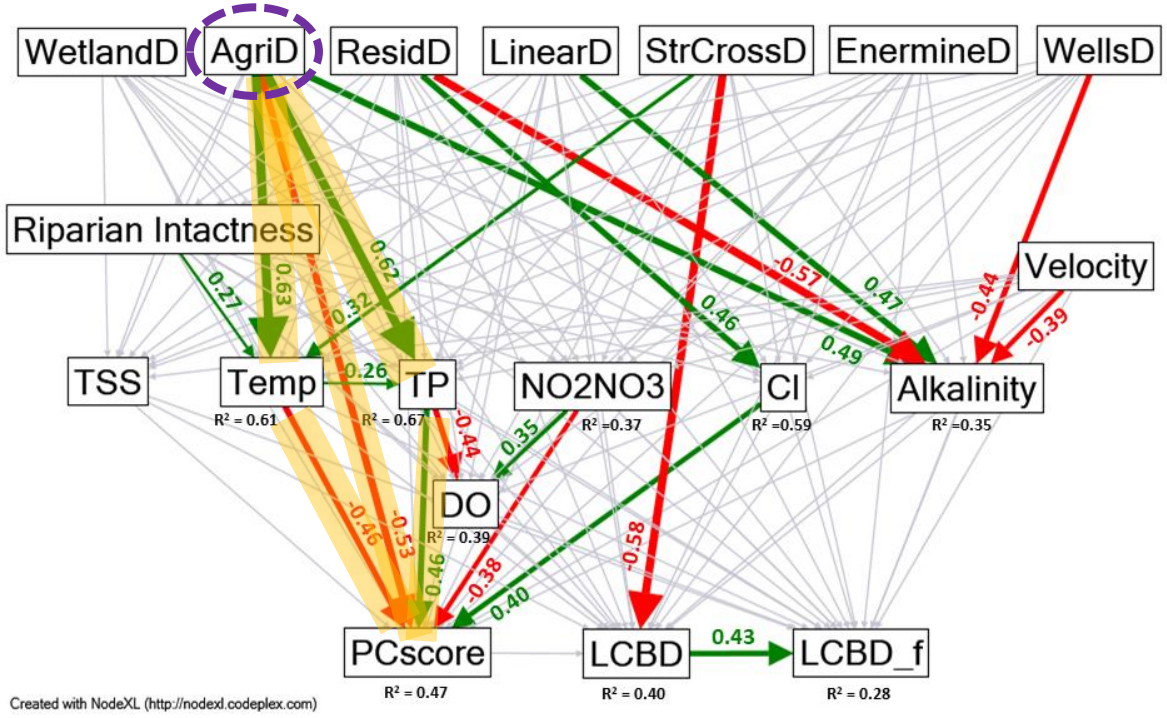
Significant ($p < 0.05$), negative relationship

Not significant ($p > 0.05$)

Thickness of arrows = Strength of the relationship

Output Models

Benthic Algae



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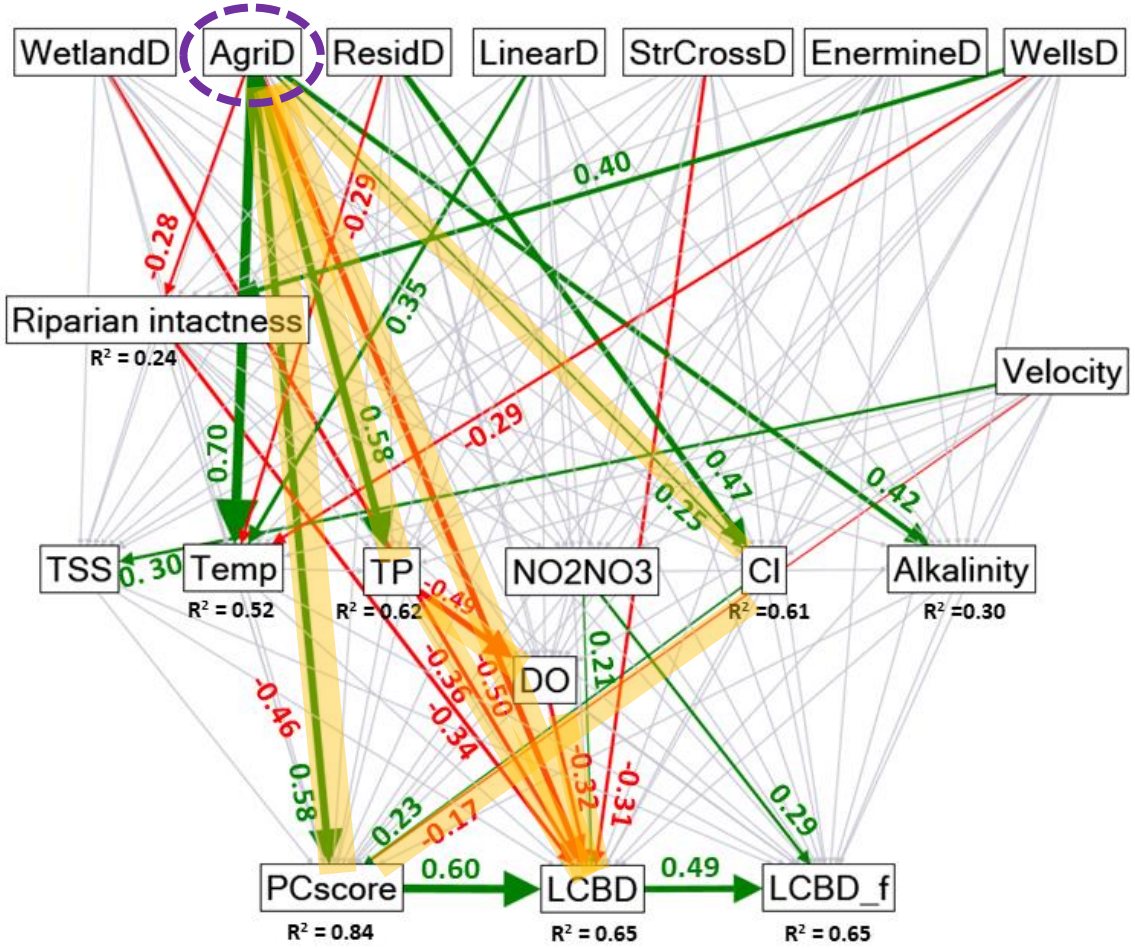


Relationships of agricultural density

- Direct
- Indirect- through nutrients, temperature, Cl

Significant, positive relationship

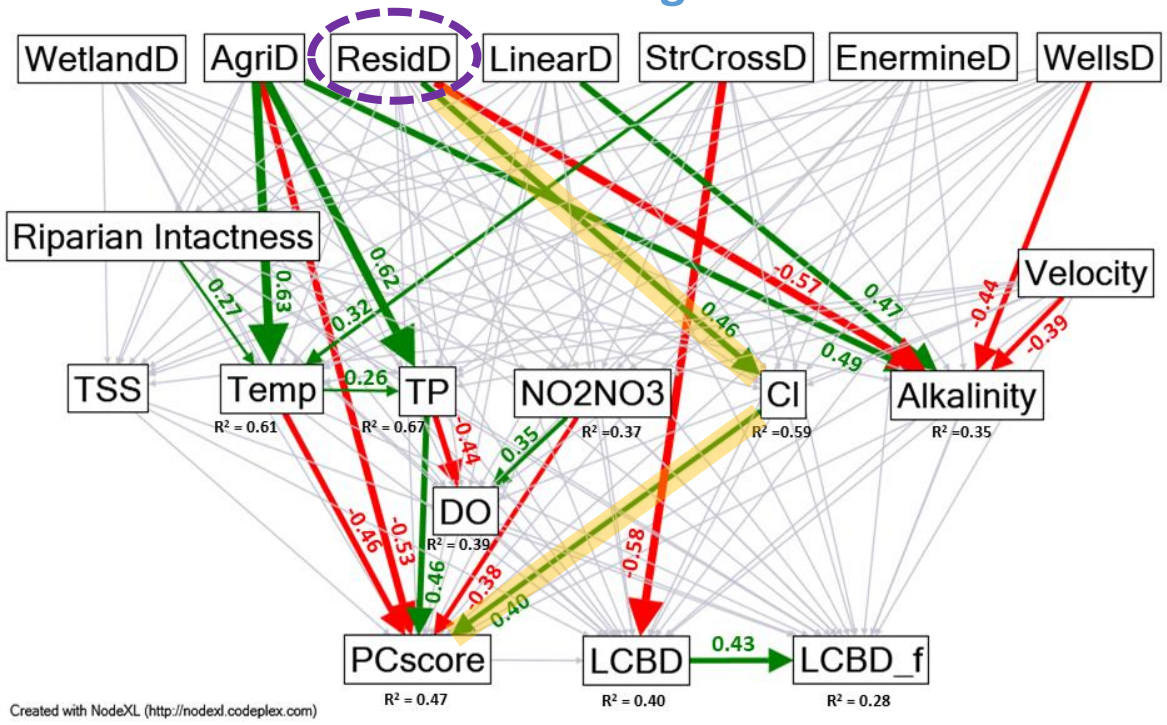
Significant, negative relationship

Not significant

Thickness = Strength of the relationship

Output Models

Benthic Algae



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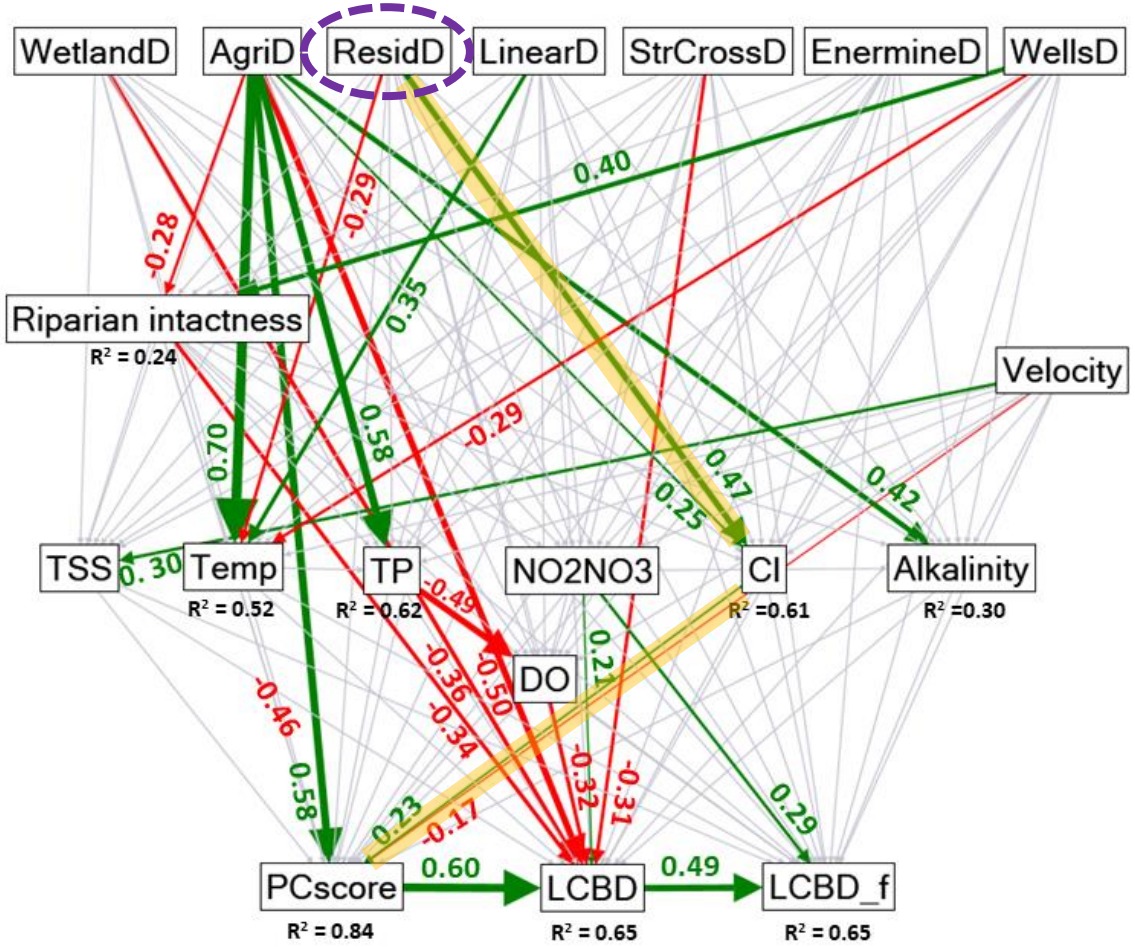


Relationships of residential density

- Indirect- through Cl
- Possible effect of salinization
  (due to road salt application and other urban sources)

Significant, positive relationship

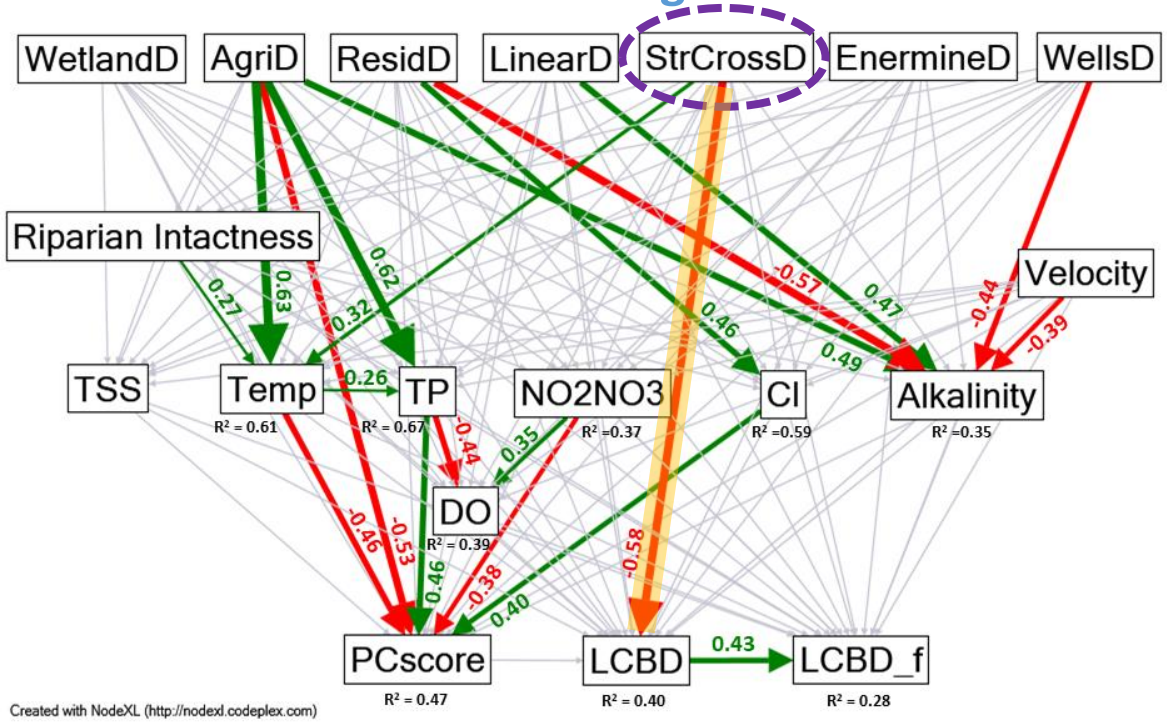
Significant, negative relationship

Not significant

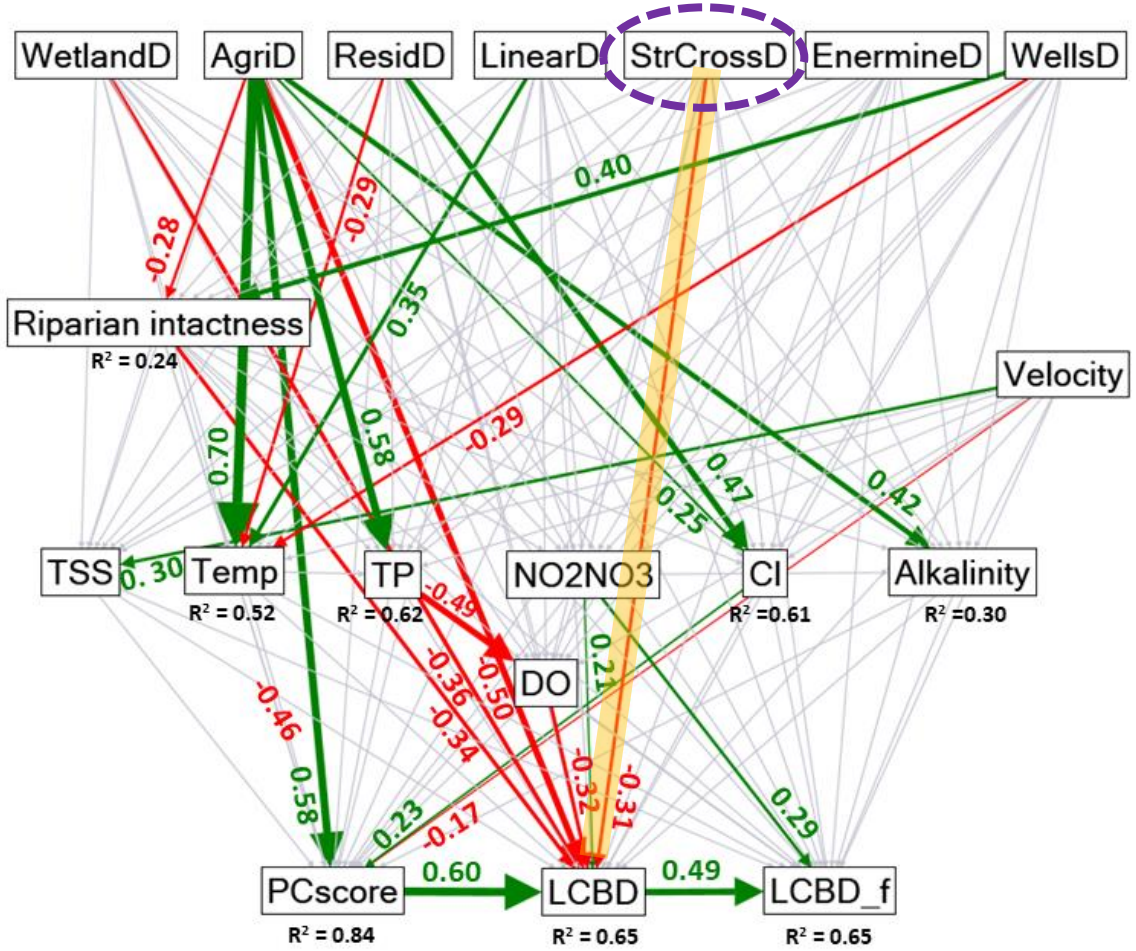
Thickness = Strength of the relationship

Output Models

Benthic Algae



Benthic Invertebrates



Relationship of stream crossing density

Significant, positive relationship

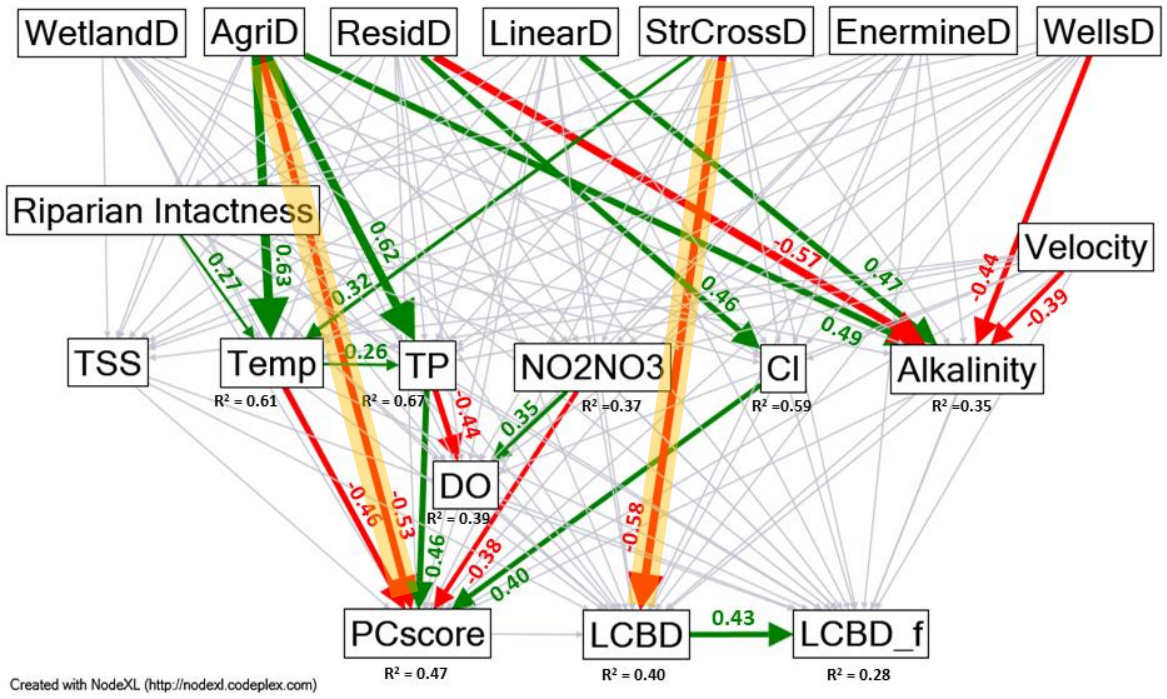
Significant, negative relationship

Not significant

Thickness = Strength of the relationship

Output Models

Benthic Algae



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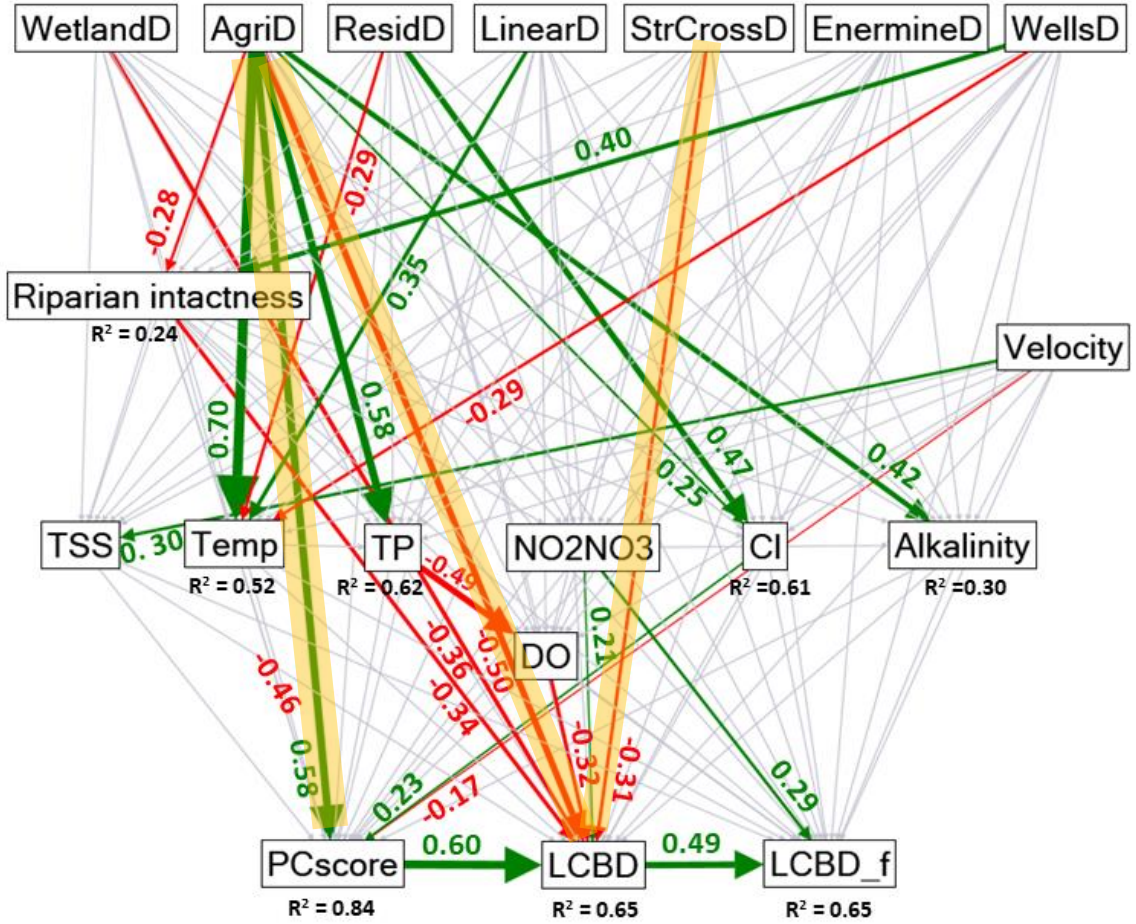


Direct relationships

- **Missing stressor pathways** that are not mediated through measured water quality parameters.
- **Biological monitoring** in addition to water quality monitoring is important!

Significant, positive relationship

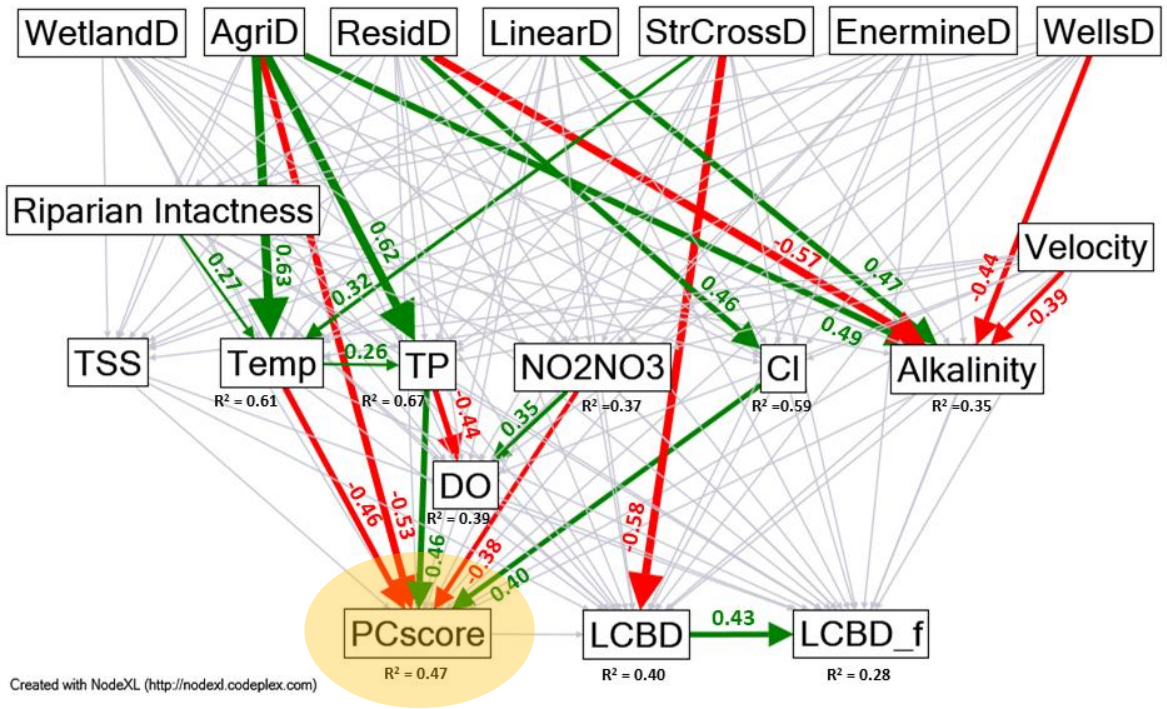
Significant, negative relationship

Not significant

Thickness = Strength of the relationship

Output Models

Benthic Algae



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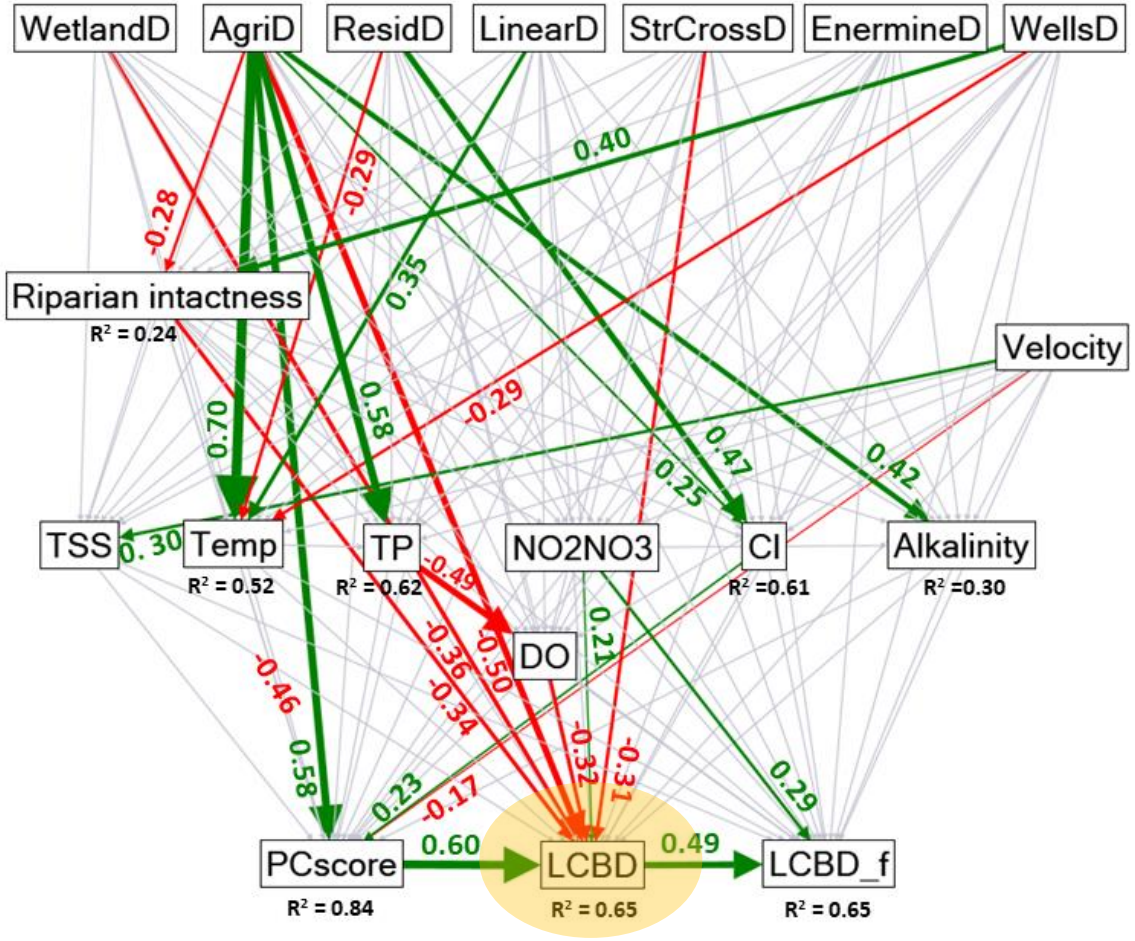


Responsiveness of indicator metrics vary between taxonomic groups.

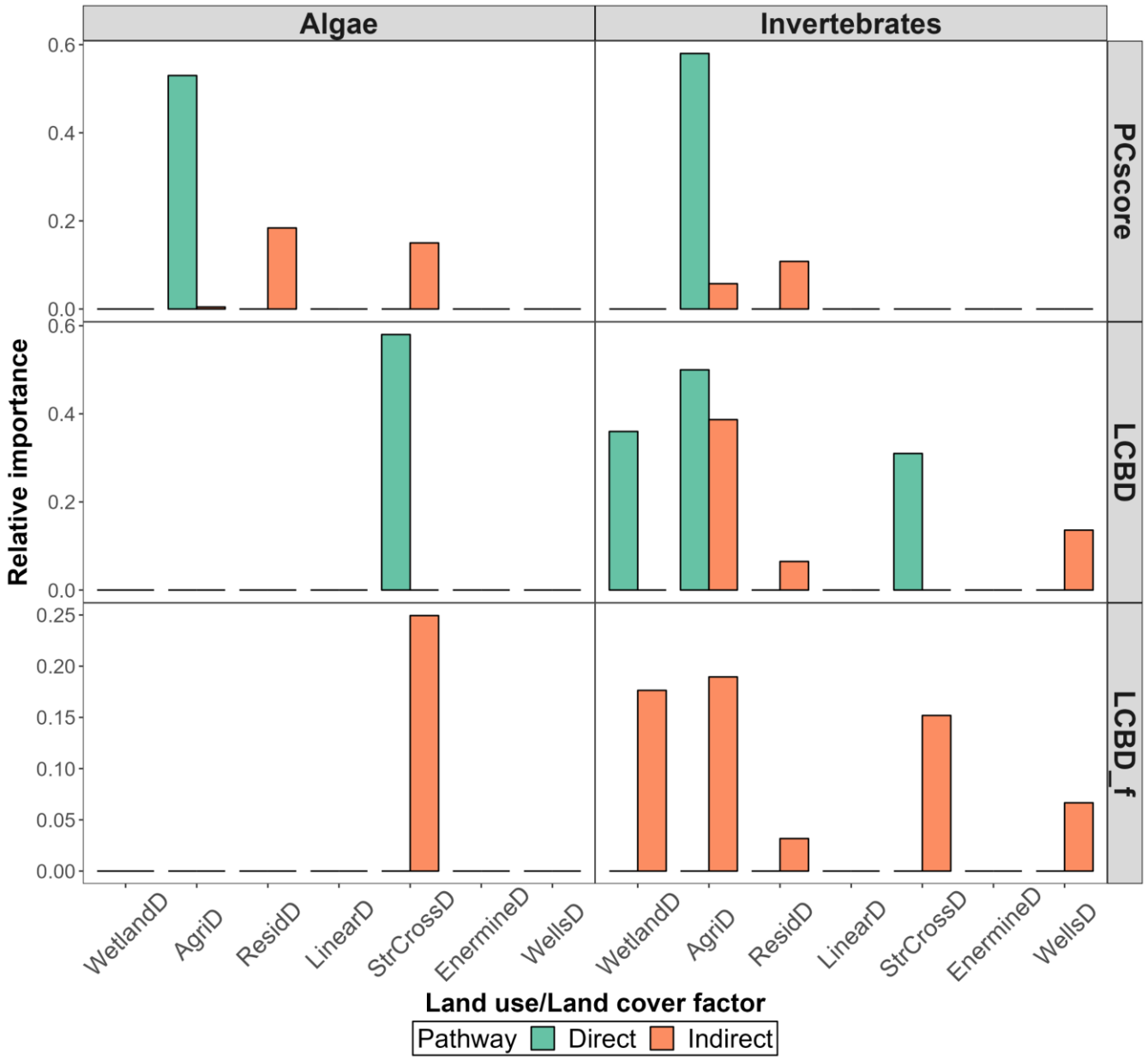
Significant, positive relationship

Significant, negative relationship

Not significant

Thickness of arrows = Strength of the relationship

Relative importance of different pathways



- More pathways for invertebrates compared to algae.
- More indirect pathways than direct ones.
- Direct pathways have higher relative importance.

Caveats

- Assumption – **Linear relationships** between stressors and ecosystem components .
- **Correlations** with variables not included in the analysis.
  Natural variability across the landscape can confound the findings.
- Different conditions (e.g. flow) among **three survey years** can confound the findings.

Conclusions

- Human activities in surrounding landscape can influence biological communities in streams via **complex pathways**.
- Often **indirect** i.e., mediated via instream physical and chemical conditions.
- Important land use factors: agricultural density, residential density, stream road crossing density and riparian intactness.
- Supportive evidence for landscape influences via **nutrient runoff and salinization**.
- **Benthic invertebrates** are better indicators than benthic algae.
- Importance of **biological monitoring** in addition to water quality monitoring.