Multi-scale Drivers of Phytoplankton Communities in North-temperate Lakes

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ALMS Workshop
Sept 19th, 2019

Alberta

Lake ecosystems as sentinels of change

- Discrete systems with distinct boundaries
- Intrinsically connected to local and regional processes and conditions by the down-gradient flow of water
- Integrate multiple stressors across space and time
- Model systems for understanding macroecological response

Local disturbance

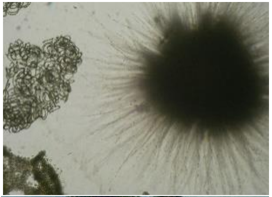
Regional land-use

Climate conditions

Spatial scale

Phytoplankton and freshwater management

- Responsive bio-indicators at the base of aquatic food webs
  - Harmful algal/cyanobacterial blooms and declining ecosystem health
- Trait response to environmental gradients offers mechanistic insights into community assembly





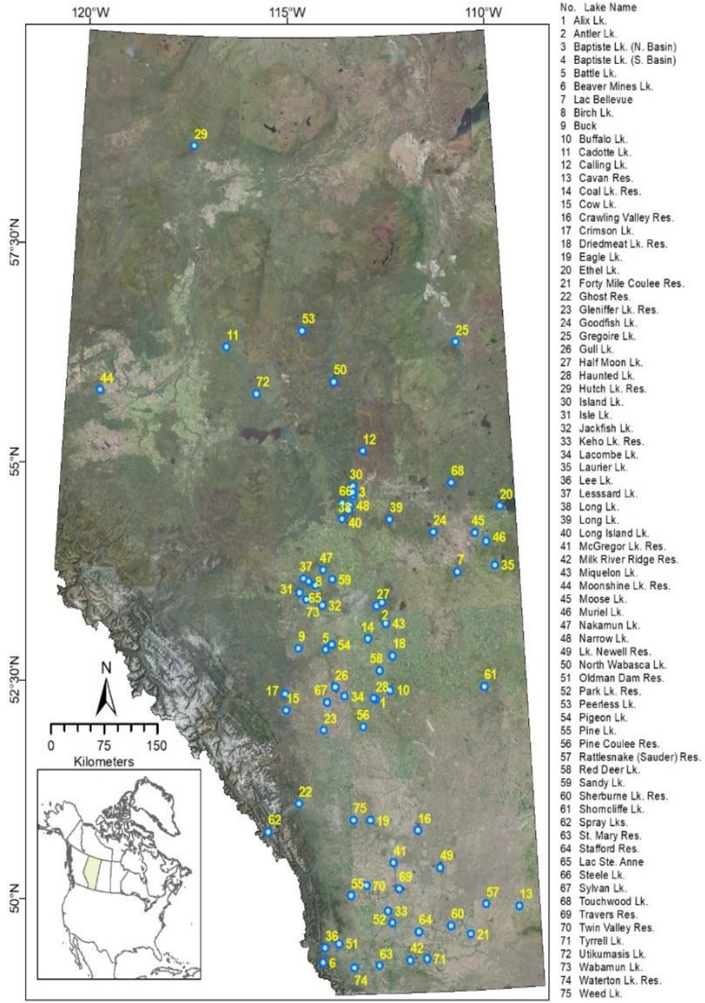
Part 1: The use of spatially-constrained null-models to disentangle the relative influence of co-occurring, multiscale drivers of phytoplankton communities in north-temperate lakes and reservoirs across Alberta, Canada.

Part 1: Identify most relevant factors explaining variation in phytoplankton (and cyanobacteria) communities to reduce number of variables required for subsequent analysis (Part 2)

Part 2: The use RLQ/fourth-corner analysis to identify seasonal trait-environment associations of phytoplankton communities in AB's north-temperate lakes and reservoirs.

Lake monitoring data

- AEP’s Lake Network & ALMS’ Lakewatch program
- Phytoplankton community biomass composition
- 75 lakes and reservoirs sampled (2011–2017)
- Monthly open-water sampling (June–September)
- 304 phytoplankton taxa (61cCyanobacteria species)
- Diverse natural regions and human-footprint



Hierarchy of environmental factors

Local factors		Regional factors	
Alkalinity (as total $CaCO_3$)	Lake area-perimeter ratio	Catchment are	Air temperature (monthly)
Bicarbonate (calculated)	Lake elevation	Mean catchment slope	Air temperature (spring)
Calcium Calcium (dissolved)	Lake/reservoir	% Canal/drainage	Solar radiation (monthly)
Carbonate (calculated)	Max depth	% Cleared land	Total precipitation (monthly)
Chloride (dissolved)	Secchi depth	% Cropland	
Hardness (as total $CaCO_3$)	Sum buoyancy frequency	% Grassland	
Magnesium (dissolved)	Surface water temperature	% Hard linear features	
Nitrogen (total)		% Harvested forest	
pH		% Intact forest	
Phosphorus (total)		% Pastureland	
Potassium (dissolved)		% Soft linear features	
Silica (reactive)		% Urban/industrial	
Sodium (dissolved)		% Wetlands	
Sulphate (dissolved)		Watercourse crossing density	
Total dissolved solids			

Water chemistry

Local factors		Regional factors	
Alkalinity (as total $CaCO_3$)	Lake area-perimeter ratio	Catchment are	Air temperature (monthly)
Bicarbonate (calculated)	Lake elevation	Mean catchment slope	Air temperature (spring)
Calcium Calcium (dissolved)	Lake/reservoir	% Canal/drainage	Solar radiation (monthly)
Carbonate (calculated)	Max depth	% Cleared land	Total precipitation (monthly)
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Hardness (as total $CaCO_3$)	Sum buoyancy frequency	% Grassland	
Magnesium (dissolved)	Surface water temperature	% Hard linear features	
Nitrogen (total)		% Harvested forest	
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Phosphorus (total)		% Pastureland	
Potassium (dissolved)		% Soft linear features	
Silica (reactive)		% Urban/industrial	
Sodium (dissolved)		% Wetlands	
Sulphate (dissolved)		Watercourse crossing density	
Total dissolved solids			

Morphometry and physical parameters

Local factors		Regional factors	
Alkalinity (as total $CaCO_3$)	Lake area-perimeter ratio	Catchment are	Air temperature (monthly)
Bicarbonate (calculated)	Lake elevation (altitude)	Mean catchment slope	Air temperature (spring)
Calcium Calcium (dissolved)	Lake/reservoir	% Canal/drainage	Solar radiation (monthly)
Carbonate (calculated)	Max depth	% Cleared land	Total precipitation (monthly)
Chloride (dissolved)	Secchi depth	% Cropland	
Hardness (as total $CaCO_3$)	Sum buoyancy frequency	% Grassland	
Magnesium (dissolved)	Surface water temperature	% Hard linear features	
Nitrogen (total)		% Harvested forest	
pH		% Intact forest	
Phosphorus (total)		% Pastureland	
Potassium (dissolved)		% Soft linear features	
Silica (reactive)		% Urban/industrial	
Sodium (dissolved)		% Wetlands	
Sulphate (dissolved)		Watercourse crossing density	
Total dissolved solids			

Catchment land-cover and human-footprint

Local factors		Regional factors	
Alkalinity (as total $CaCO_3$)	Lake area-perimeter ratio	Catchment are	Air temperature (monthly)
Bicarbonate (calculated)	Lake elevation	Mean catchment slope	Air temperature (spring)
Calcium Calcium (dissolved)	Lake/reservoir	% Canal/drainage	Solar radiation (monthly)
Carbonate (calculated)	Max depth	% Cleared land	Total precipitation (monthly)
Chloride (dissolved)	Secchi depth	% Cropland	
Hardness (as total $CaCO_3$)	Sum buoyancy frequency	% Grassland	
Magnesium (dissolved)	Surface water temperature	% Hard linear features	
Nitrogen (total)		% Harvested forest	
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Sodium (dissolved)		% Wetlands	
Sulphate (dissolved)		Watercourse crossing density	
Total dissolved solids			

Atmospheric climate conditions

Local factors		Regional factors	
Alkalinity (as total $CaCO_3$)	Lake area-perimeter ratio	Catchment are	Air temperature (monthly)
Bicarbonate (calculated)	Lake elevation	Mean catchment slope	Air temperature (spring)
Calcium Calcium (dissolved)	Lake/reservoir	% Canal/drainage	Solar radiation (monthly)
Carbonate (calculated)	Max depth	% Cleared land	Total precipitation (monthly)
Chloride (dissolved)	Secchi depth	% Cropland	
Hardness (as total $CaCO_3$)	Sum buoyancy frequency	% Grassland	
Magnesium (dissolved)	Surface water temperature	% Hard linear features	
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Sulphate (dissolved)		Watercourse crossing density	
Total dissolved solids			

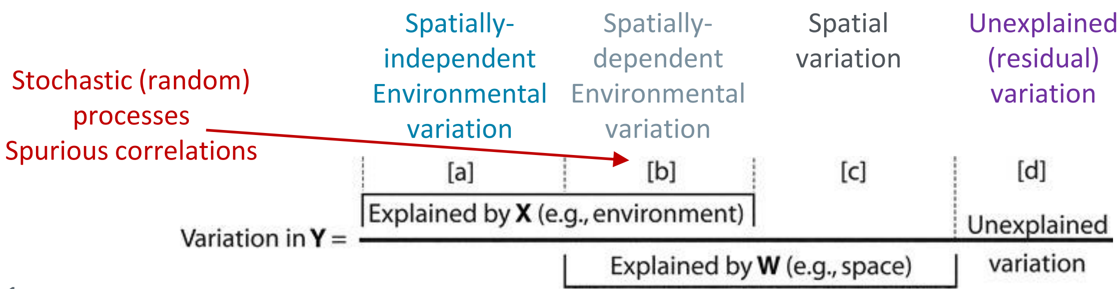
The challenge: spatial autocorrelation

Spatially-correlated responses along biogeographic/environmental gradients

- Failure to meet assumption of independence (inflation of Type I statistical error)
- Is variation due to: Environmental factors? Spatial factors? Shared Environmental-Spatial factors? Or purely Spurious correlation due to stochastic (random) processes?

Confounds interpretation of results

- If ignored: risk of type I statistical error (i.e. falsely assume environment induced)
- If controlled by partial analysis risk of type II error (i.e. falsely assumed spurious)



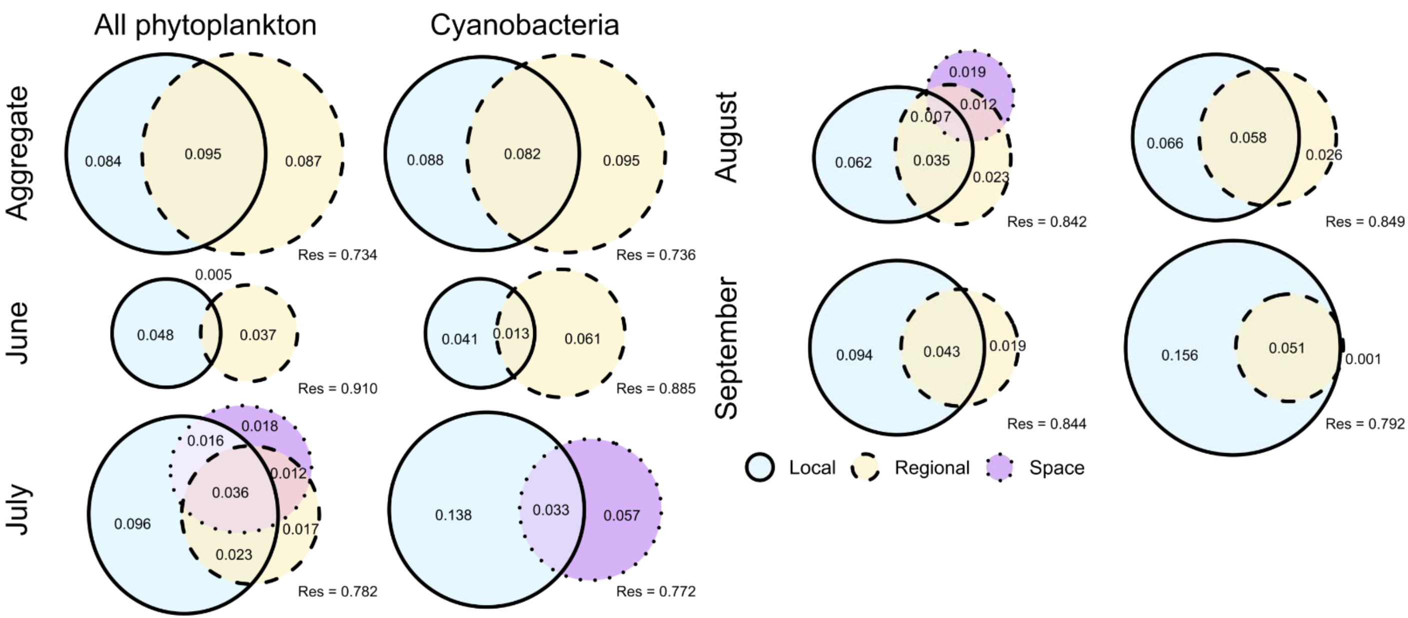
Peres-Neto, Legendre, Dray, and Borcard. 2006. *Ecology*

Spatially-constrained null model approach

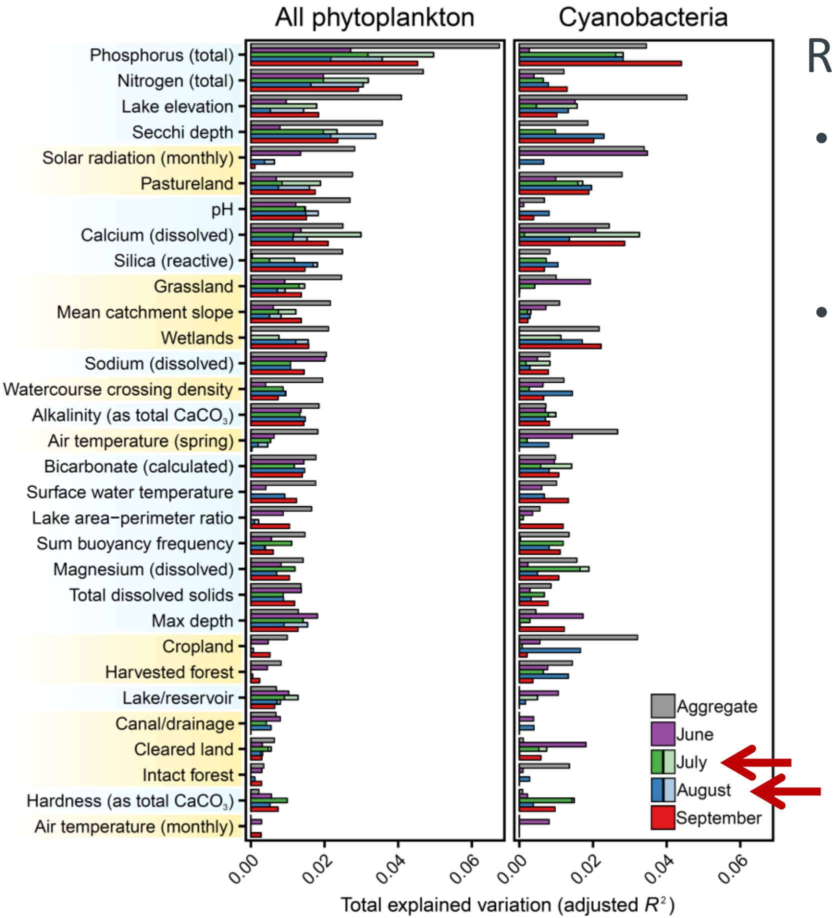
Moran's spectral randomization for irregularly spaced data

- Wagner & Dray (2015) adapted by Clappe, Dray, and Peres-Neto (2018)
- Allows for estimation/adjustment of spuriously correlated portion of overlapping variation (fraction "b")

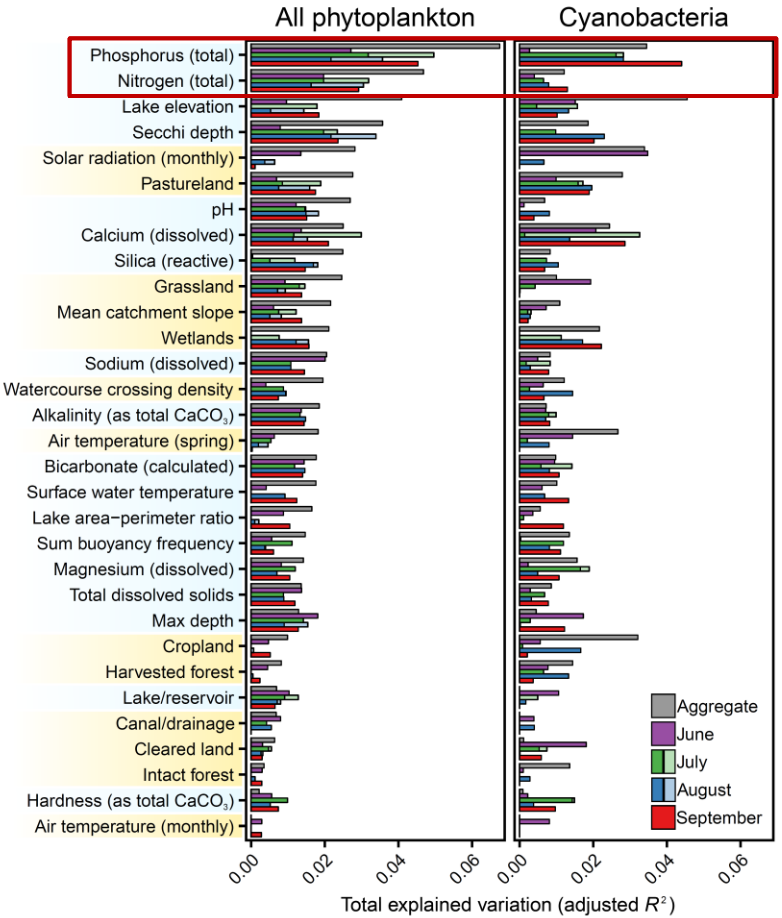
Local vs. Regional vs. Space



Ranking individual factors

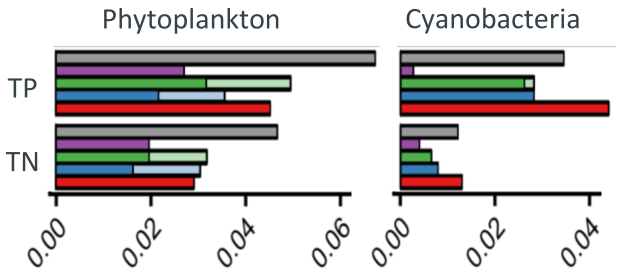


- Local factors (blue); Regional factors (yellow)
- Adjusting for significant spatial autocorrelation in July and August only



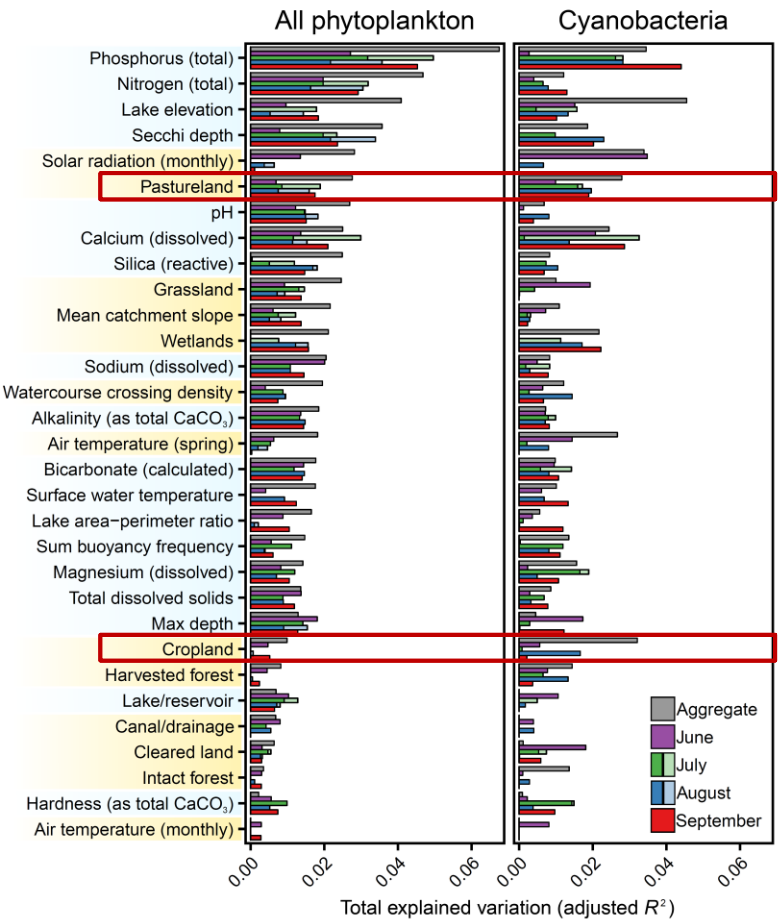
Nutrients reign

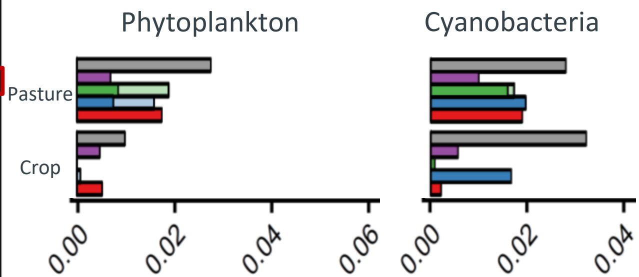
- Phosphorous and nitrogen lead for Phytoplankton overall
- Phosphorus but NOT nitrogen important for cyanobacteria
- Both nutrients become increasingly important over summer

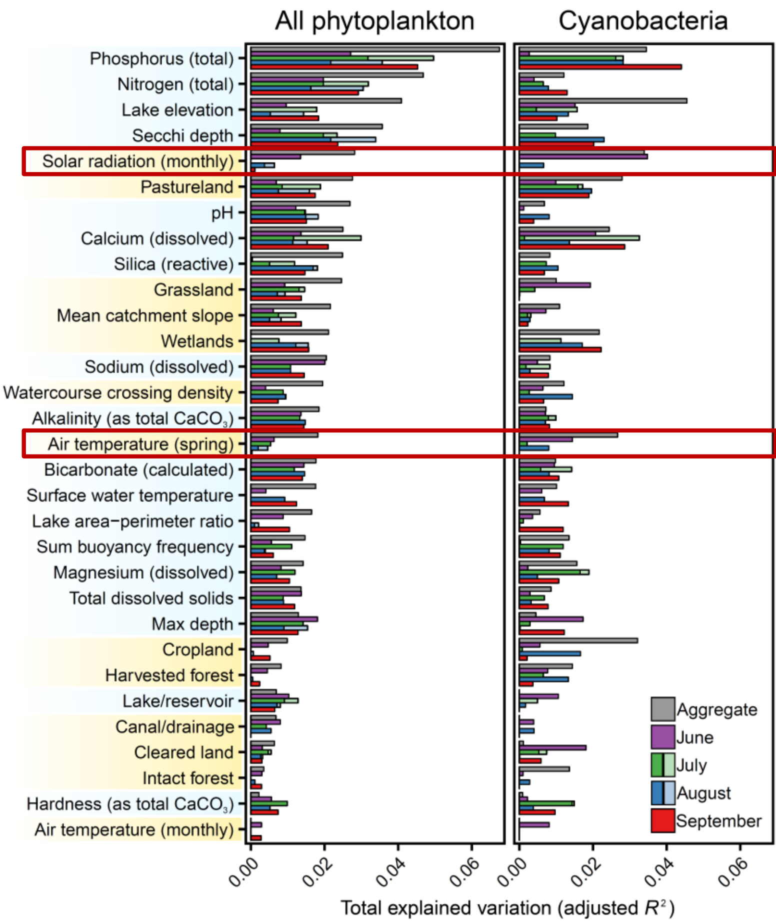


Connection to agriculture

- Pasture was top land-use factor for overall phytoplankton community
- Cropland top land-use for cyanobacteria
  - Both covary with nutrient concentrations

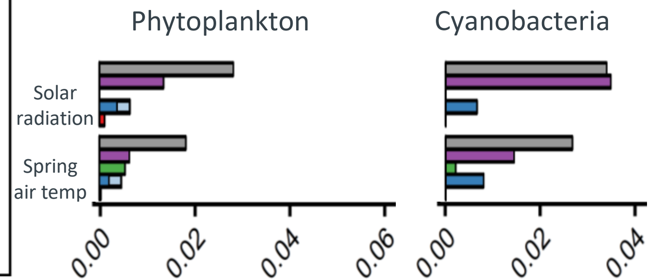


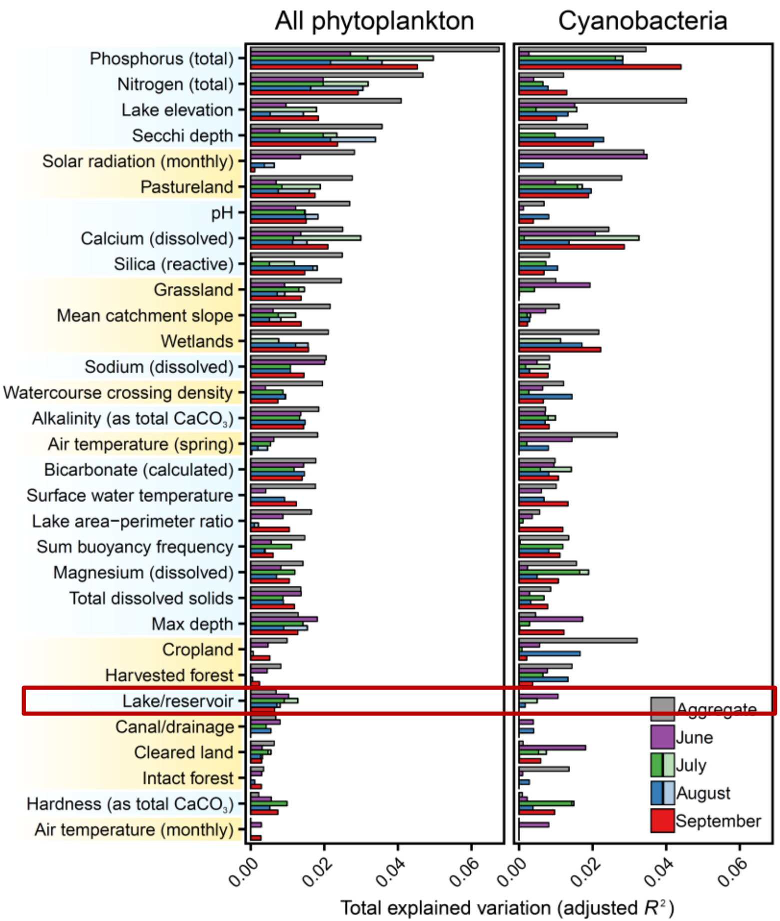




Early-season climate

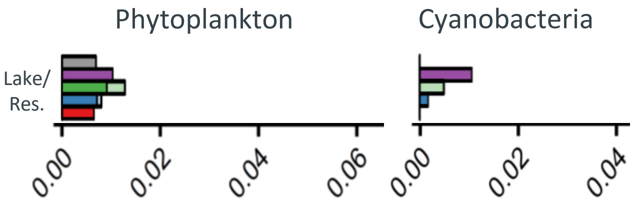
- Solar radiation and spring air temperature most important for June communities
  - Decreasing importance over summer





Lake/Reservoir Class

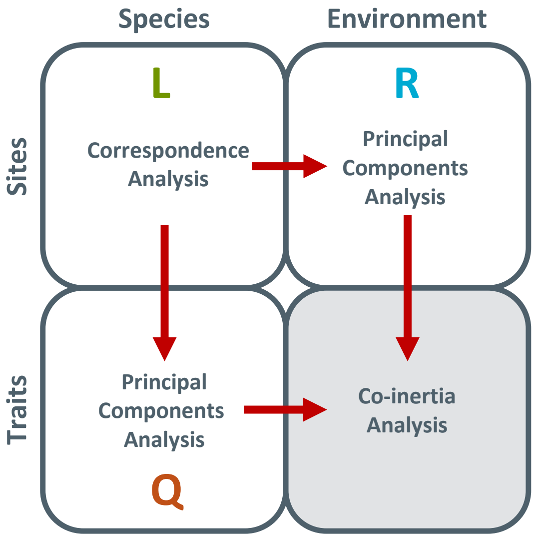
- Negligible difference between natural and constructed waterbodies
- Reservoirs naturalized rapidly



Linking environment to species' traits

Peering into the fourth-corner with RLQ

Environmental variables		Trait variables
Air temperature (monthly)	Max depth	Buoyancy regulating
Air temperature (spring)	Mean catchment slope	Greatest axial length
Alkalinity (as total $CaCO_3$)	Nitrogen (total)	Nitrogen-fixing
Bicarbonate (calculated)	Pastureland	Silica-requirement
Calcium (dissolved)	pH	Flagellar motility
Canal/drainage	Phosphorus (total)	Heterotrophy
Cleared land	Secchi Depth	Phycobilins producing
Cropland	Silica (reactive)	Chlorophyll c producing
Forest intact	Sodium (dissolved)	Chlorophyll b producing
Forest harvested	Solar radiation (monthly)	Chain/colony forming
Grassland	Sum buoyancy frequency	Mucilaginous sheaths
Hardness (as total CaCO3)	Surface water temperature	Spine/pole producing
Lake area-perimeter ratio	Total dissolved solids	Toxin producing
Lake elevation	Watercourse crossing density	
Lake/reservoir	Wetlands	
Magnesium (dissolved)		

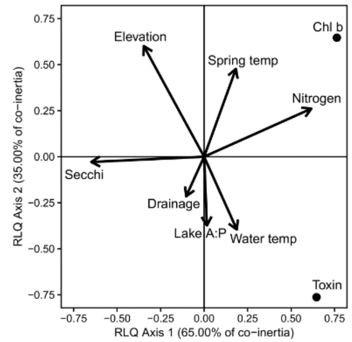


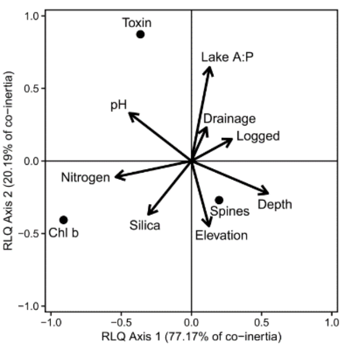
Alberta

RLQ Results:

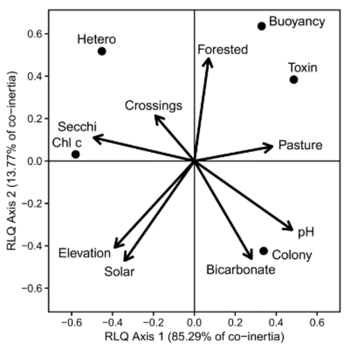
Dominant trait-environment associations over time

Aggregate

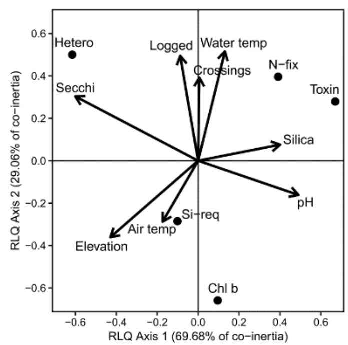




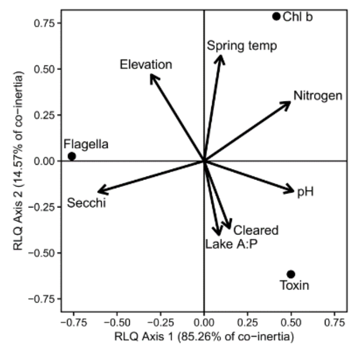
June



July



August



September

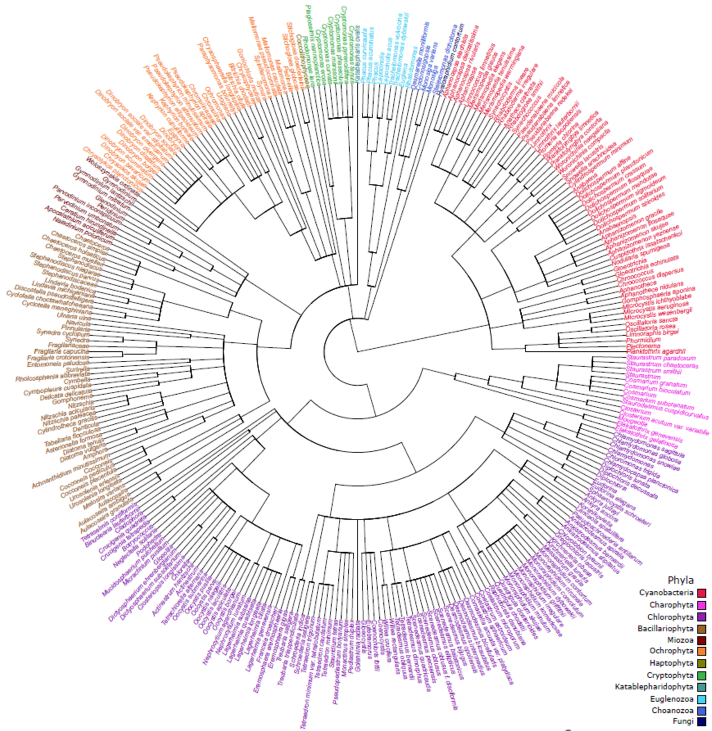
Fourth-corner analysis

Determine individual trait-environment associations

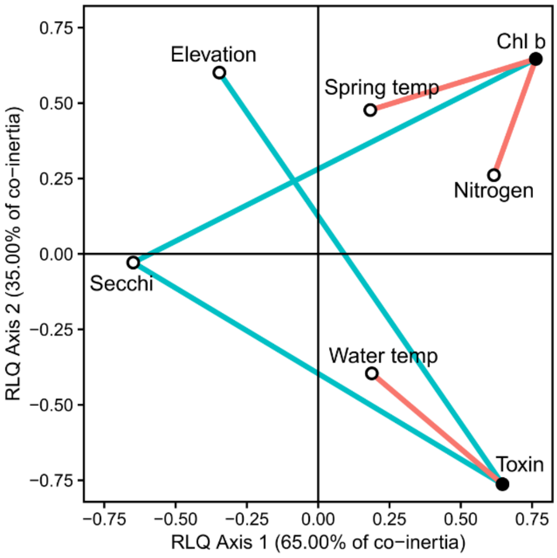
- Moran's spectral randomization
- Spatially and phylogenetically-constrained analysis

Optimized phylogenetic eigenvector maps based on topology of taxonomic tree

- Significant phylogenetic autocorrelation found in July and August



Significant relationships in Aggregate



Chlorophyll b (+) Spring air temperature

Chlorophyll b (+) Nitrogen

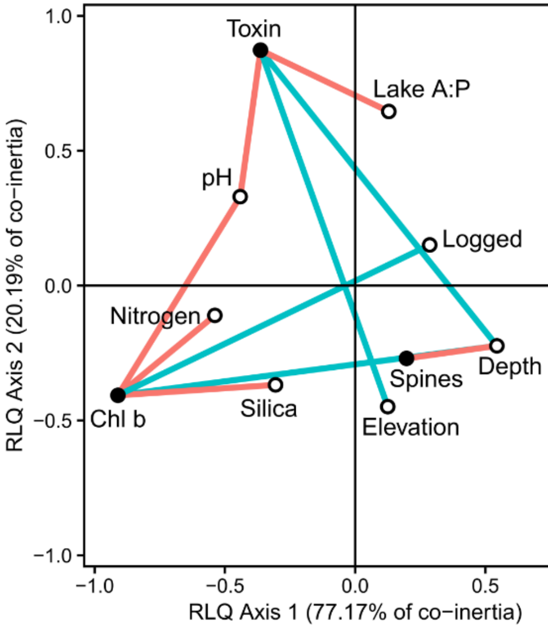
Chlorophyll b (-) Secchi depth

Presumptive toxin producing (+) Surface water temperature

Presumptive toxin producing (-) Elevation

Presumptive toxin producing (-) Secchi depth

Significant relationships in June

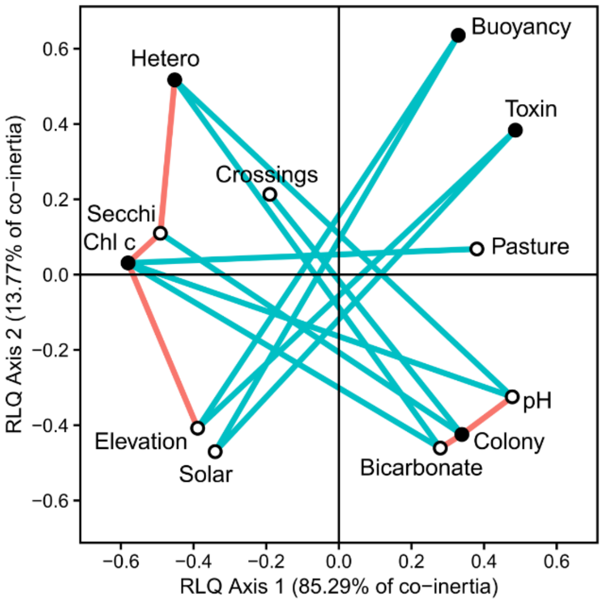


Presumptive toxin producing (+) Lake A:P
Presumptive toxin producing (+) pH
Presumptive toxin producing (-) Max depth
Presumptive toxin producing (-) Elevation

Chlorophyll b (+) pH
Chlorophyll b (+) Nitrogen
Chlorophyll b (+) Silica
Chlorophyll b (-) Logged (harvested forest)
Chlorophyll b (-) Max depth

Spines (+) Max depth

Significant relationships in July



Colonial (+) pH

Colonial (+) Bicarbonate

Colonial (-) Crossings

Colonial (-) Secchi depth

Heterotrophy (+) Secchi depth

Heterotrophy (-) pH

Heterotrophy (-) Bicarbonate

Chlorophyll c (+) Secchi depth

Chlorophyll c (+) Elevation

Chlorophyll c (-) Pastureland

Chlorophyll c (-) pH

Chlorophyll c (-) Bicarbonate

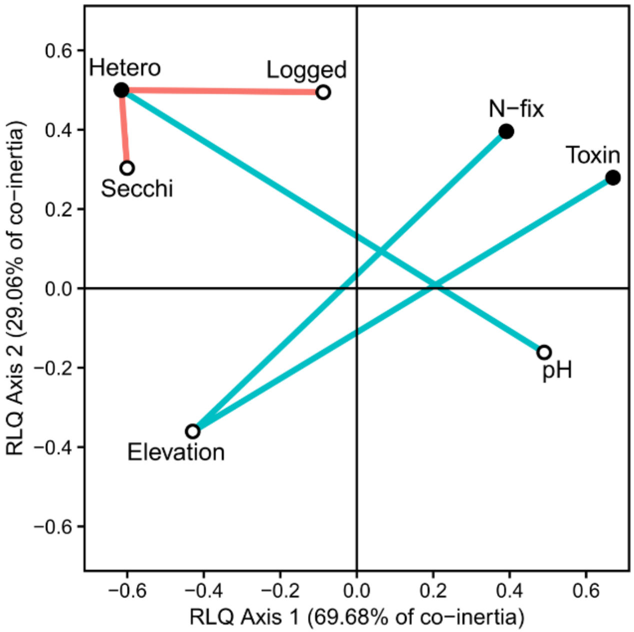
Buoyancy regulation (-) Elevation

Buoyancy regulation (-) Solar radiation

Presumptive toxin producing (-) Elevation

Presumptive toxin producing (-) Solar radiation

Significant relationships in August



Heterotrophy (+) Logged (harvested forest)

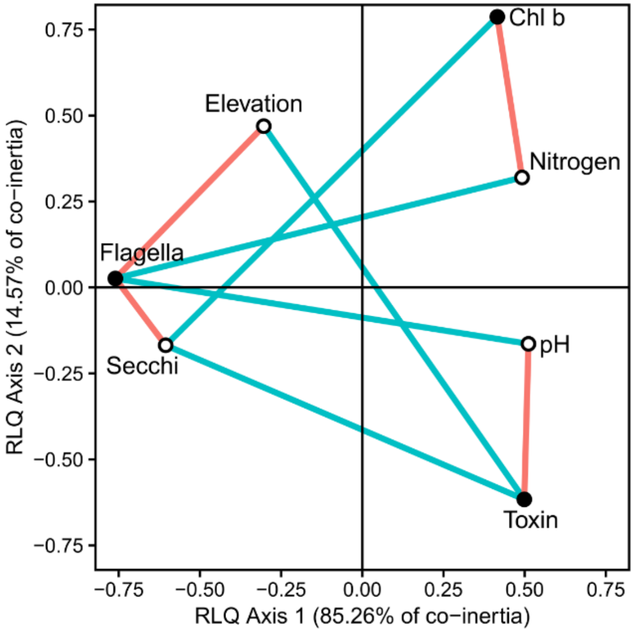
Heterotrophy (+) Secchi depth

Heterotrophy (-) pH

Nitrogen fixation (-) Elevation

Presumptive toxin producing (-) Elevation

Significant relationships in September



Flagellar motility (+) Elevation

Flagellar motility (+) Secchi depth

Flagellar motility (-) Nitrogen

Flagellar motility (-) pH

Chlorophyll b (+) Nitrogen

Chlorophyll b (-) Secchi depth

Presumptive toxin producing (+) pH

Presumptive toxin producing (-) Elevation

Presumptive toxin producing (-) Secchi depth

Summary

- Despite broad biogeographic gradients, communities showed little spatial autocorrelation—environmental associations were independent of space (except July and August)
- Seasonal differences in the influence of environmental factors on phytoplankton (and cyano) diversity exists—local (in-lake) factors better explained taxonomic variation especially as growing season progressed
  - Regional factors (eg. solar radiation, spring air temp) most important in early growing season only
  - Nutrients and land-use relating to nutrient export key factors
- Local and regional factors were more complementary for seasonally aggregated data—highlight importance of collecting data over the entire growing season
- Phytoplankton and cyanobacteria communities of reservoirs appear similar to natural lakes—indicating rapid naturalization of reservoirs

Summary cont'd

- Differing drivers for toxin vs. chlorophyll-b producers
  - Toxin under warm, low elevation (solar radiation), and high pH
  - Chlorophyll-b under high nitrogen and smaller logging footprints

- Phytoplankton trait-environment associations offer mechanistic insights
  - Natural/anthropogenic associations generate hypotheses

Acknowledgements

- Sample collection: The Alberta Lake Management Society & EMSD Field Staff
- Data validation: Jenny Pham, AEP
- Data Preparation: Rabekah Adams & Alex Lake, EMSD
- Watershed Data/Co-authors: Faye Wyatt and Colleen Mortimer, GIS Specialists, EMSD
- Co-author: Rolf Vinebrooke, U of A

Part 1:

"Multiscale drivers of phytoplankton communities in north-temperate lakes"

Charlie J. G. Loewen, Faye R. Wyatt, Colleen A. Mortimer, Rolf D. Vinebrooke, and Ron W. Zurawell

Submitted to: *Ecological Applications*

Part 2:

"Seasonal trait-environment associations of phytoplankton communities in north-temperate lakes "

Charlie J. G. Loewen, Rolf D. Vinebrooke, and Ron W. Zurawell

In prep