Utah Lake Bioassay Final Report-Nutrient Limitation of Phytoplankton, Cyanobacteria and Cyanotoxins

Professors in order of overall contribution

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Co-PI: Dr. Ben W. Abbott, Brigham Young University

Co-PI: Dr. Michelle A. Baker, Utah State University

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Gabriella M. Lawson, Brigham Young University (MS candidate)

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Dr. Michael J. Paul Tetra Tech

Dr. Mitch Hogsett, Forsgren Associates Inc.


Pleasant Grove
Saratoga Springs
Vineyard
Orem
Main Body West
Main Body East
Utah Lake
Provo
Utah Lake
Provo Bay
Bird Island
Benjamin
West Mountain
Payson

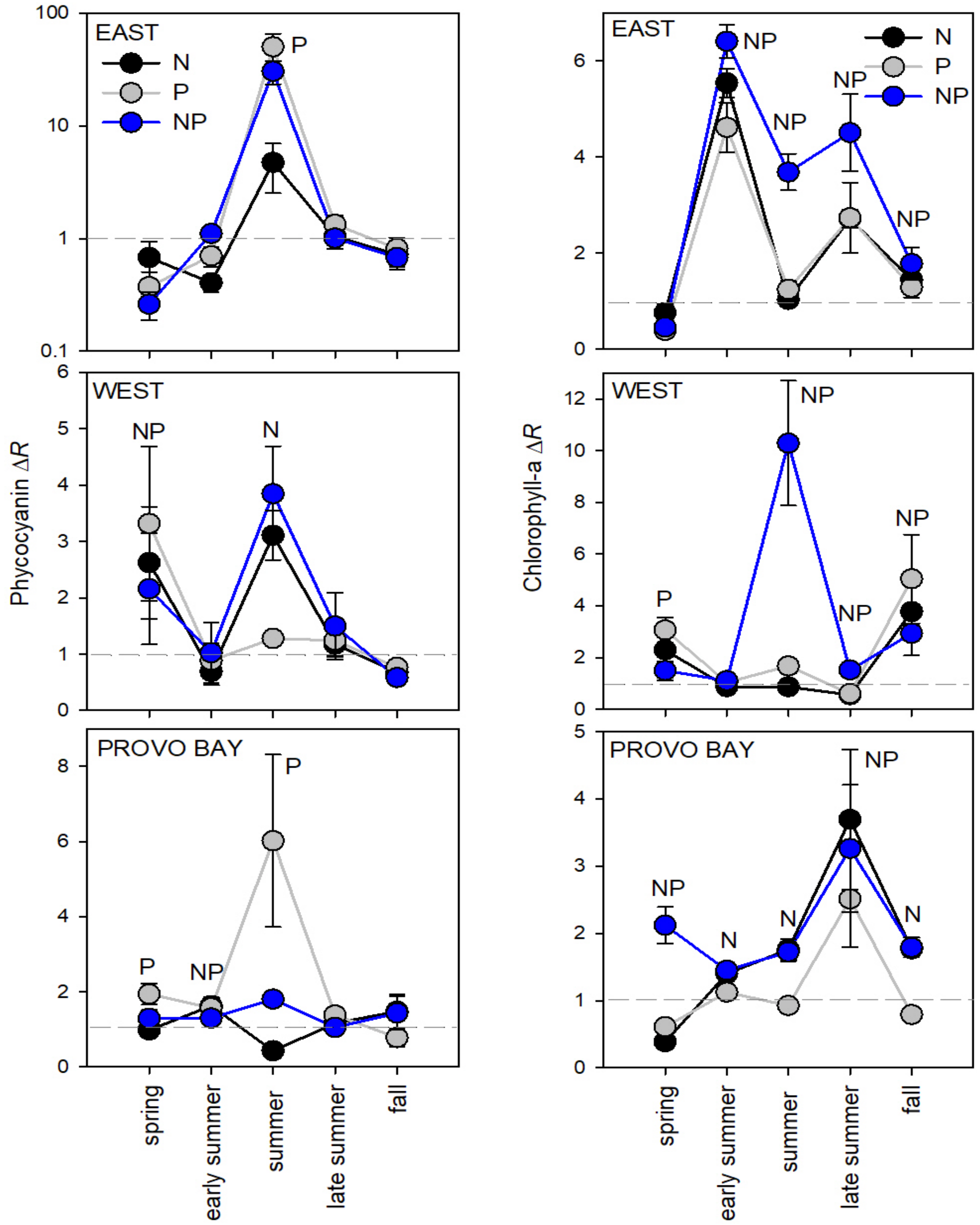
phytoplankton as all prokaryotic or eukaryotic organism containing chlorophyll-a (e.g., chlorophytes, diatoms, and cyanobacteria)

P amendment = 0.10 mg-P/L above background concentrations added as K_2HPO_4,

N amendment = 0.72 mg-N/L added as NH_4NO_3 to achieve a 16:1 molar ratio of DIN:SRP

ΔR = mean chlorophyll-a treatment/mean chlorophyll-a control)

- The nutrient limitation of cyanobacteria and to a lesser extent phytoplankton were influenced by season and space
- N or P limited cyanobacteria in the summer across all three locations. P limited cyanobacterial responses in East and Provo Bay water, while N limited cyanobacteria in West water
- Cyanobacteria were not limited by either N or P in the late summer and fall,
- Nutrient colimitation of phytoplankton occurred in the summer, late summer, and fall
- In the relatively nutrient rich Provo Bay that supported orders of magnitude more phytoplankton biomass than the main body, phytoplankton was limited during every season with N limiting phytoplankton responses when a co-limitation was not present



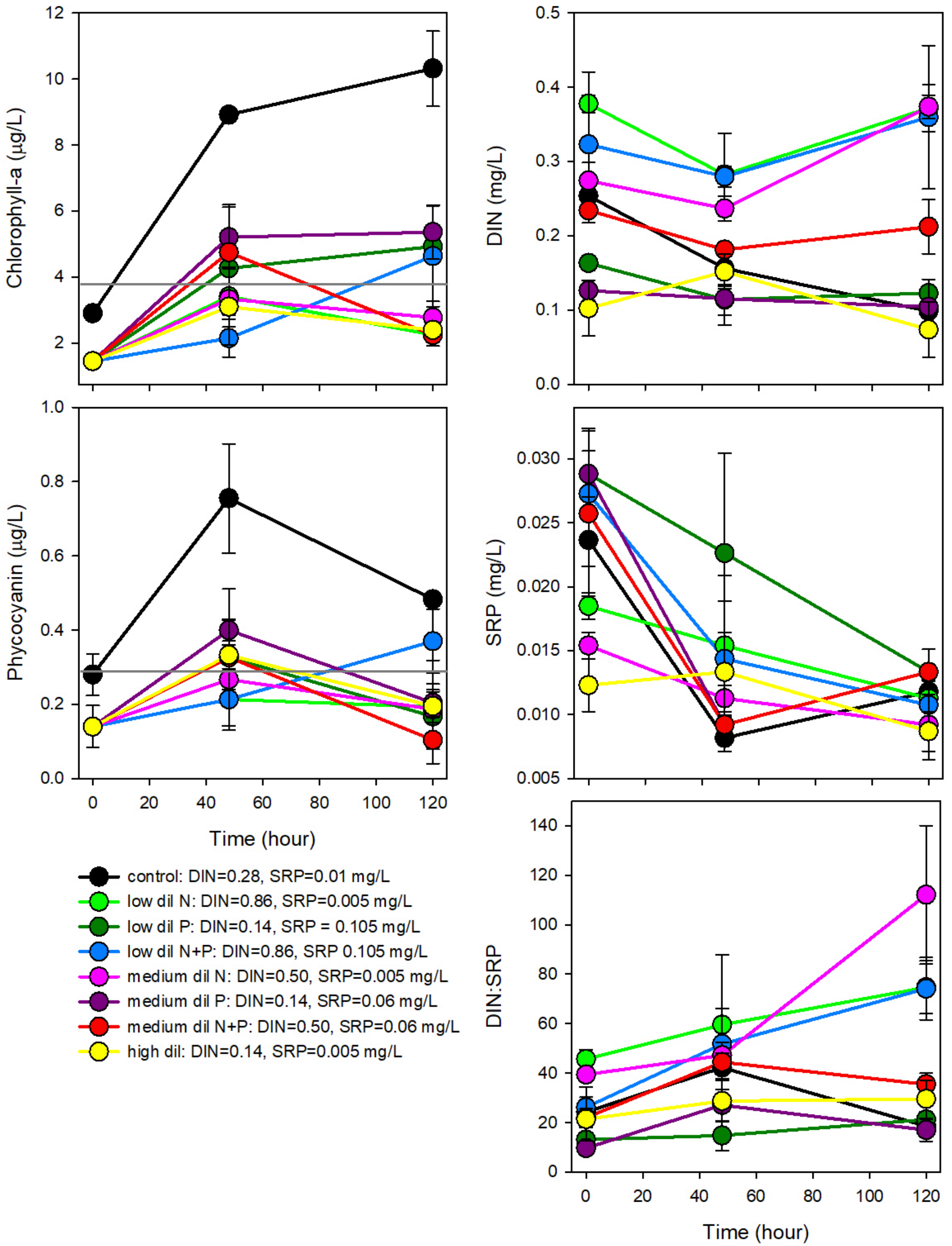
- The DIN and SRP was biologically available to the cyanobacteria and phytoplankton with the concentrations of DIN and SRP consistently declining in treatments—the addition of N resulted in lower P concentrations and the addition of P leading to lower N concentrations

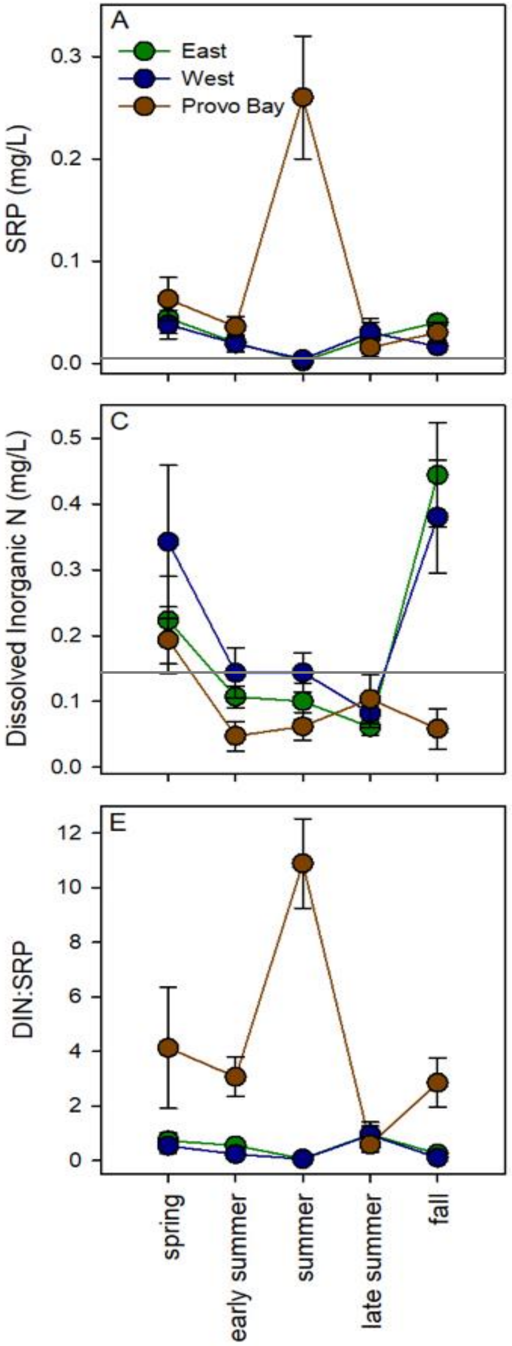
- During the summer seasons, across all locations, the ratio of DIN to SRP in the N+P addition remained close to 16:1 indicating that phytoplankton and/or cyanobacteria were still utilizing N and P even under excessive nutrient conditions

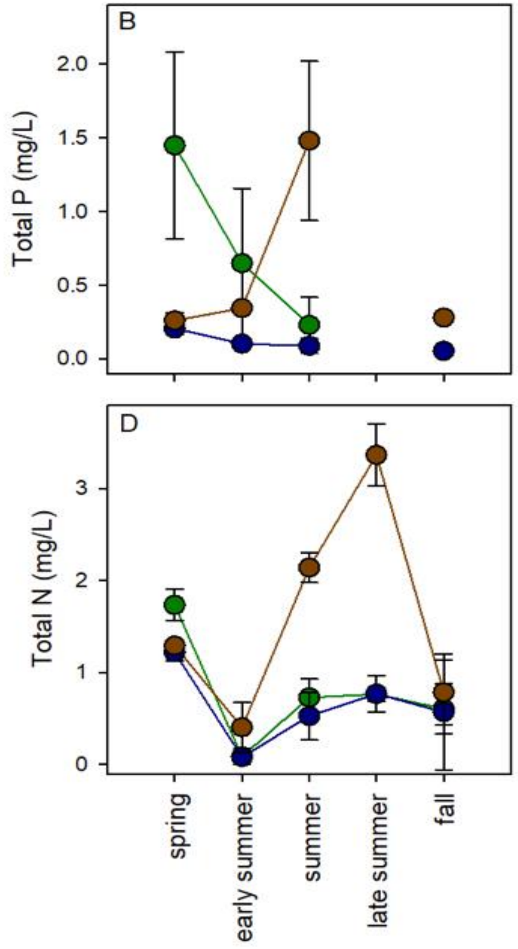
- Biogeochemically co-limited instead of community-level co-limited

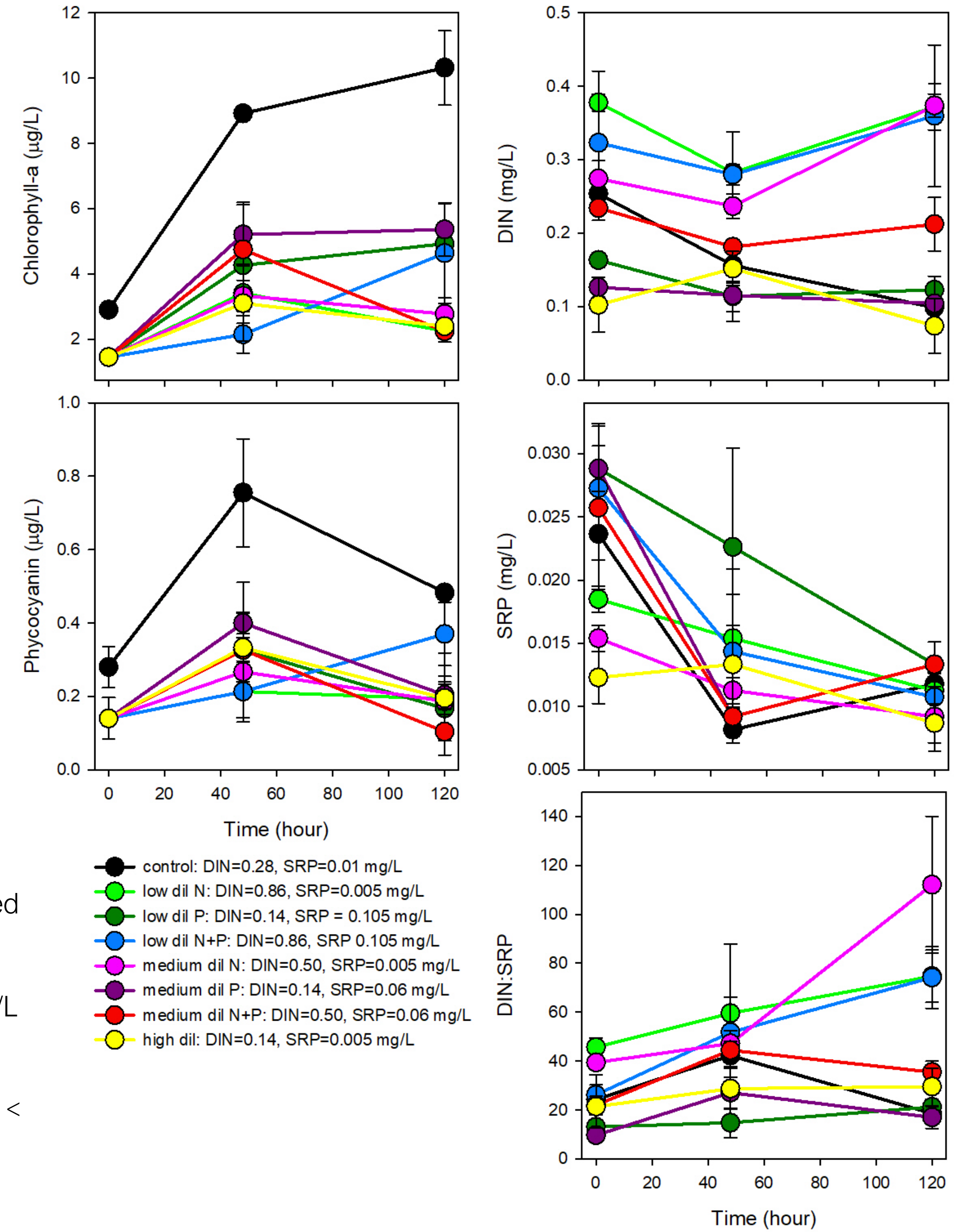
Location	Treatment	Treatment	SRP (mg/L)	DIN (mg/L)	DIN:SRP (mole:mole)
EAST	spring	N	0.013 ±0.002	0.05 ±0.02	9.22 ±3.33
		P	0.029 ±0.015	0.26 ± 0.01	32.6 ±12.8
		N+P	0.016 ±0.004	0.49 ± 0.33	55.5 ±25.5
	early summer	N	0.005 ±0.001	0.19 ±0.01	117 ±4.88
		P	0.008 ±0.003	0.07 ±0.06	16.2 ±8.66
		N+P	0.007 ±0.001	0.02 ± 0.001	5.30 ±1.25
	summer	N	0.004 ±0.002	0.86 ±0.08	800 ± 405
		P	0.100 ±0.001	0.06	1.33
		N+P	0.096 ±0.20	0.70 ±0.15	16.2 ±0.614
	late summer	N	0.031 ±0.012	0.39 ±0.06	33.5 ±7.72
		P	0.067 ±0.033	0.02 ±0.01	8.49 ±7.95
		N+P	0.037 ±0.033	0.17 ±0.06	94.1 ±53.2
	fall	N	0.008 ±0.004	1.00 ±0.06	122 ±61.5
		P	0.140 ±0.020	0.29 ±0.06	4.58 ±0.365
		N+P	0.123 ±0.021	1.18 ±0.38	12.0 ±6.45
WEST	spring	N	0.022 ±0.021	0.14 ±0.07	104 ±93.8
		P	0.084 ±0.026	0.06 ± 0.04	1.36 ±0.469
		N+P	0.117 ±0.043	0.25 ± 0.23	3.17 ±2.33
	early summer	N	0.005 ±0.002	0.28 ±0.01	372 ±278
		P	0.006 ±0.001	0.03 ±0.01	11.2 ±4.12
		N+P	0.009 ±0.002	0.23± 0.001	75.0
	summer	N	0.003 ±0.002	1.0 ±0.13	2859 ±1764
		P	0.094 ±0.002	0.14	3.43
		N+P	0.068 ±0.003	0.63 ±0.04	20.3 ±0.962
	late summer	N	0.065 ±0.037	0.75 ±0.04	13.0 ±7.78
		P	0.020 ±0.014	0.08 ±0.02	49.0 ±39.2
		N+P	0.037 ±0.021	0.50 ±0.09	19.7 ±14.3
	fall	N	0.009 ±0.006	0.96 ±0.11	913 ±712
		P	0.141 ±0.009	0.34 ±0.04	5.41 ±0.263
		N+P	0.106 ±0.003	0.96 ±0.06	20.0 ±0.836
PROVO BAY	spring	N	0.024 ±0.006	0.30 ±0.16	34.5 ±24.7
		P	0.015 ±0.002	0.31 ± 0.02	45.1 ±1.55
		N+P	0.021 ±0.006	0.14 ± 0.04	18.9 ±8.72
	early summer	N	0.012 ±0.002	0.30 ±0.16	31.4 ±14.6
		P	0.010 ±0.002	0.31 ±0.02	2.42
		N+P	0.010 ±0.002	0.14 ±0.04	17.7 ±14.1
	summer	N	0.008 ±0.001	0.14 ±0.06	41.0 ±29.1
		P	0.246 ±0.020	0.37 ±0.31	3.68 ±3.13
		N+P	0.074 ±0.018	0.26 ±0.12	11.1 ±7.11
	late summer	N	0.021 ±0.005	0.09 ±0.06	16.9 ±13.9
		P	0.114 ±0.010	0.19 ±0.06	3.72 ±1.08
		N+P	0.056 ±0.032	0.19 ±0.07	3.84 ±1.66
	fall	N	0.009 ±0.001	0.09 ±0.07	26.9 ±19.8
		P	0.084 ±0.006	0.01 ±0.001	0.257 ±0.129
		N+P	0.010 ±0.001	0.11 ±0.05	29.5 ±16.4

- In the spring, the nutrient levels needed to curb phytoplankton are a DIN concentration < 0.14 mg/L combined with an SRP concentration < 0.06 mg/L
- The nutrient level needed to curb cyanobacteria is a SRP concentration < 0.005 mg/L
- The decline in SRP, when DIN was relatively available (0.86 mg/L), caused a decline in phycocyanin concentrations and potentially cyanobacteria





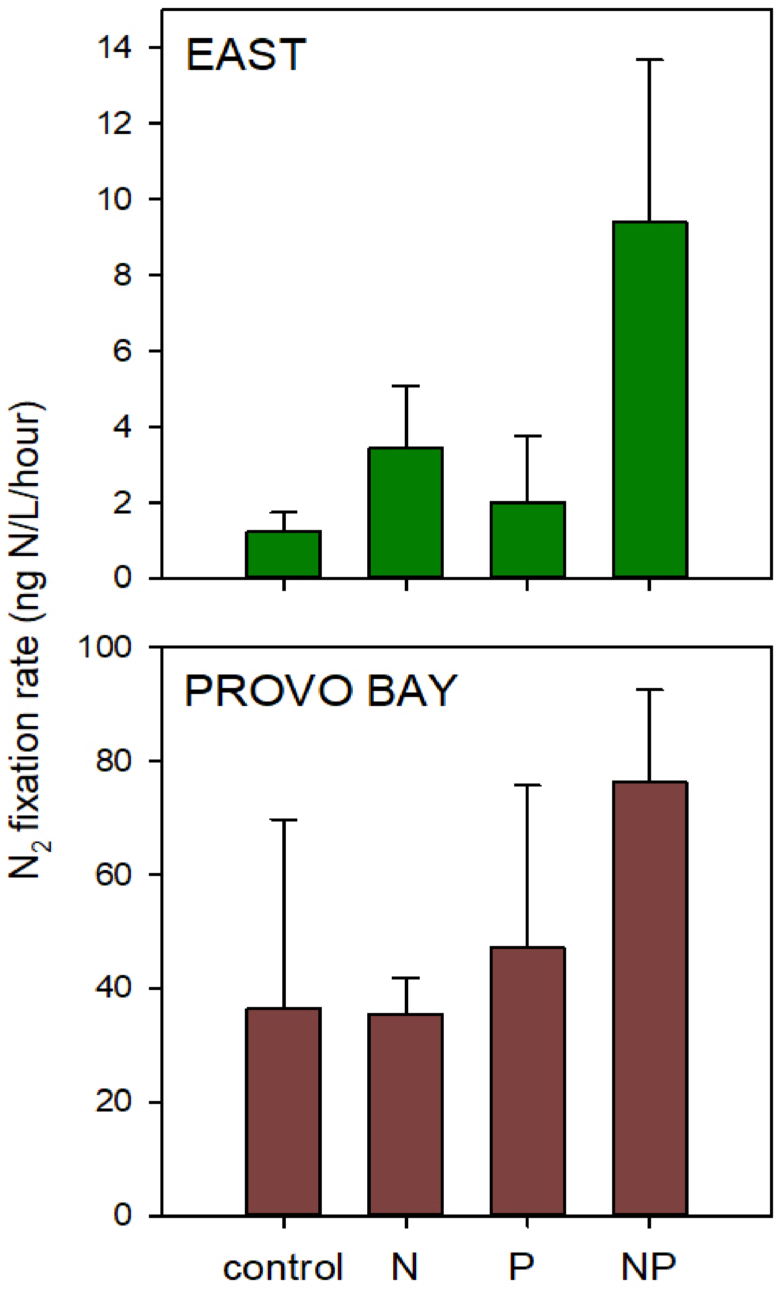


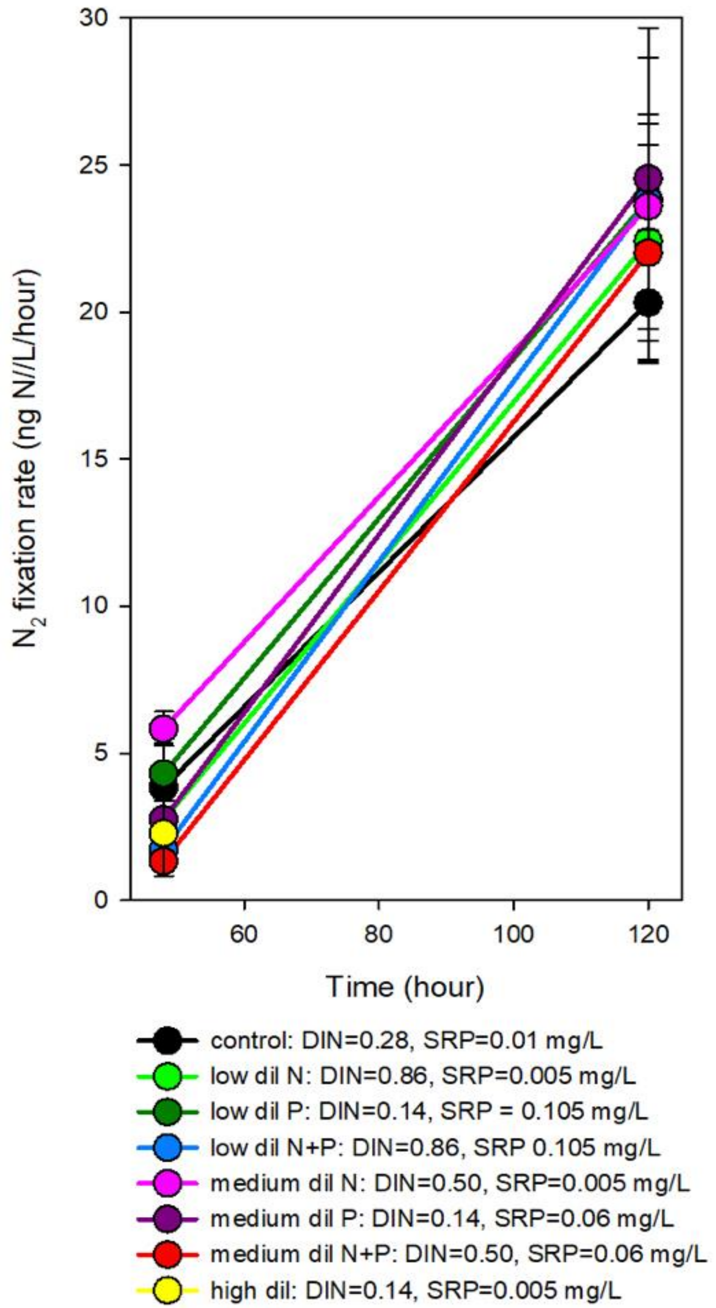


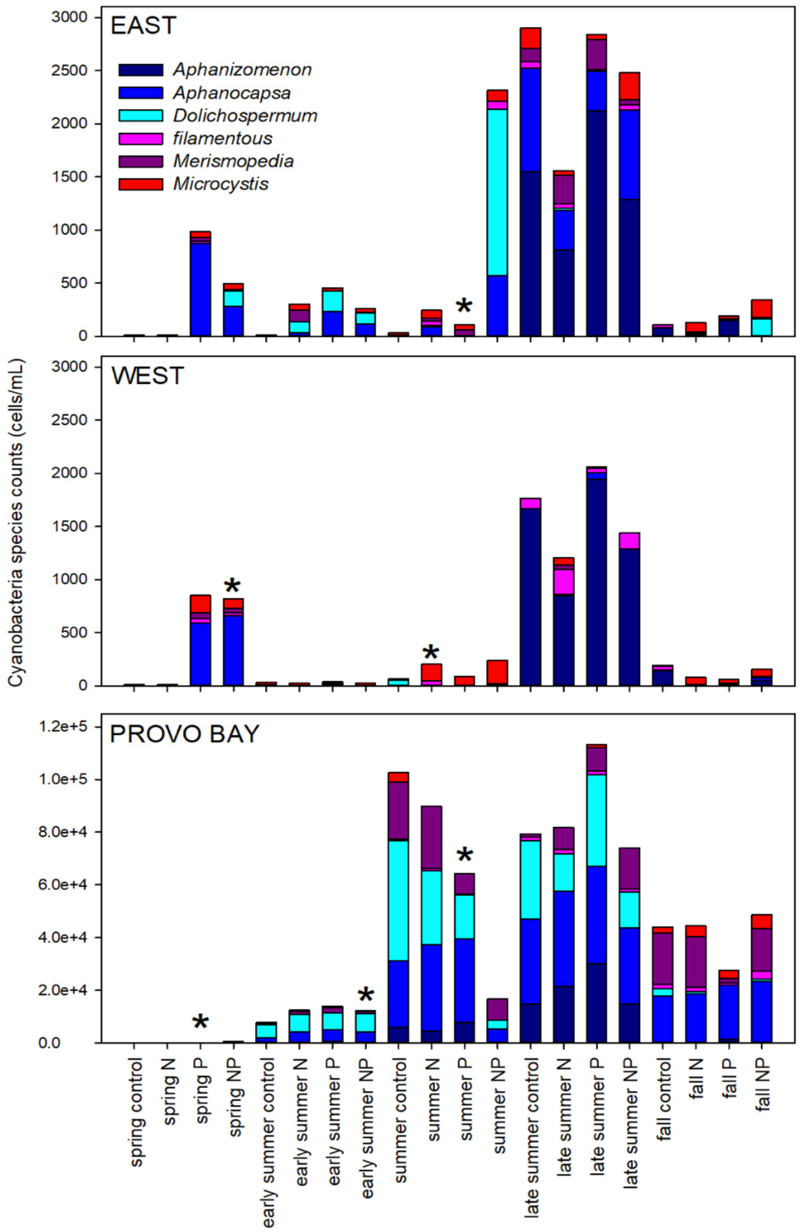
- In the spring, the nutrient levels needed to curb phytoplankton are a DIN concentration < 0.14 mg/L combined with an SRP concentration < 0.06 mg/L
- The nutrient level needed to curb cyanobacteria is a SRP concentration < 0.005 mg/L

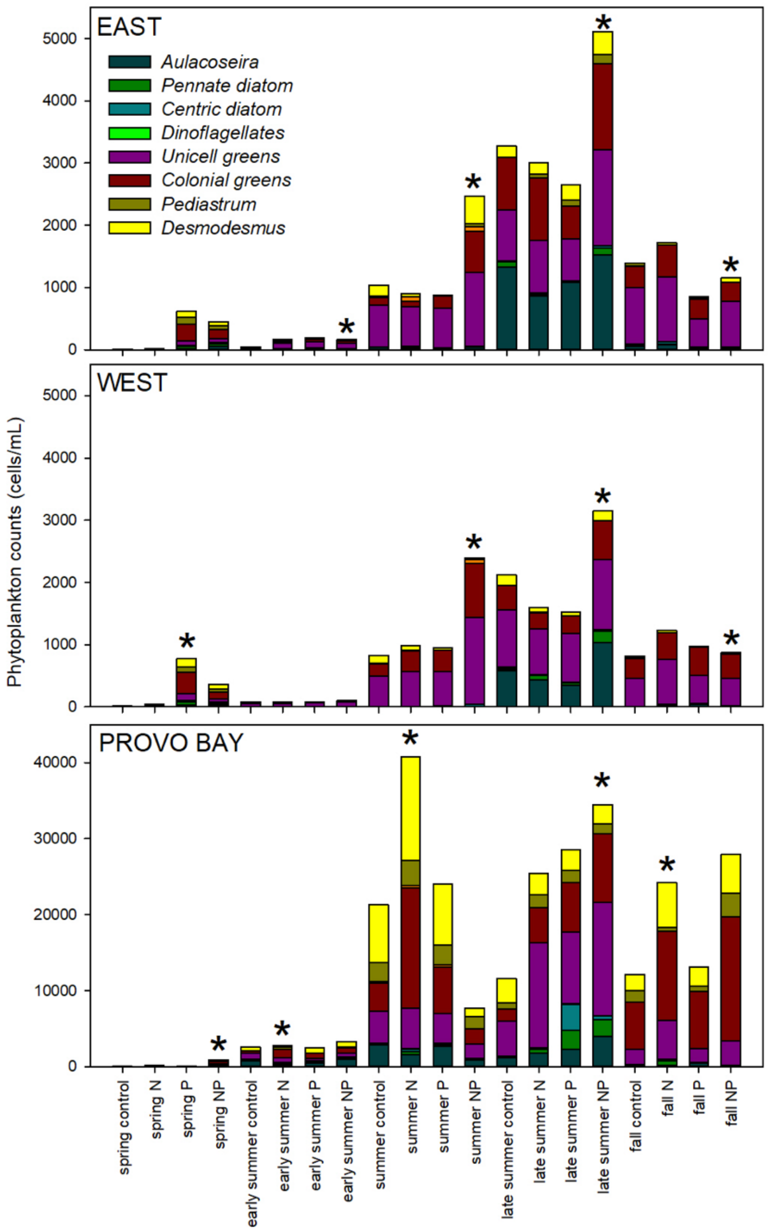
- In the early summer, N+P additions increased N_2 fixation 7.7-fold (N+P=9.41 ng N/L/hour ±4.27, control=1.23 ng N/L/hour ±0.523) in East water. In Provo Bay, N_2 fixation rates were at least 4-times higher than in East but were not influenced by nutrient addition. N_2 fixation was non-detectable in West water

- Regardless of treatment, N_2 fixation dramatically increased at least 5.5-fold from 48 to 120 hours (mean of all treatments: 48 hours=3.33 ±0.442 and 120 hours=22.9 ±1.08 ng N/L/hour



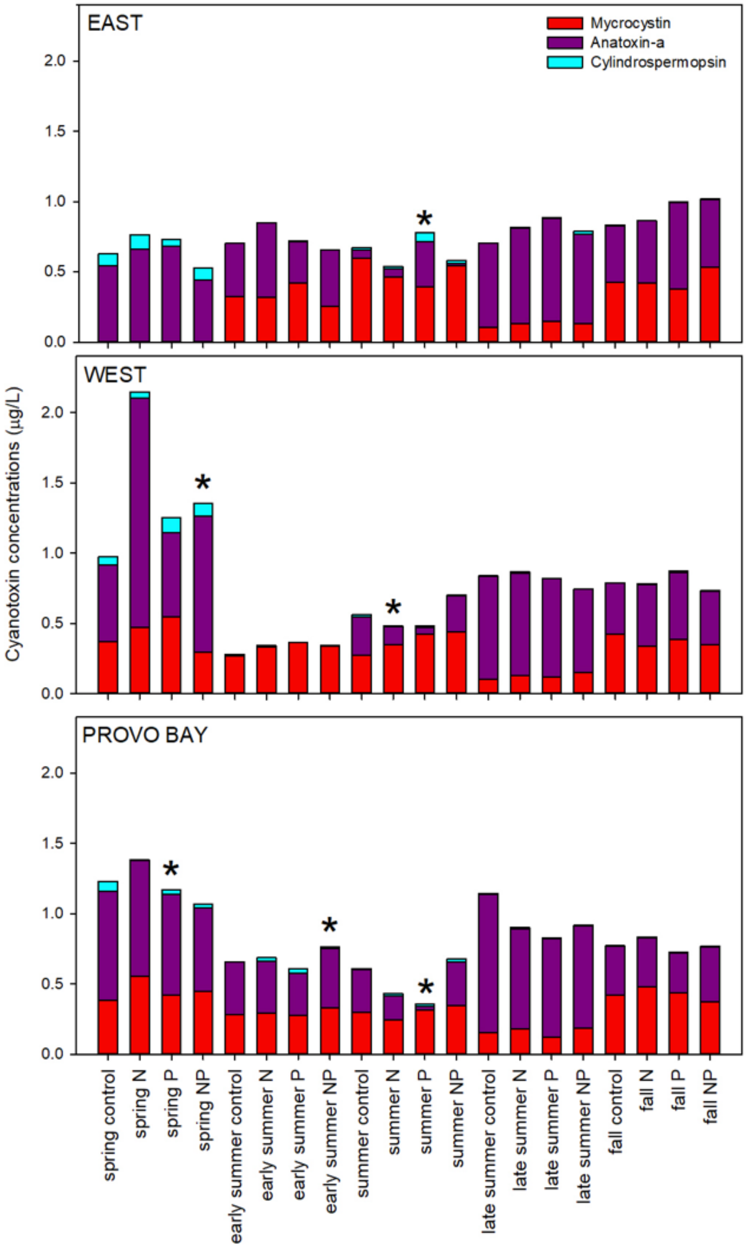


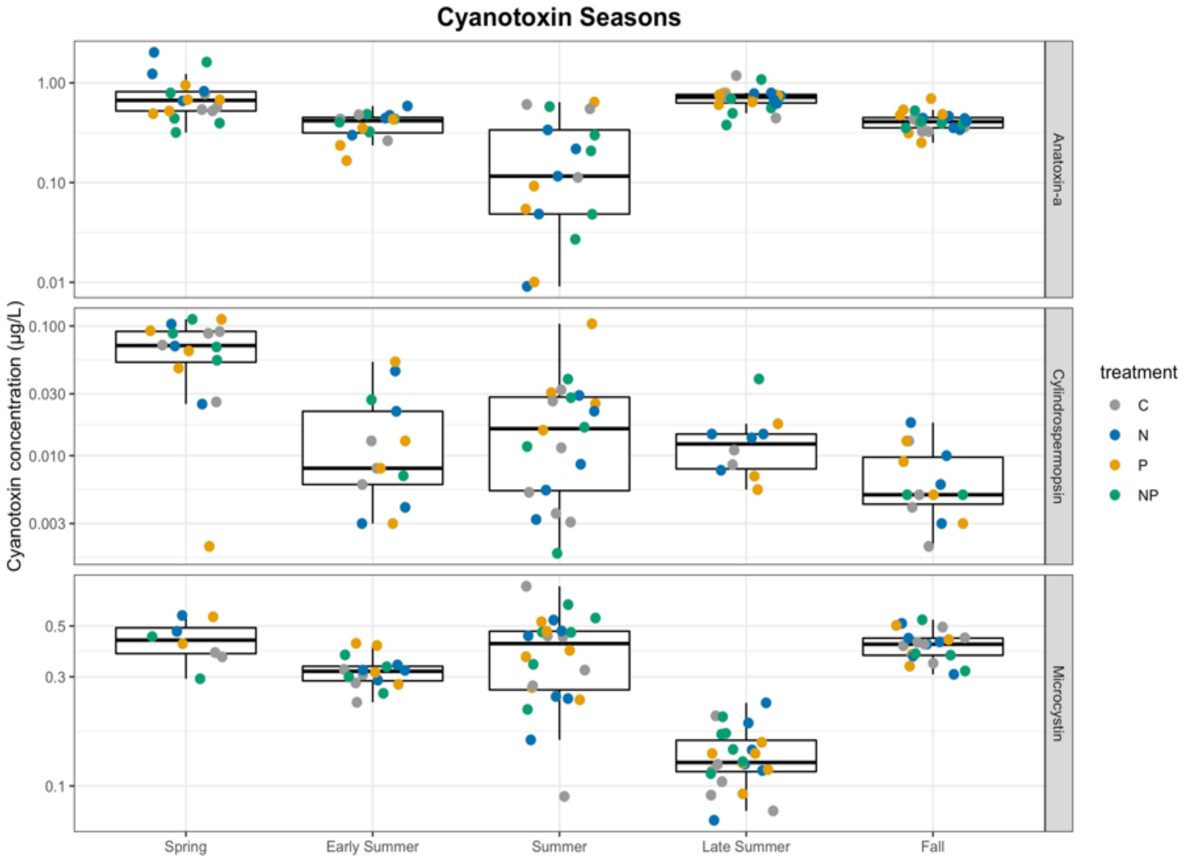




- During the summer, Microcystis sp. was associated with cyanobacterial nutrient limitation in the East and West. In the bay, Aphanocapsa, Dolichospermum, Merismopedia, and Aphanizomenon spp. were associated with nutrient limitation in the early summer and summer.
- Aulacoseira and Desmodesmus spp. and two taxonomical categories of algae (i.e., unicellular and colonial green algae) were primarily associated with the phytoplankton nutrient limitations across Utah Lake regardless of season.

	EAST						WEST						PROVO BAY					
	counts (#)	richness = 18					counts (#)	richness = 15					counts (#)	richness = 12				
Species		SP	ES	S	LS	F		SP	ES	S	LS	F		SP	ES	S	LS	F
Aphanizomenon flosaquae	47,463-234,076						5,466-81,833						100,476-344,058					
Aphanocapsa grevillei	728																	
Aphanocapsa holsatica	3,528																	
Aphanocapsa planctonica	1,568-10,662						314-627											
Aphanocapsa species	2,394-10,591						532-8,512						1,862-46,075					
Calothrix species	157																	
Chroococcus species							62											
Chrococcus dispersus													3,240					
Chroococcus limeticus	101												101					
Coelosphaerium species							45						1,440					
Cyanodictyon planctonicum	336-2,688						2,520						2,700-54,000					
Dolichospermum circinalis	645-74,650						946-3,830						1,125-630,157					
Dolichospermum species													6,413					
Gomphosphaeria aponina	5,018																	
Leptolyngbya species	3,928-9,565						3,007						7,515-17,763					
Merismopedia glauca	3,472-48,288						5,555						6,535-65,596					
Microcystis aeruginosa	686						392											
Microcystis species	2,688-3,584						6,272						12,600					
Phormidium species	1,456-2,058						2,464						1,456-12,555					
Phormidium species 3	168-8,623																	
Planktothrix species	826-19,936						9,390-15,680						5,376-36,000					
Pseudanabaena species	162-1,217						324-1,966						1,620-3,035					
Snowella lacustris	784						2,867											





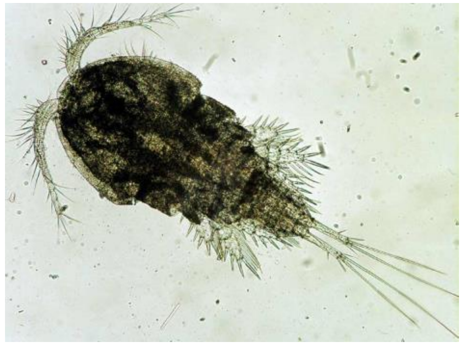
- The three cyanotoxins measured demonstrated a seasonal signal that was not dependent on the cell density of cyanobacteria know to generate the cyanotoxin.
- Cylindrospermopsin concentration was highest in the spring.
- Anatoxin-a concentration was generally higher in the spring, late summer, and fall.
- Microcystin was most prevalent in the early summer and summer, regardless of nutrient treatment or a specific nutrient limitation to phytoplankton.

		Chlorophyll-a		Phycocyanin	
Location	Treatment	plus grazers	minus grazers	plus grazers	minus grazers
EAST	Control	2.28 ±0.870	8.72 ±0.344	0.01 ±0.005	0.540 ±0.56
	N	2.48 ±1.07	48.2 ±4.81	0	2.62 ±0.254
	P	4.84 ±3.44	40.2 ±8.84	0.01 ±0.035	2.08 ±0.344
	N+P	3.90 ±2.49	55.8 ±5.64	0.01 ±0.045	2.64 ±0.333
WEST	Control	2.56 ±1.17	21.5 ±0.558	0.01 ±0.01	0.960 ±0.051
	N	2.41 ±1.01	18.4 ±0.649	0.01 ±0.005	0.870 ±0.006
	P	4.49 ±3.09	22.1 ±2.51	0.01 ±0.055	0.953 ±0.087
	N+P	3.97 ±2.57	23.6 ±4.78	0.01 ±0.050	0.990 ±0.107
PROVO BAY	Control	78.2 ±10.4	41.5 ±5.57	3.27 ±0.340	5.21 ±2.00
	N	101 ±12.9	55.7 ±2.61	4.26 ±0.645	7.71 ±0.254
	P	76.5 ±12.1	44.8 ±2.13	3.22 ±0.390	7.26 ±0.155
	N+P	89.3 ±0.660	57.7 ±2.61	3.76 ±0.145	7.09 ±0.274

Calanoida (Calanoids)

Phyllopoda
(Diplostraca, Notostraca)

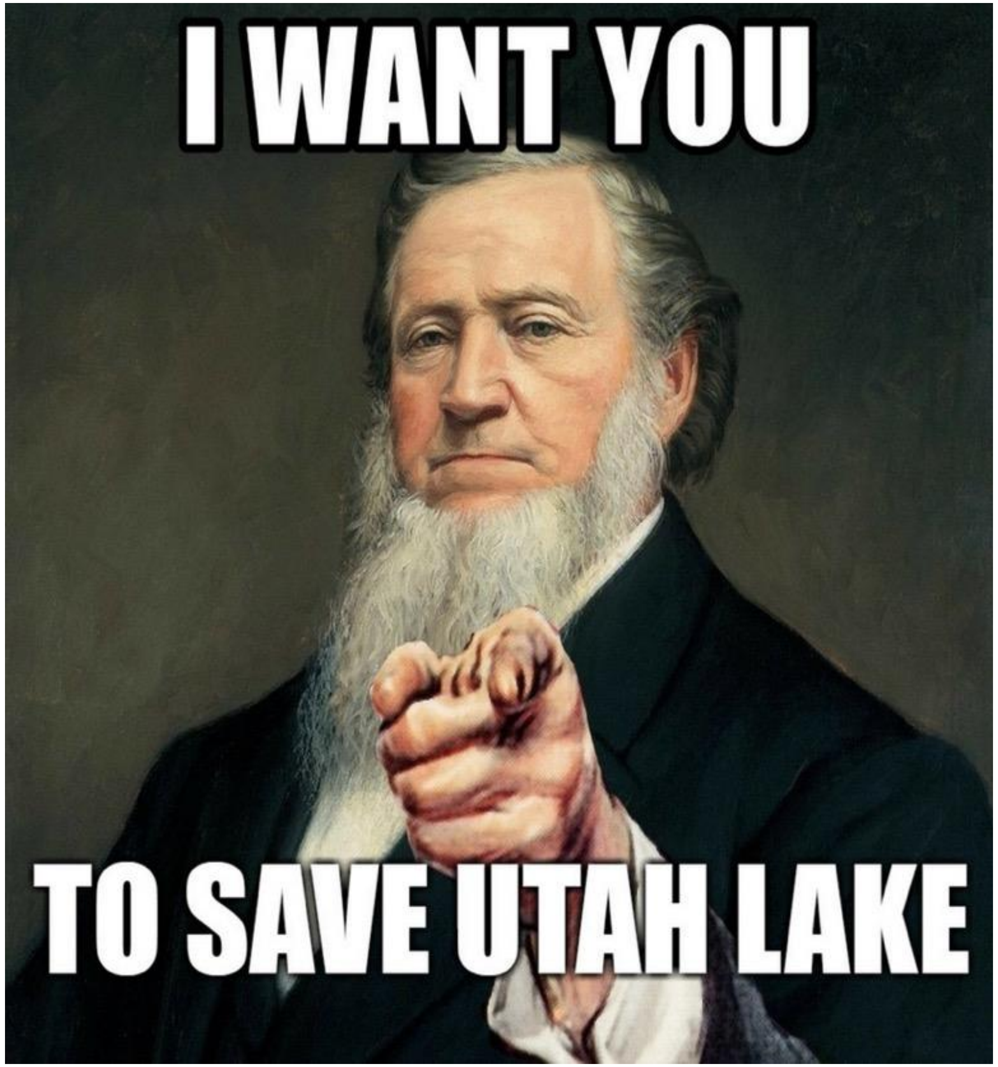
Diplostraca
(Cladocera)



Cycolopoida (Cyclopoids)

Monogononta (Rotifers)

Ploimida (Rotifers)



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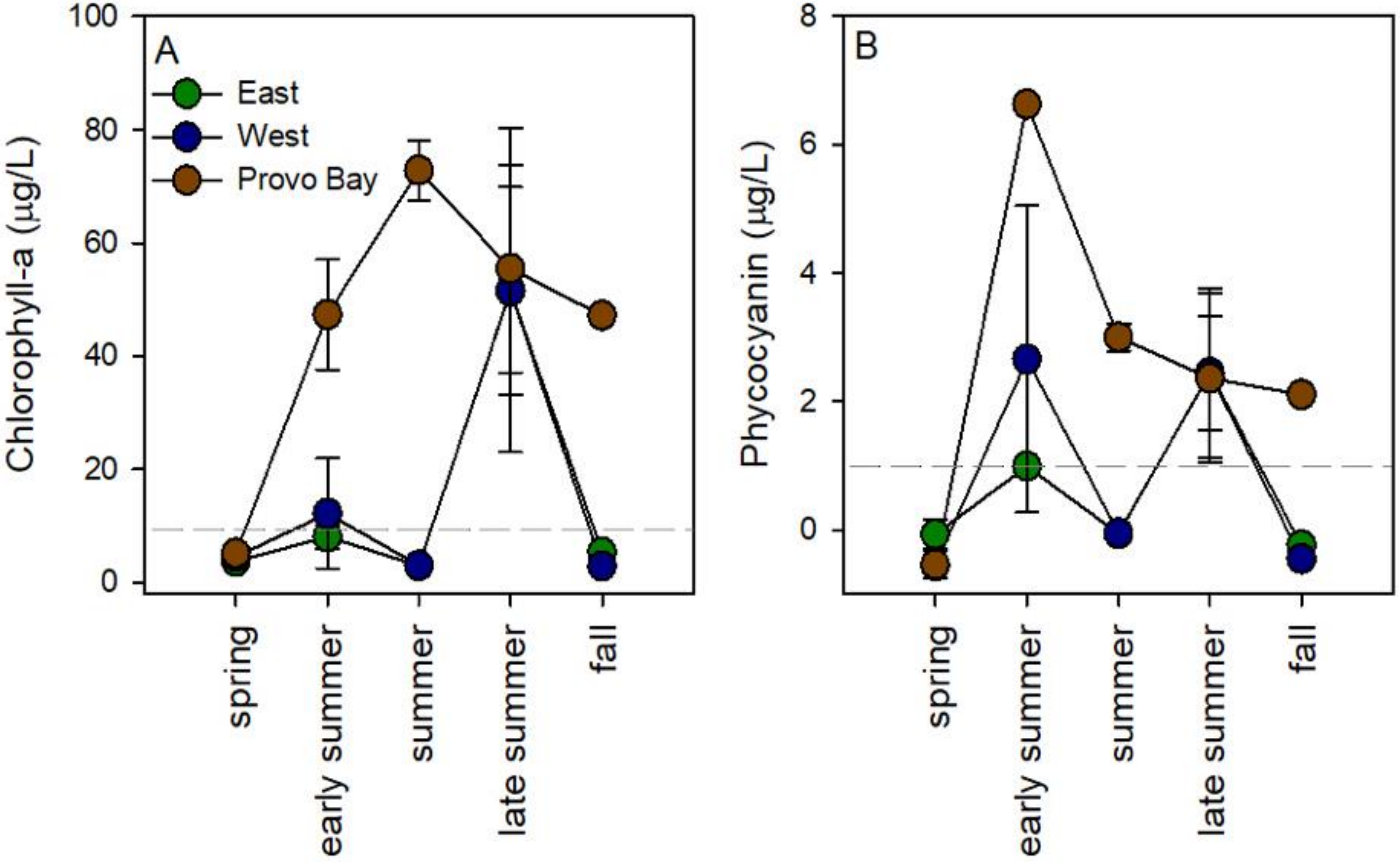
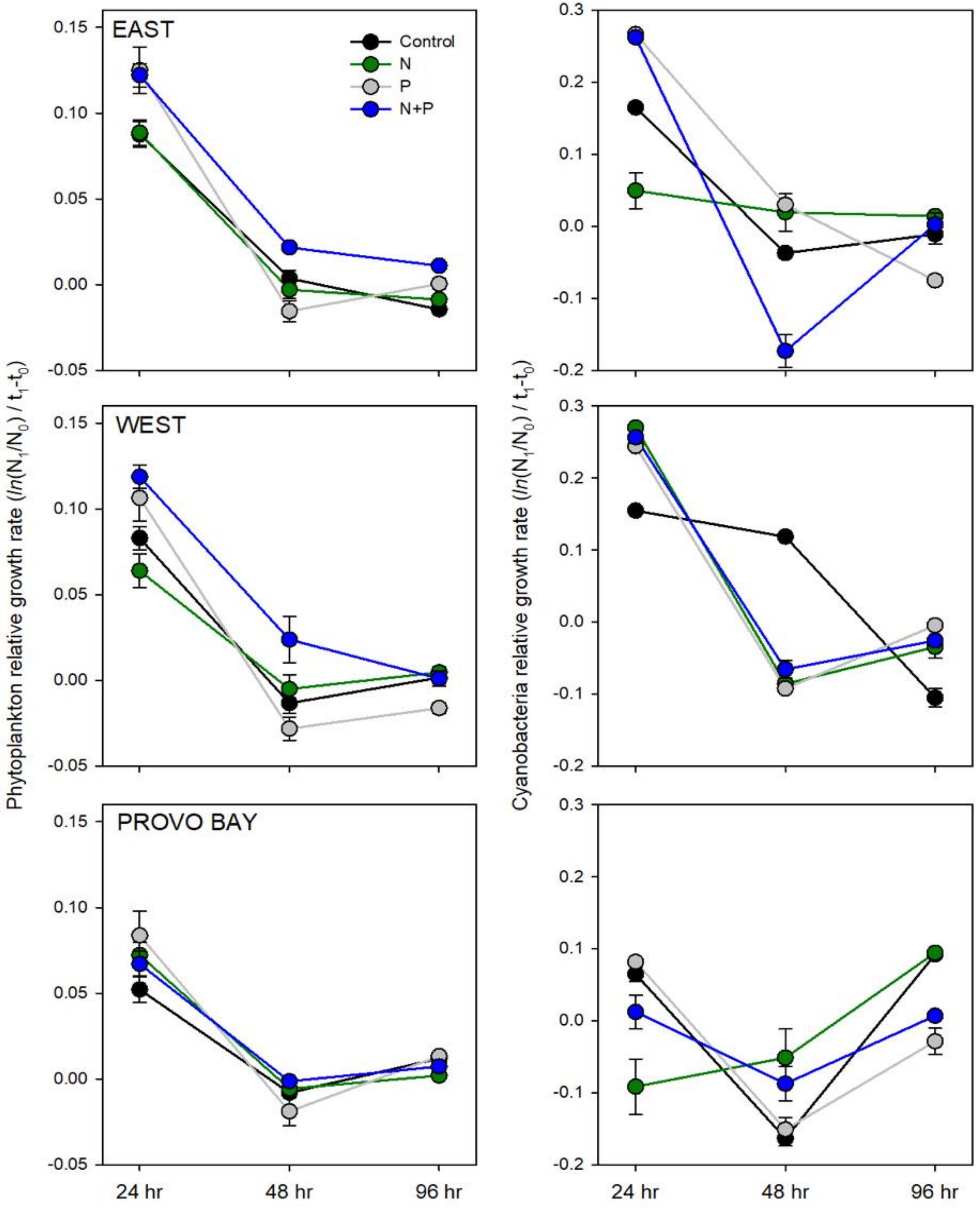
Utah Lake
Research
Collaborative

- SRP in the dilutions was bioavailable with all treatments exhibiting a decline in SRP levels, regardless of receiving various levels of SRP. A decrease in DIN only occurred in treatments that did not receive an N addition. Taken together, SRP, instead of DIN, exerts more control over phytoplankton and cyanobacteria.

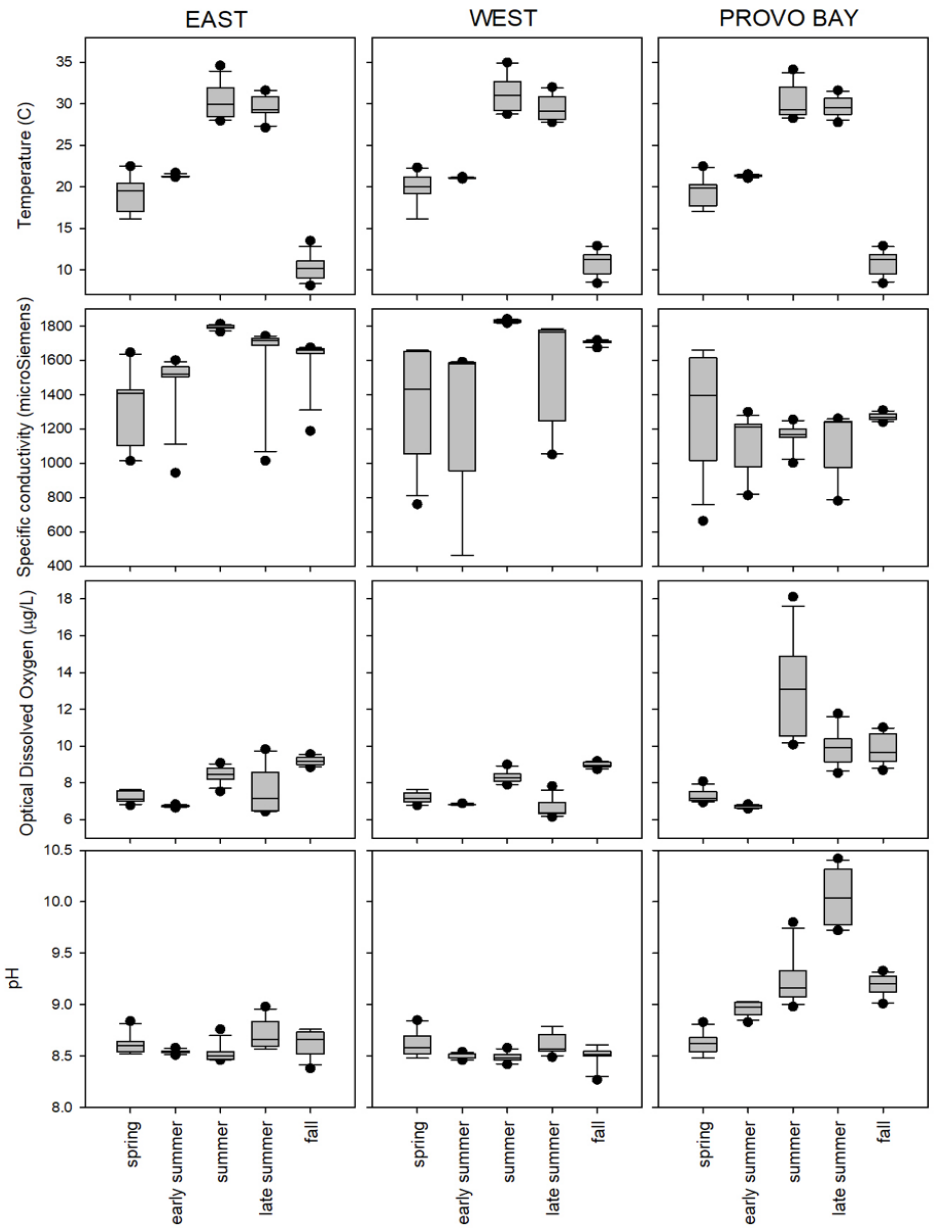
- Mycrocystin was detected after 120 hours and N+P additions supported the highest concentrations. Cylindrospermopsin was most abundant in the first 48 hours of the dilution; dilutions that received relatively high nutrient inputs of N and/or P supported the highest cylindrospermopsin concentrations. Anatoxin-a was consistently high through time and was often the most abundant of the three toxins evaluated.



A
East
West
Provo Bay
Chlorophyll-a (µg/L)
0
20
40
60
80
100
spring
early summer
summer
late summer
fall
B
Phycocyanin (µg/L)
0
2
4
6
8
spring
early summer
summer
late summer
fall



EAST
WEST
PROVO BAY
Control
N
P
N+P
Phytoplankton relative growth rate (ln(N1/N0) / t1-t0)
Cyanobacteria relative growth rate (ln(N1/N0) / t1-t0)
0.15
0.10
0.05
0.00
-0.05
0.3
0.2
0.1
0.0
-0.1
-0.2
24 hr
48 hr
96 hr


EAST
WEST
PROVO BAY
Temperature (C)
Specific conductivity (microSiemens)
Optical Dissolved Oxygen (µg/L)
pH
spring
early summer
summer
late summer
fall

Chemical form	Final concentration of the major ion solution used to dilute the assays (mg/L or element)
Si^{4+} as Na2 SiO3 9H2O	0.037
Ca^{2+} as CaCl2 2H2O	44.0
Mg^{2+} as MgSO4 7H2O	77.0
Na^{+} as Na2SO4	50.0
K^{+} as K2 SO4	10.6
SO42- as MgSO4 7H2O	304
Cl^{-} as CaCl2 2H2O	165

Phosphorus binding

Outline

- Research team introductions
- Objectives
- Progress update

Research team

- Steve Nelson, geochemist
- Greg Carling, hydrologist
- Kevin Rey, geologist
- Undergraduate research assistants
- Masters' degree student
- Josh LeMonte

Overarching study objective

This research will help inform charge question 2.3.5: What is the role of calcite "scavenging" [i.e., binding] in the phosphorus cycle?

Study objectives

1. Create a reaction network of processes involving the chemical species of P in Utah Lake.
2. Characterize the chemical speciation of P in the water column and sediment, including free forms, soluble complexes, precipitates, and sorbed species under a series of specified water quality conditions representing existing and potential future conditions in Utah Lake.
3. Characterize P scavenging and release from the water column and sediments under a series of specified conditions (e.g., pH, redox, etc.) in order to identify contributing mechanisms such as precipitation and sorption and estimate of the expected fractional distribution of P in each form.
4. Evaluate the kinetics of P sorption and desorption of P onto sorbing surfaces (e.g., calcite, Fe, Mn, organics) and evaluate desorption hysteresis (e.g., speed or irreversibility of desorption and under what conditions) for a series of relevant conditions for Utah Lake.
5. Evaluate predictive relationships to characterize binding of P onto sorbing surfaces in the water column and sediments such as using sorption isotherms and/or partition coefficients over a range of specified conditions (e.g., pH, redox, etc.).

Objective 1: Create a reaction network of processes involving the chemical species of P in Utah Lake.

Reaction network will be created using PHREEQC or GeoChemists’ Workbench

Preliminary reaction network will be delivered in draft form by 22 March, 2021

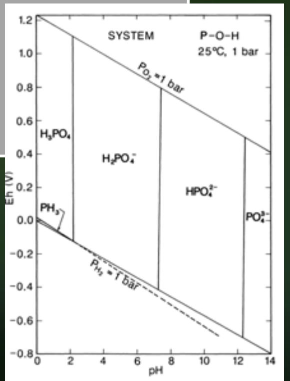


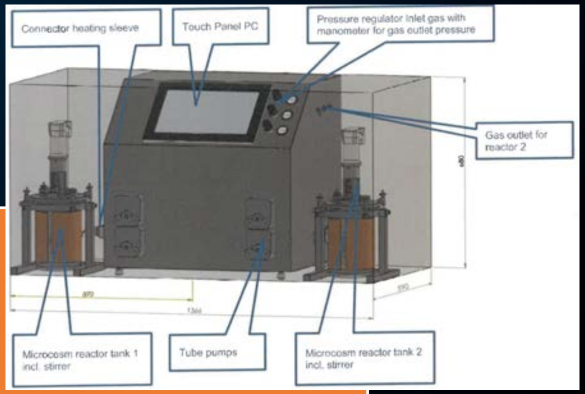
Fig. 8. Eh-pH diagram for part of the system P-O-H. The assumed activity of dissolved $P = 10^{-6}$. See text for discussion

Objective 2: Characterize the chemical speciation of P in the water column and sediment, including free forms, soluble complexes, precipitates, and sorbed species under a series of specified water quality conditions representing existing and potential future conditions in Utah Lake.

Field observations

Utilize methods of published works

Objective 3: Characterize P scavenging and release from the water column and sediments under a series of specified conditions (e.g., pH, redox, etc.) in order to identify contributing mechanisms such as precipitation and sorption and estimate of the expected fractional distribution of P in each form.



Systematic controlled laboratory experiments

Advanced automated biogeochemical microcosm reactors (microcosms), like biogas reactors

Objective 4: Evaluate the kinetics of P sorption and desorption of P onto sorbing surfaces (e.g., calcite, Fe, Mn, organics) and evaluate desorption hysteresis (e.g., speed or irreversibility of desorption and under what conditions) for a series of relevant conditions for Utah Lake.

Systematic controlled laboratory experiments

Batch sorption ($Q_{eq} = \frac{S_{max} K_L C_{eq}}{K_L + C_{eq}}$)

Stirred-flow (K_d)

$$R\frac{\partial C}{\partial t} = \frac{q}{V_T}(C_{in} - C_{out})$$

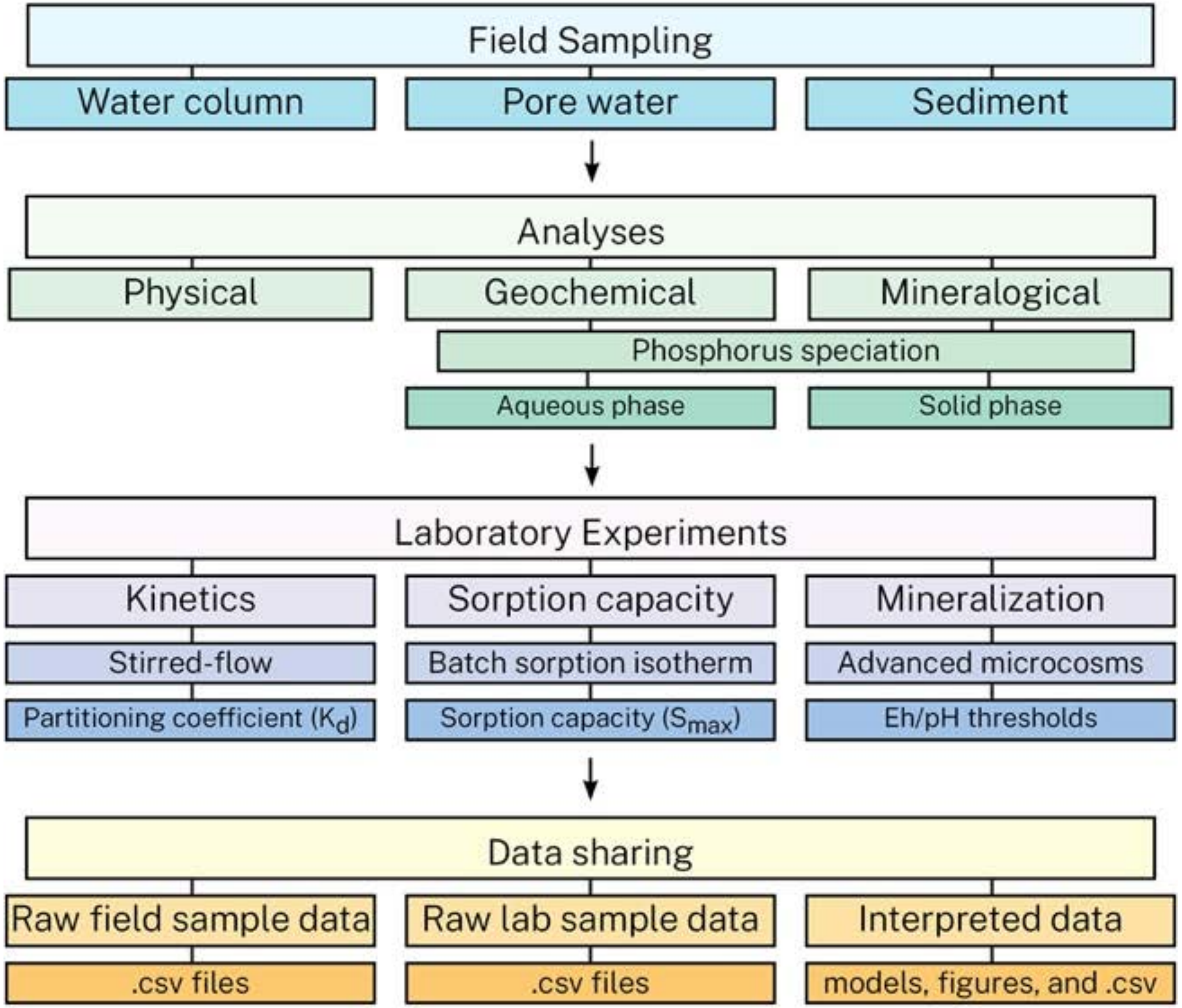
Here the retardation factor R is expressed as

$$R = 1 + K_d\frac{\rho}{\theta}$$

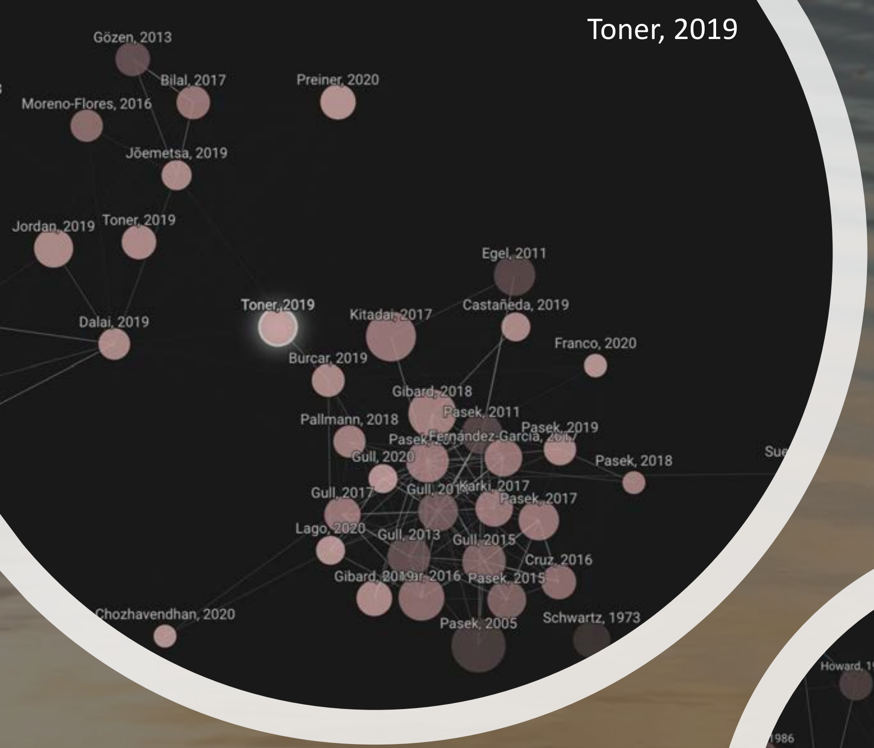
Objective 5: Evaluate predictive relationships to characterize binding of P onto sorbing surfaces in the water column and sediments such as using sorption isotherms and/or partition coefficients over a range of specified conditions (e.g., pH, redox, etc.).

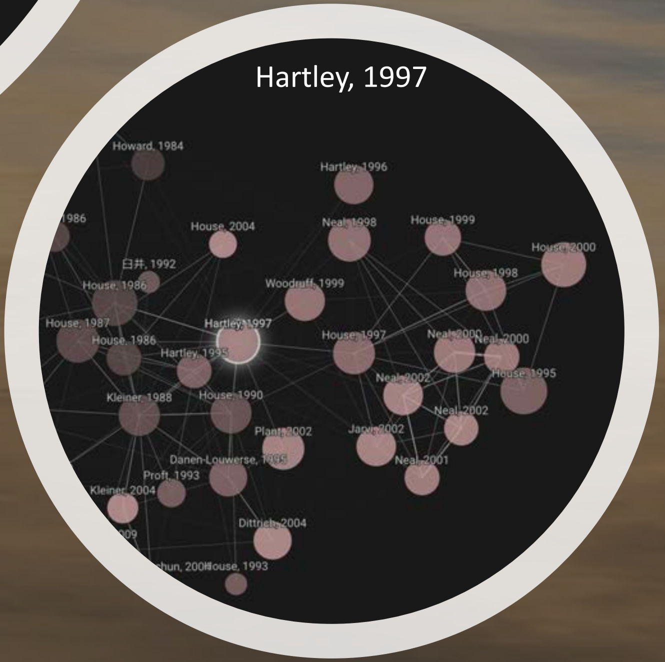
Use experimentally-derived sorption and kinetic data

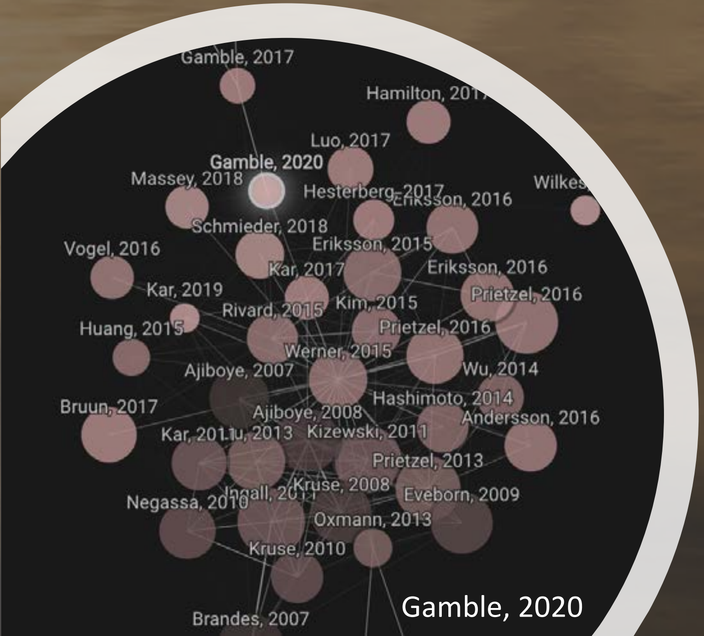
create simple models and parameters that can be used in the Utah Lake Water Quality Model (EFDC-WASP)



Field Sampling
Water column
Pore water
Sediment
Analyses
Physical
Geochemical
Mineralogical
Phosphorus speciation
Aqueous phase
Solid phase
Laboratory Experiments
Kinetics
Sorption capacity
Mineralization
Stirred-flow
Batch sorption isotherm
Advanced microcosms
Partitioning coefficient (K_d)
Sorption capacity (S_{max})
Eh/pH thresholds
Data sharing
Raw field sample data
Raw lab sample data
Interpreted data
.csv files
.csv files
models, figures, and .csv







Literature Review

- Utilize list of supporting materials and existing literature reviews
- Comb through previously reviewed literature, paying special attention to any and all references pertinent to the scope of this study
- Created connected papers maps (figures on left) to visualize published works and attempt to not miss any important papers as well as discover the most important prior and derivative publications

Student Training

- 6 undergraduate research assistants hired
- 1 masters' student (2 applicants, both admitted)

Draft literature review & preliminary reaction network

Final technical lit review memo & references

21 Mar.

2 Apr.

9 Apr.

23 Apr.

Draft sampling and analysis plan (SAP)

Finalized SAP


Questions

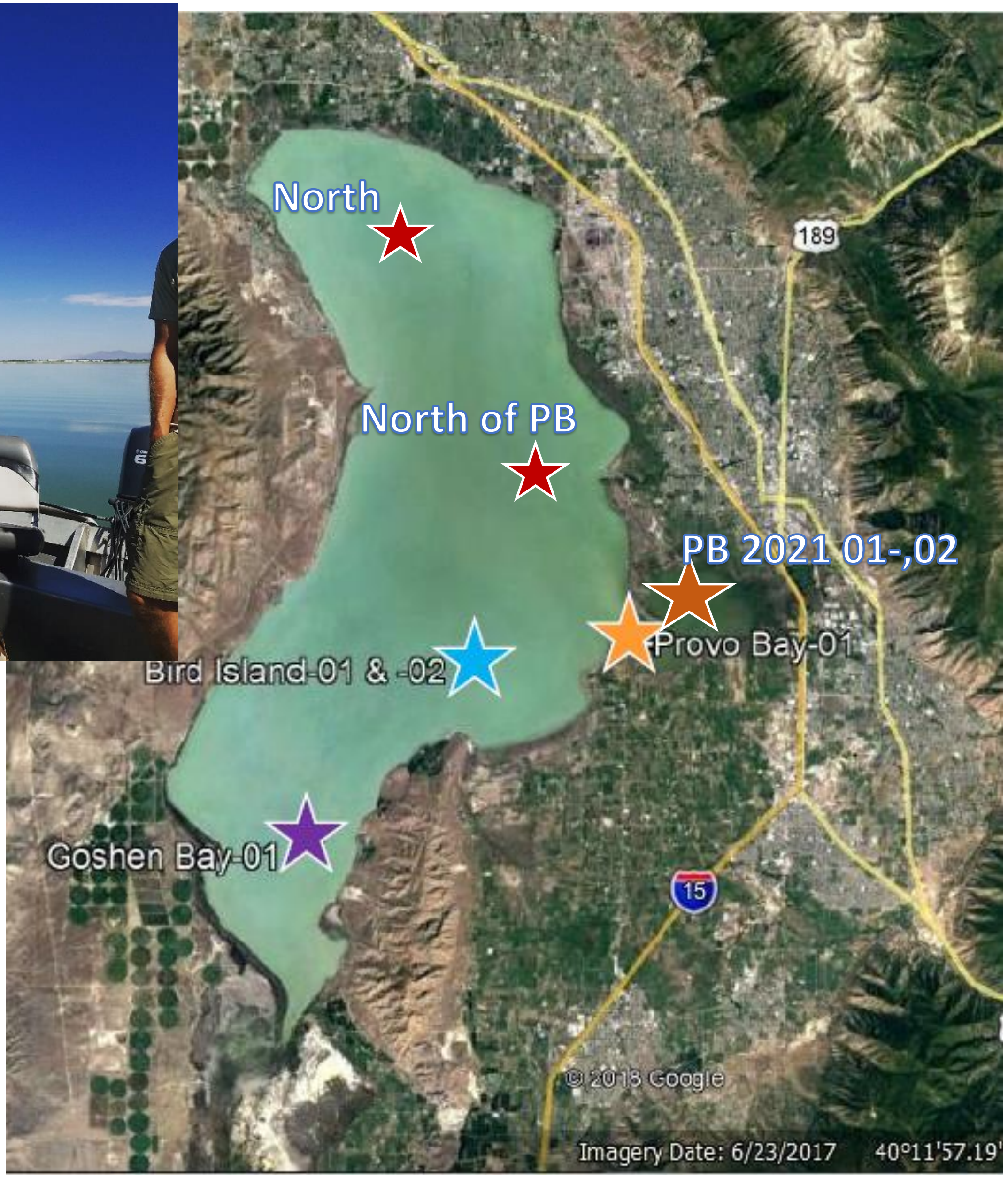
Utah Lake Paleolimnology: Update March, 2020

Brahney et. al.
MSc: Leighton King, Mark Devey
Ugrad: Audree Provard, Brynn Young, Ryan West.
Co-I's/Collaborators: Peter Leavitt, Mitch Power, Yarrow Axford, Steve Nelson, Soren Brothers

Task 1 : **Sampling and Analysis Plan – Completed**
Task 2a: **Collect Cores – Completed**
: **Initial Cores Description - Completed**
Task 3 : Analyze Cores – Ongoing
- **Dating 1/3 Lab Closure (Leavitt)**
- **Diatoms - Completed**
- **Geochemistry – Lab Closure (UU,USU)**
- **Pigments 2/4 – Lab Closure (Leavitt)**
- Cladocera/Chironomid - Ongoing
- P fractionations – Ongoing
- Calcite P – Ongoing
- **Pollen/Charcoal – Lab Closure (Power)**
- **Oospores/Benthic Modeling - Completed**

Utah Lake Paleolimnology: Update

Brahney et. al.



<u>2018 Cores</u>
- Bird Island (A, B) ✓
- Goshen Bay ✓
- Provo Bay X

<u>2019 Cores</u>
- North ✓
- North of Provo Bay Mitch ✓

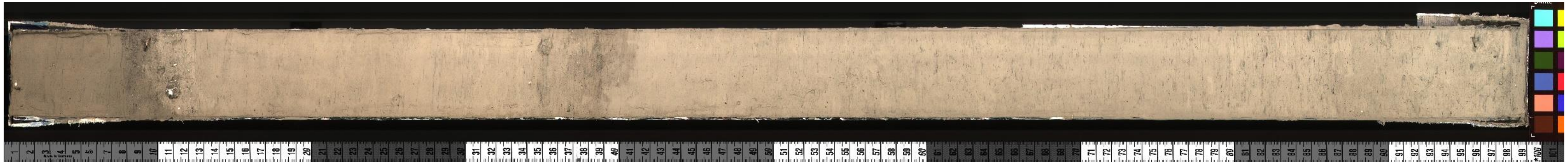
<u>2020</u>
- Provo Bay ✓

Utah Lake Paleolimnology: Update December, 2019

Brahney et. al.

Initial Cores Description

Bird Island



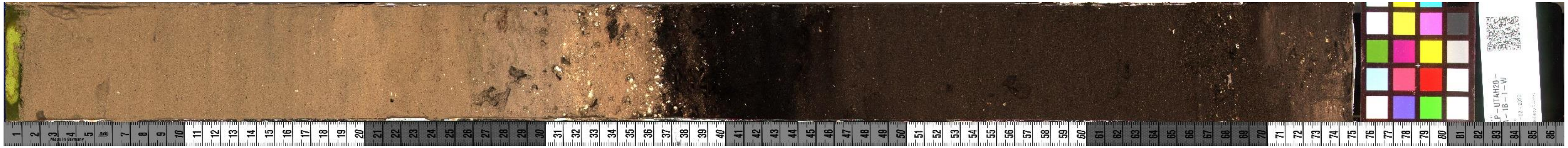
Goshen Bay

*Goshen was sectioned for eDNA

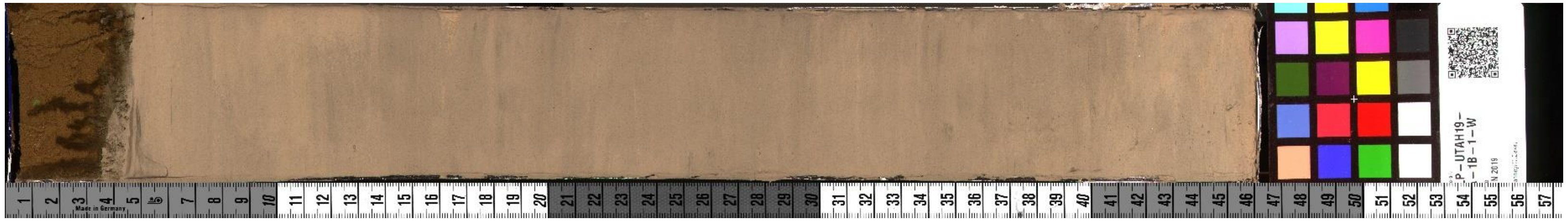
Lighter

Darker

Provo Bay 2

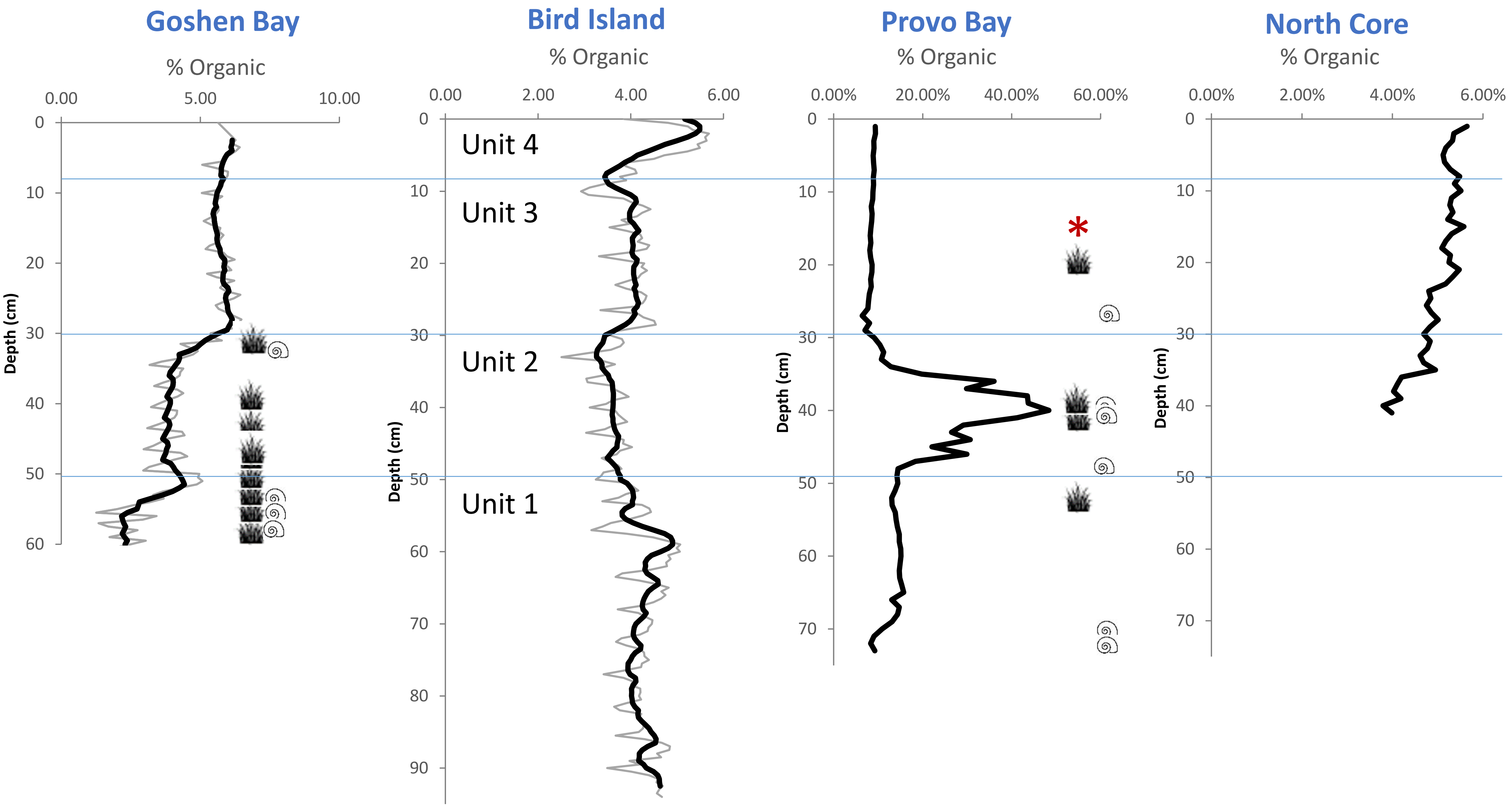


North Core



Utah Lake Paleolimnology: Update

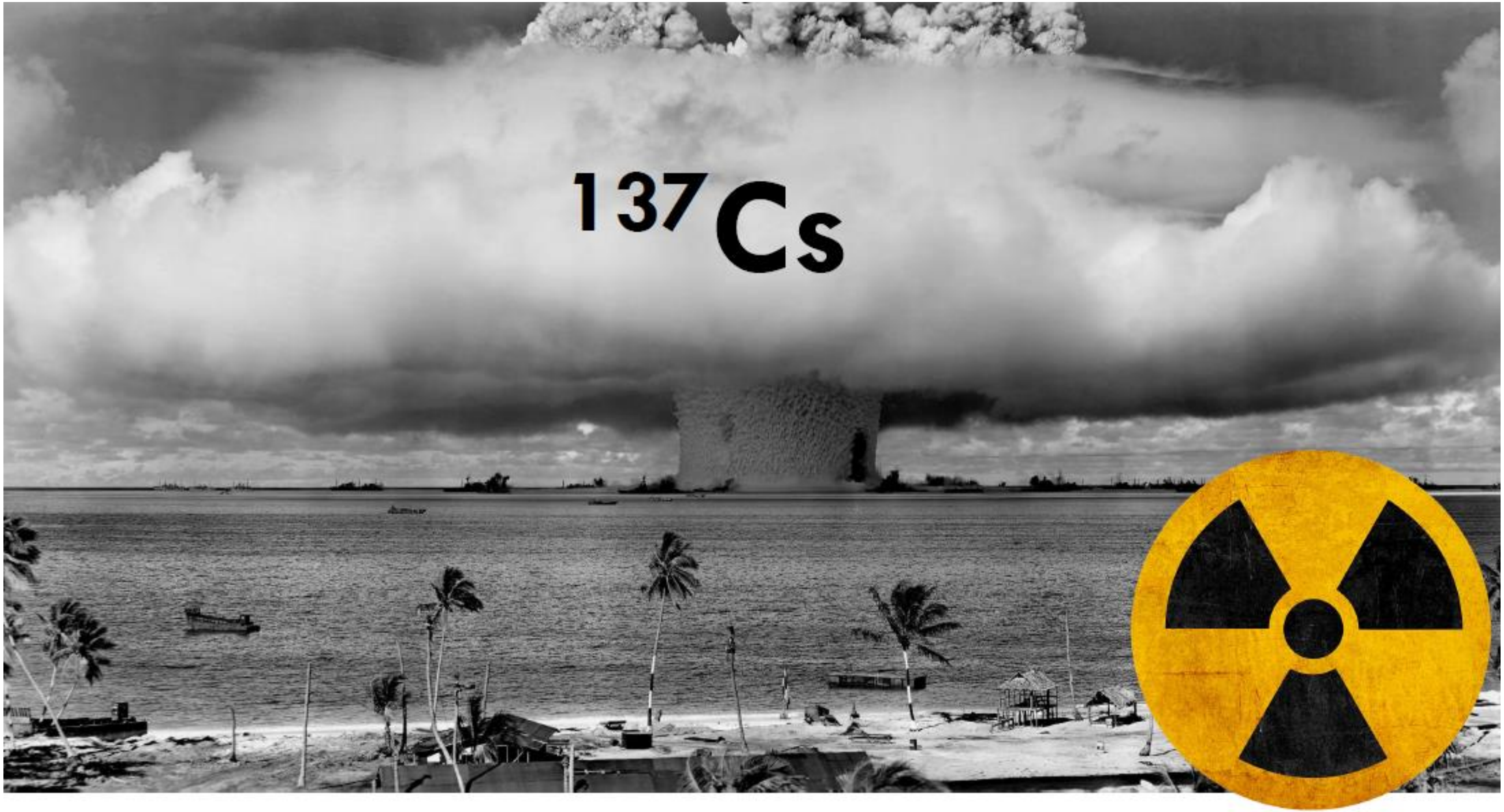
Brahney et. al. **Initial Cores Description**



Utah Lake Paleolimnology: Update December, 2019

Brahney et. al.

Dating



Utah Lake Paleolimnology: Update December, 2019

Brahney et. al.

Dating

Goshen Bay - complete

- ^{210}Pb not usable (Low production in desert environments)
- ^{137}Cs - clean record
- ^{14}C for older sediments

Submitted

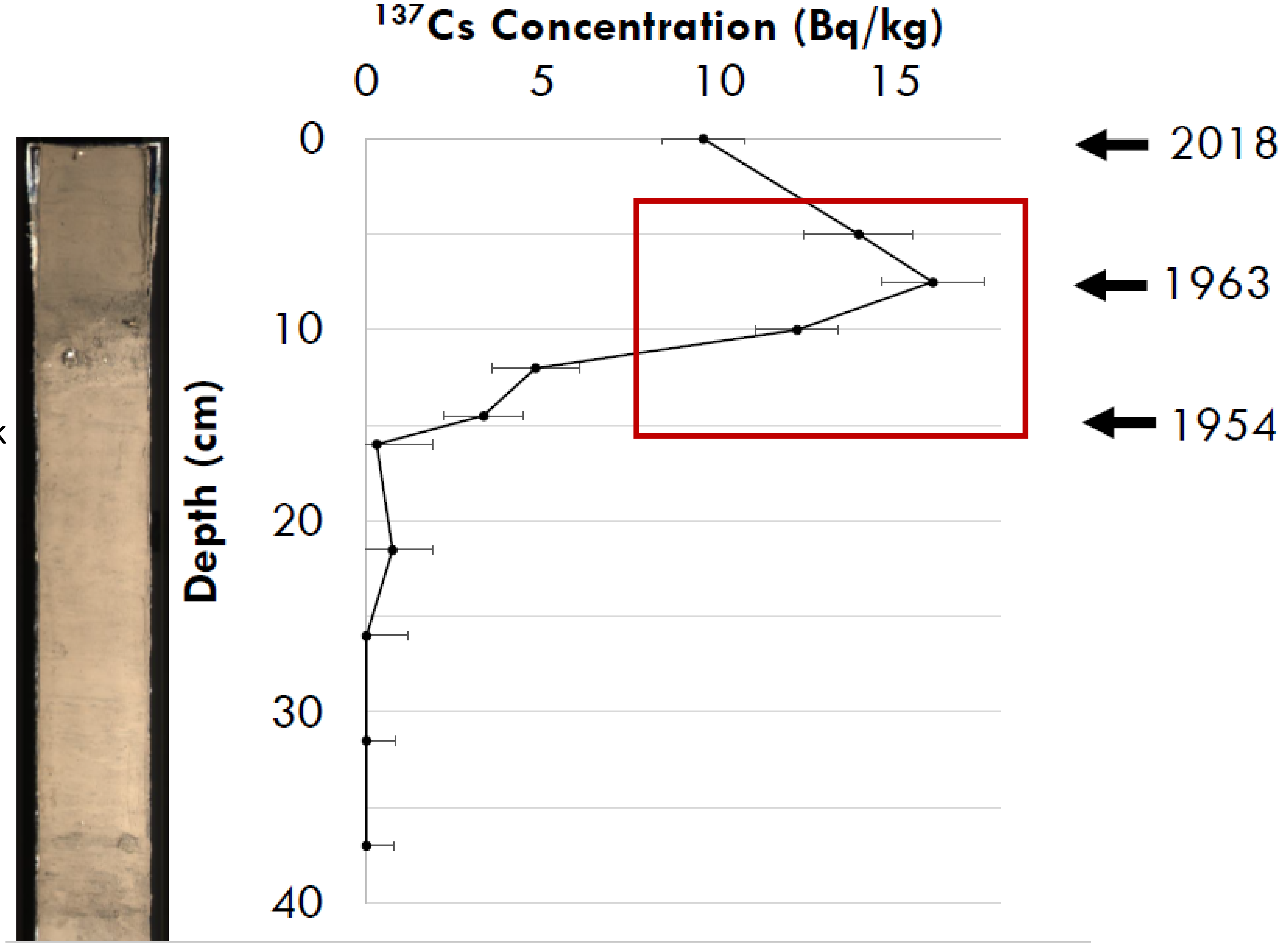
- ^{137}Cs for BI and PB
- Sample at higher density around peak

To be Submitted

- ^{137}Cs for PB (2nd), NC
- Sample at higher density around peak

To be Submitted

- ^{14}C for PB (2nd)



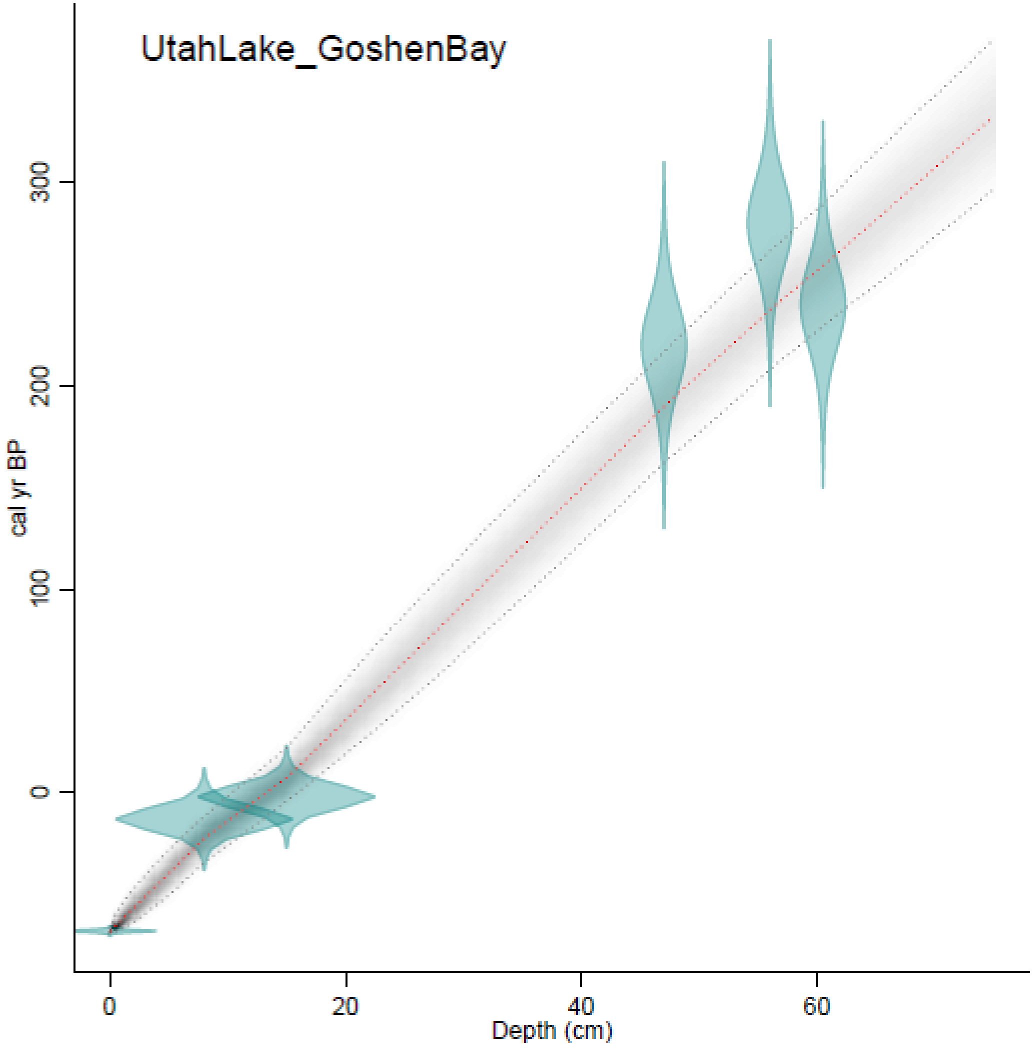
Utah Lake Paleolimnology: Update December, 2019

Brahney et. al.

Dating

Bayesian Age-Depth Modeling

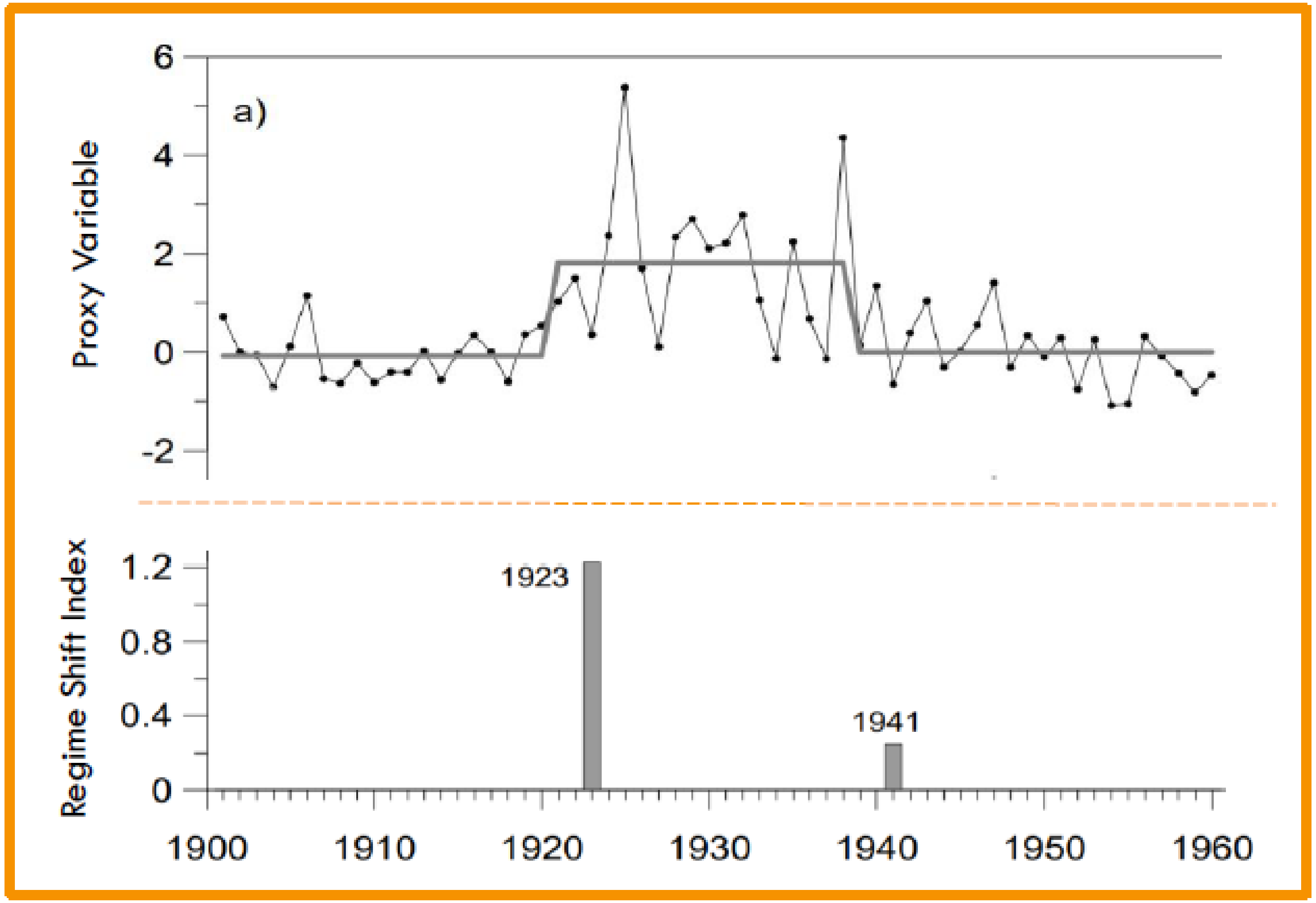
- Prediction intervals
- Intensity of shading reflects certainty



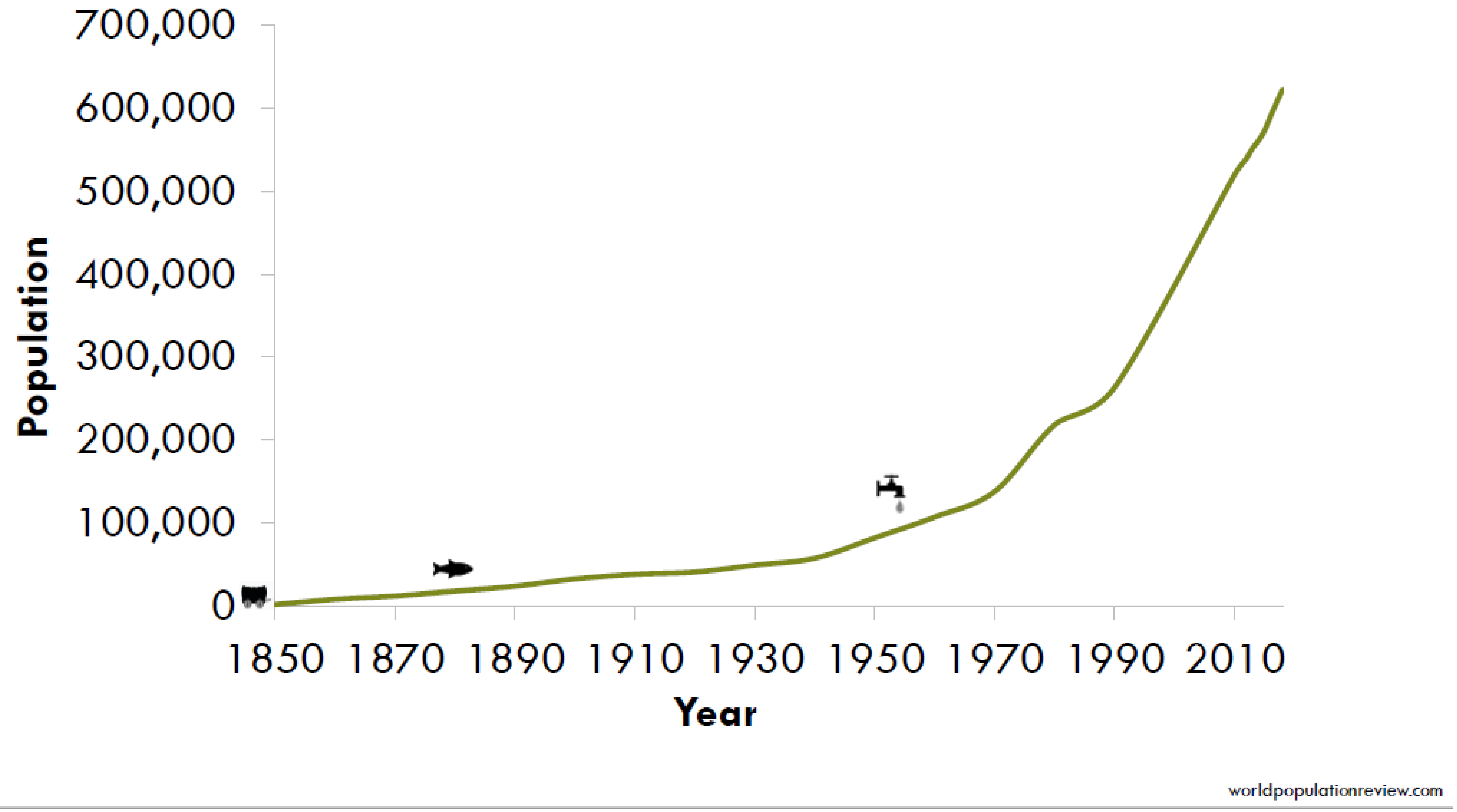
SEQUENTIAL REGIME SHIFT DETECTION

Sequential t-test analysis

(Rodionov, 2004)

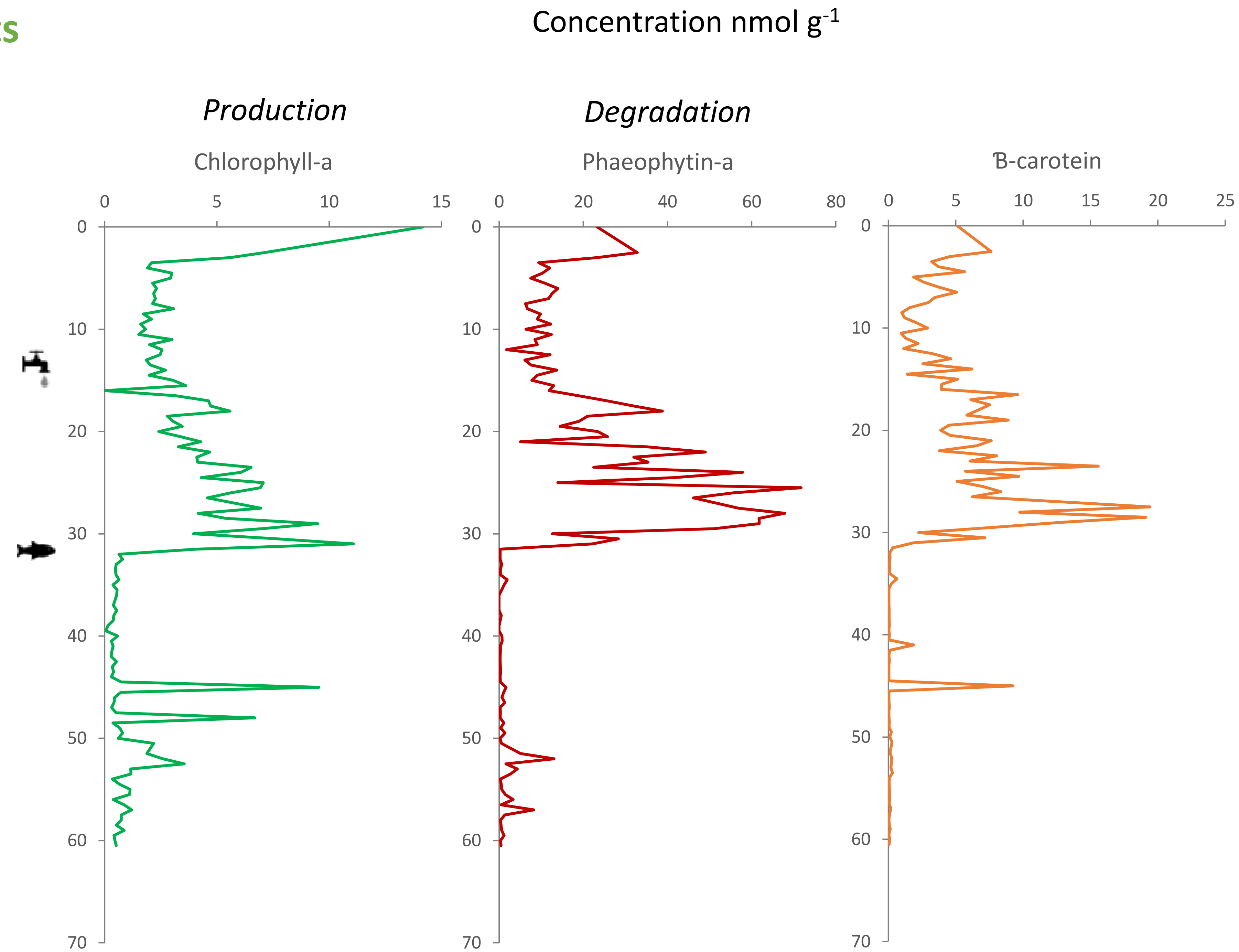


Adapted from (Rodionov, 2005)

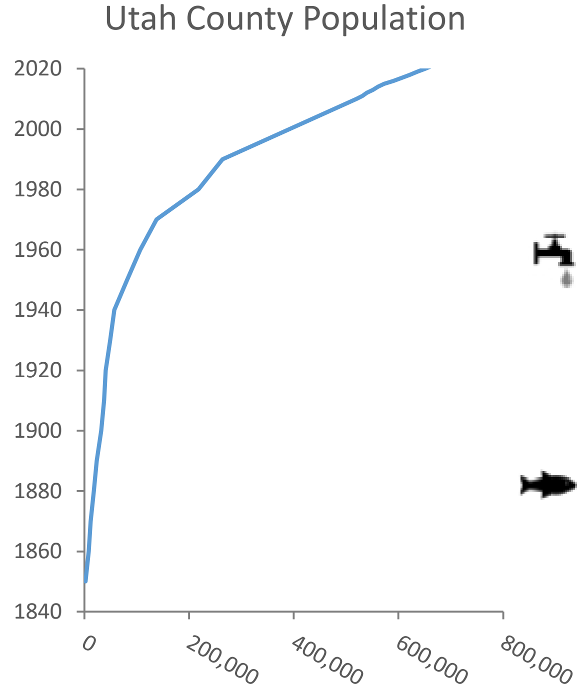


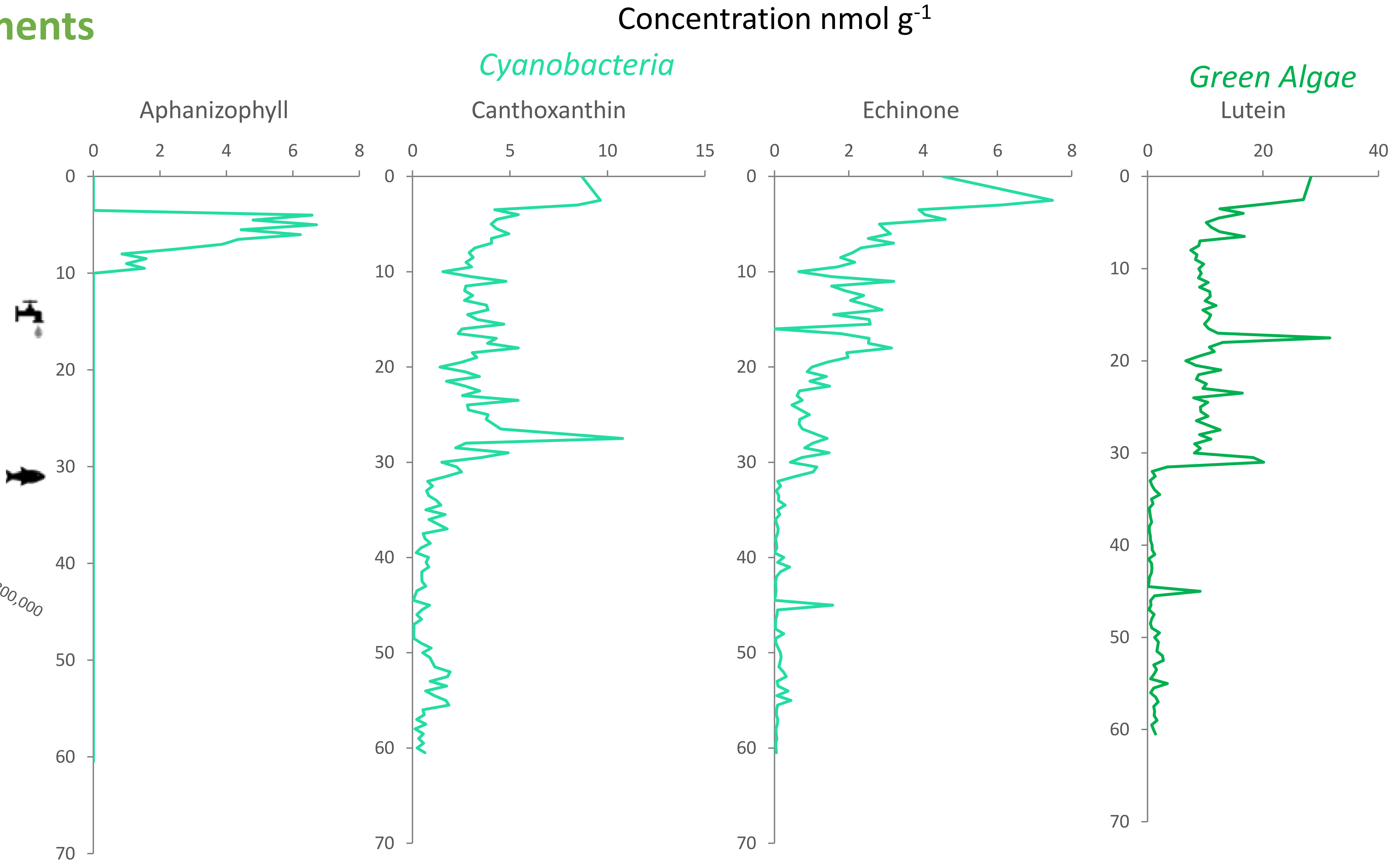
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Population
1850
1870
1890
1910
1930
1950
1970
1990
2010
Year
worldpopulationreview.com

Goshen Bay - Pigments

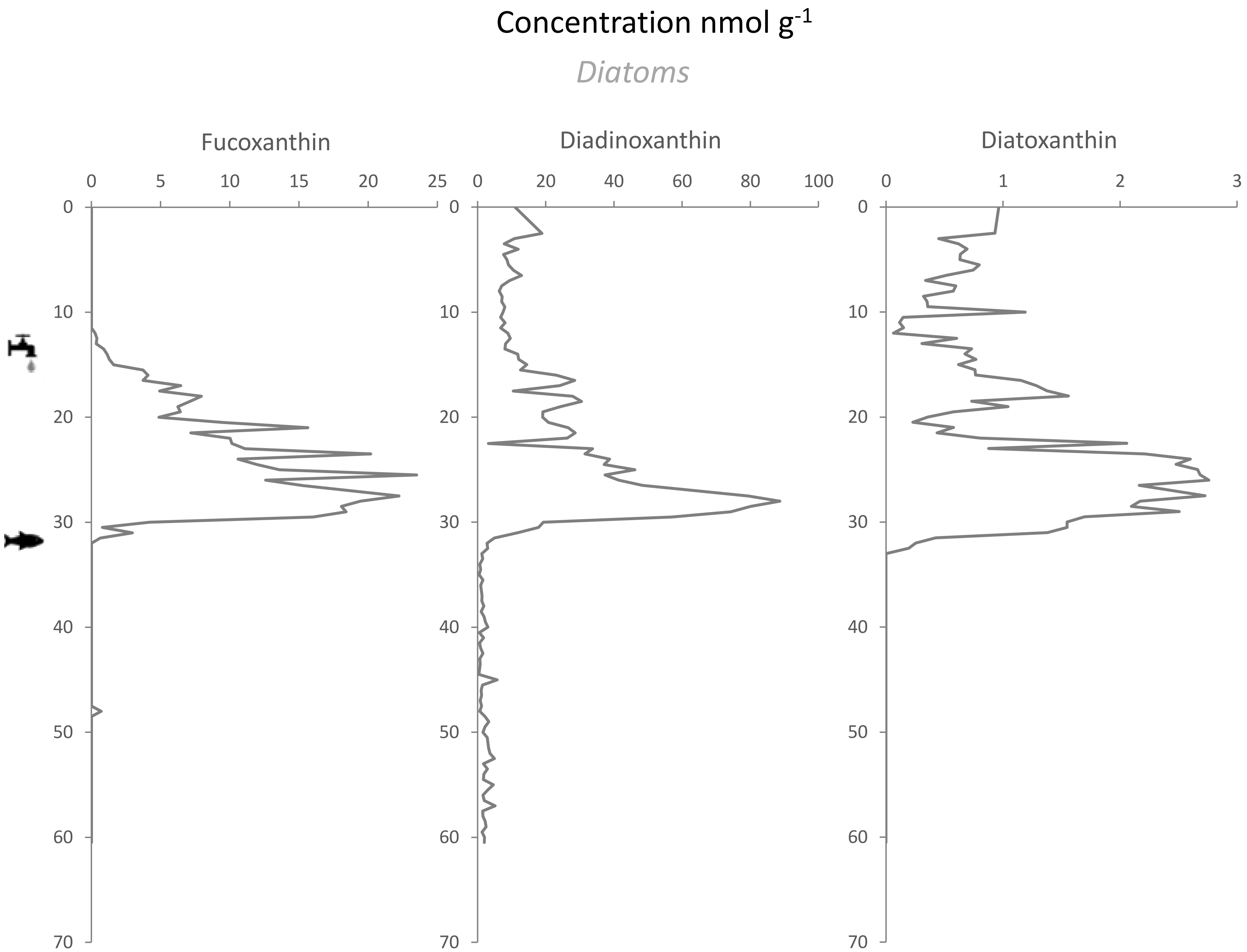


Goshen Bay - Pigments

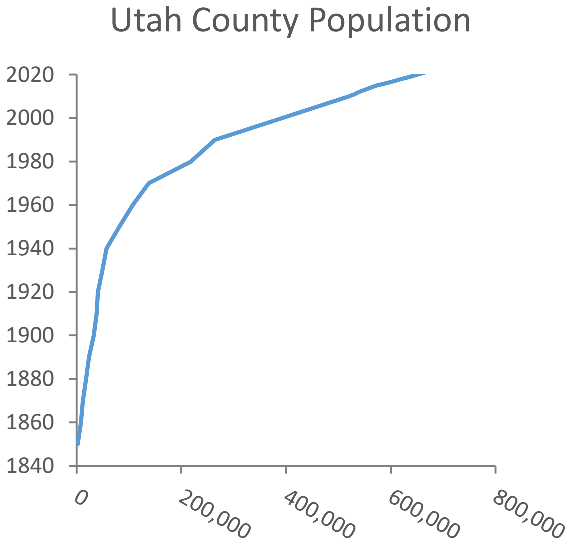




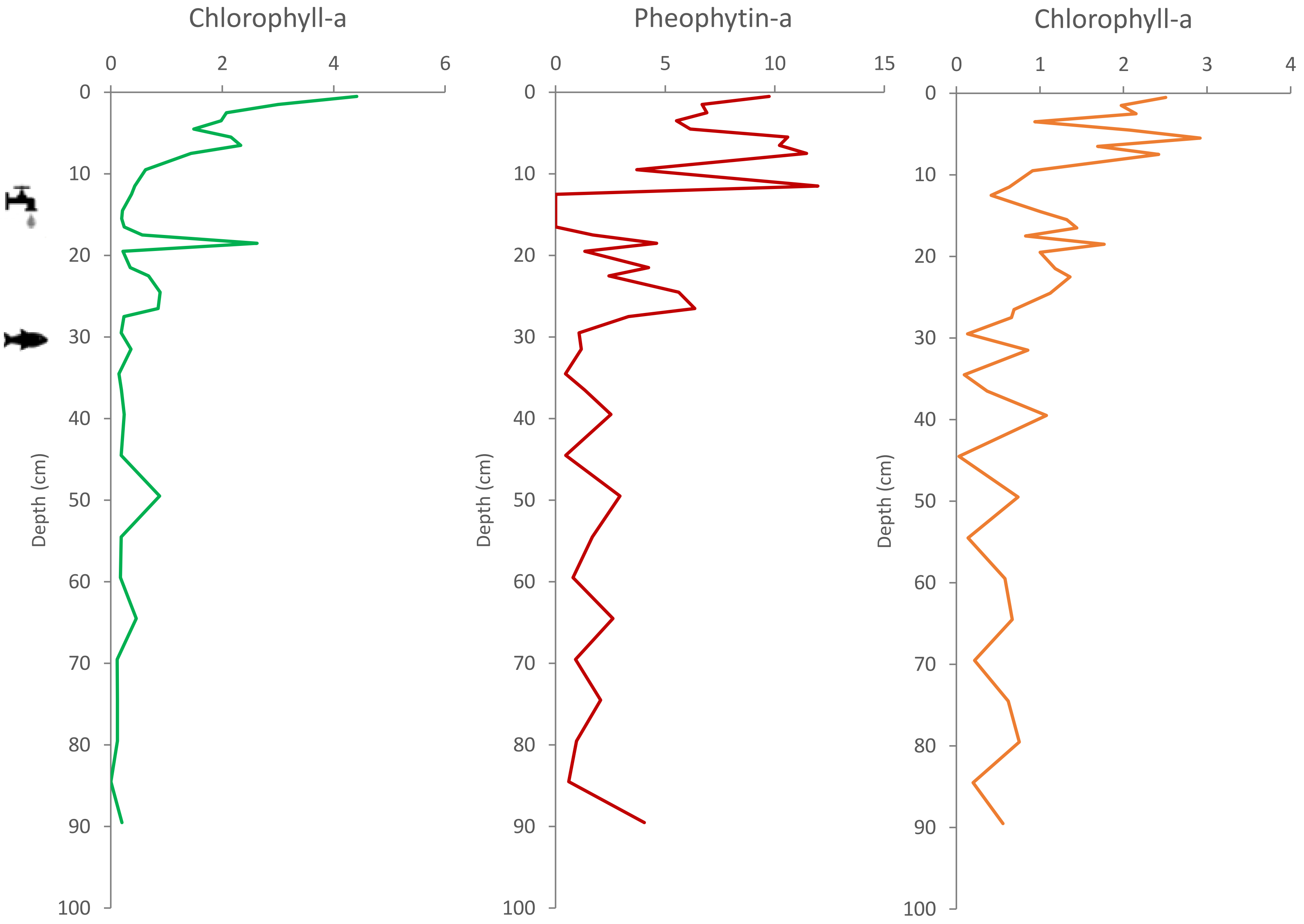
Goshen Bay - Pigments



Bird Island- Pigments



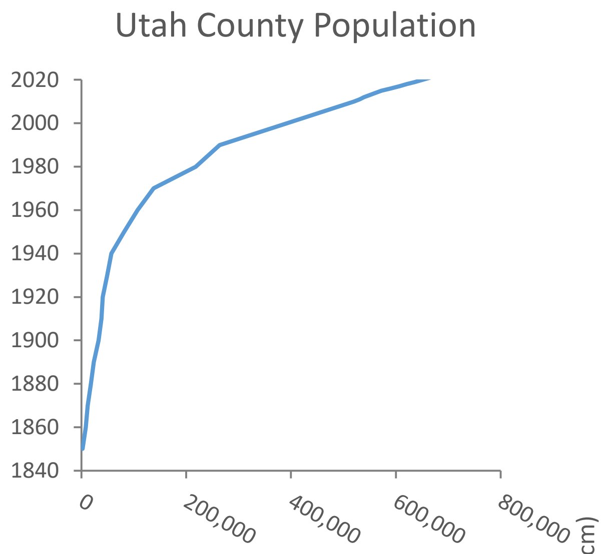
Concentration nmol g^{-1}

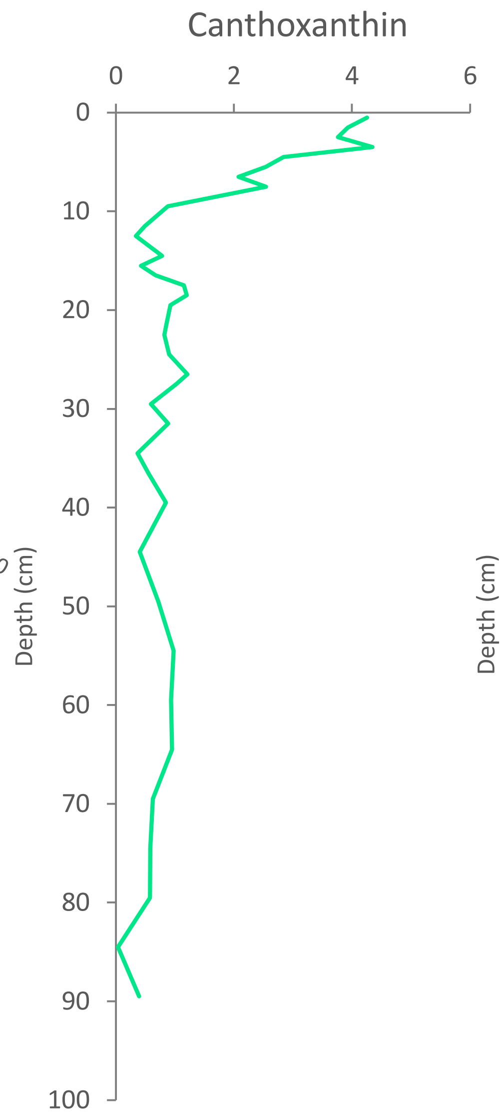


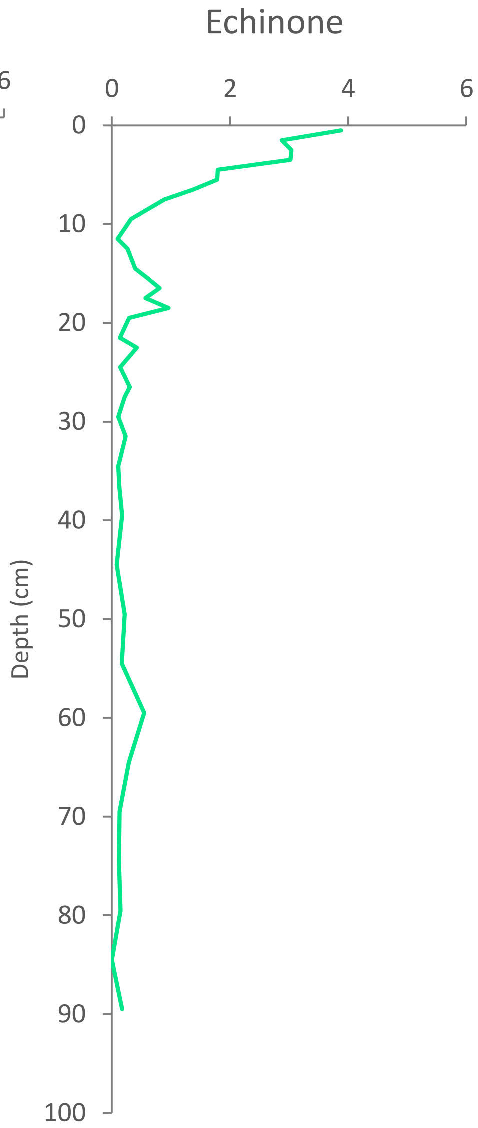
Bird Island- Pigments

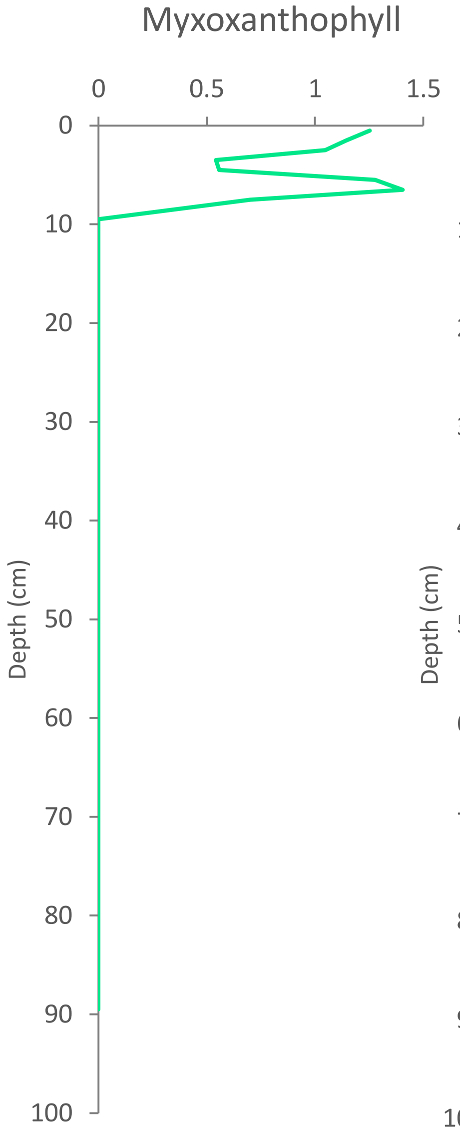
Concentration nmol g^{-1}

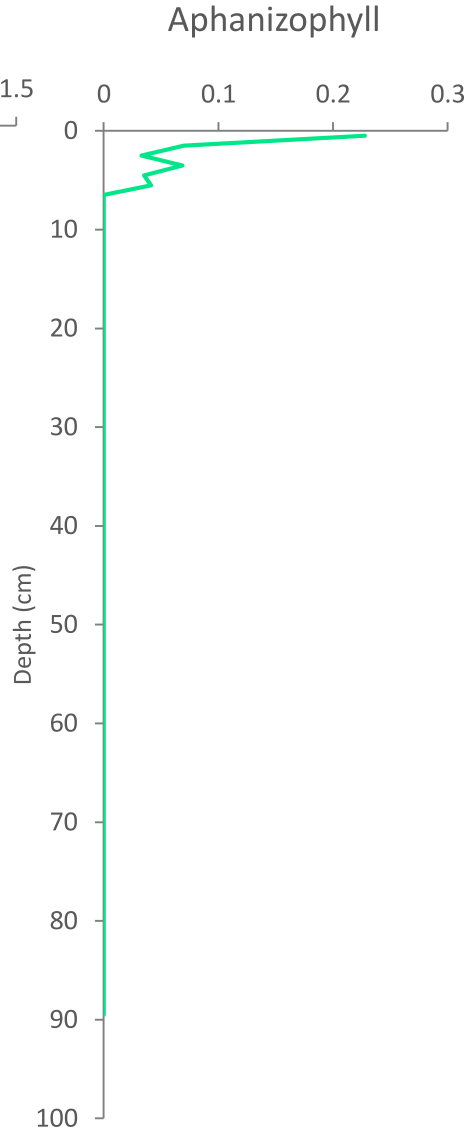
Cyanobacteria











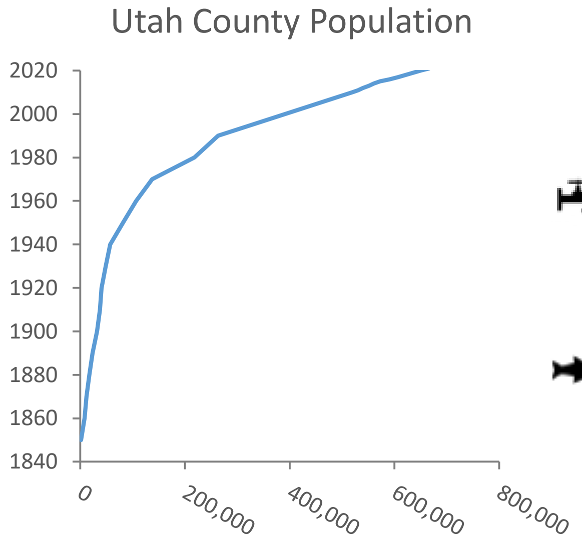
Bird Island- Pigments

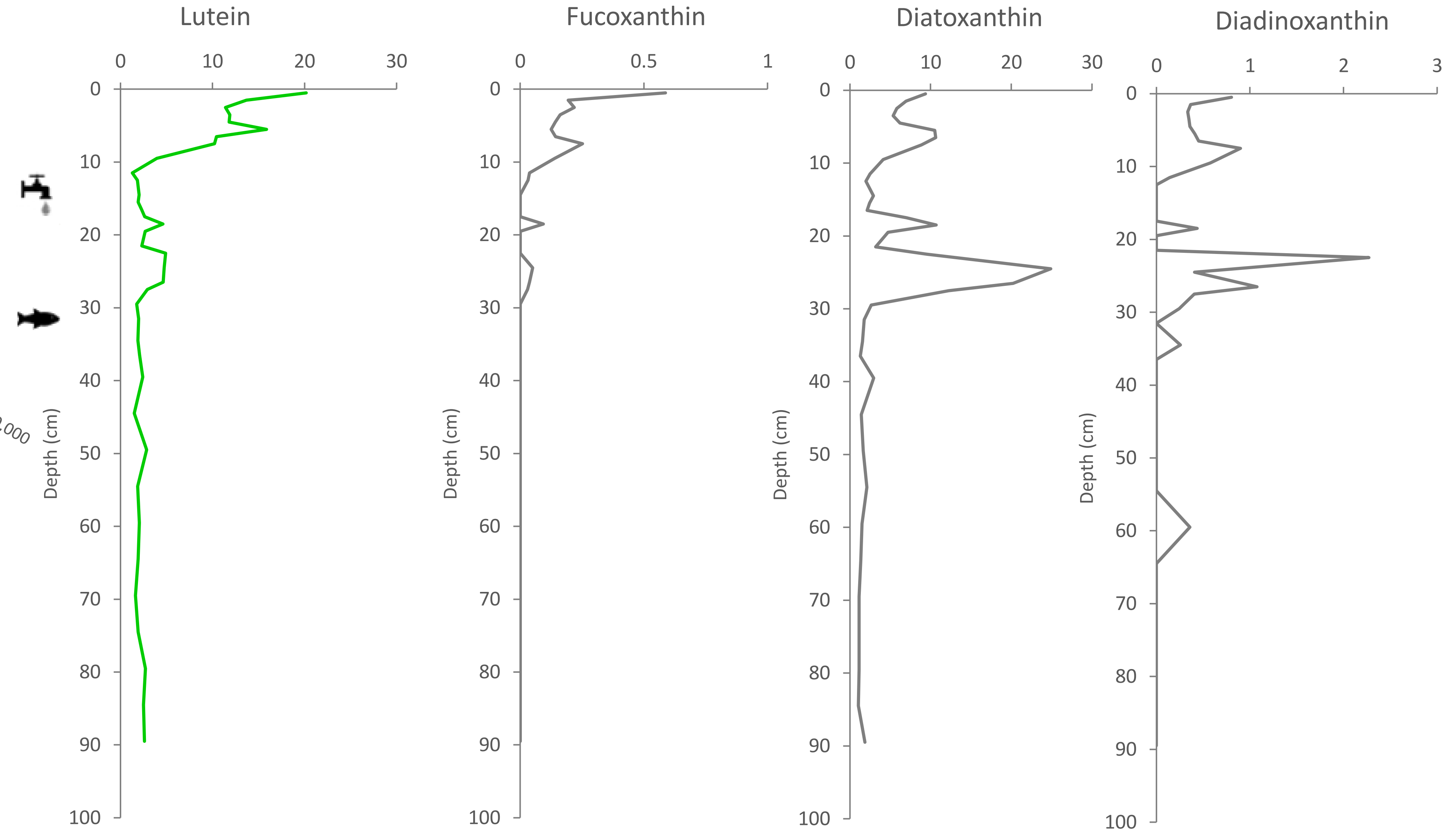
Concentration nmol g^{-1}

Cyanobacteria

Diatoms

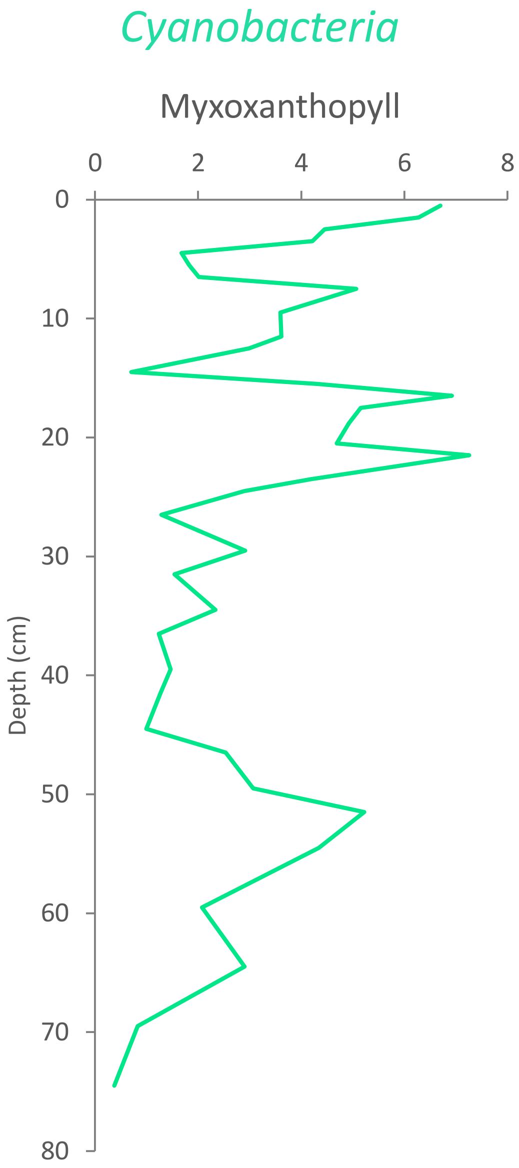
Green Algae

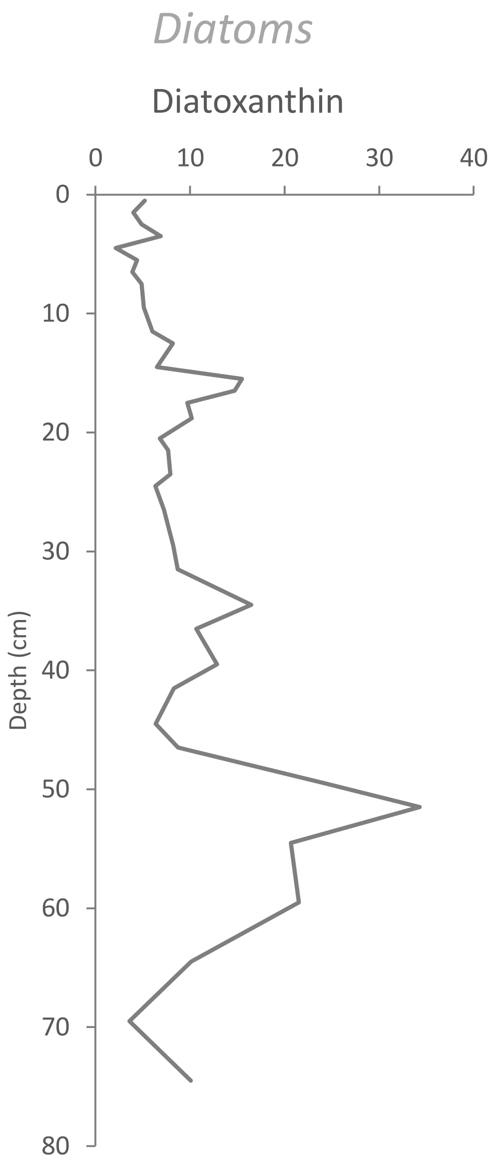




Provo Bay – FIRST CORE - Pigments

Concentration nmol g^{-1}

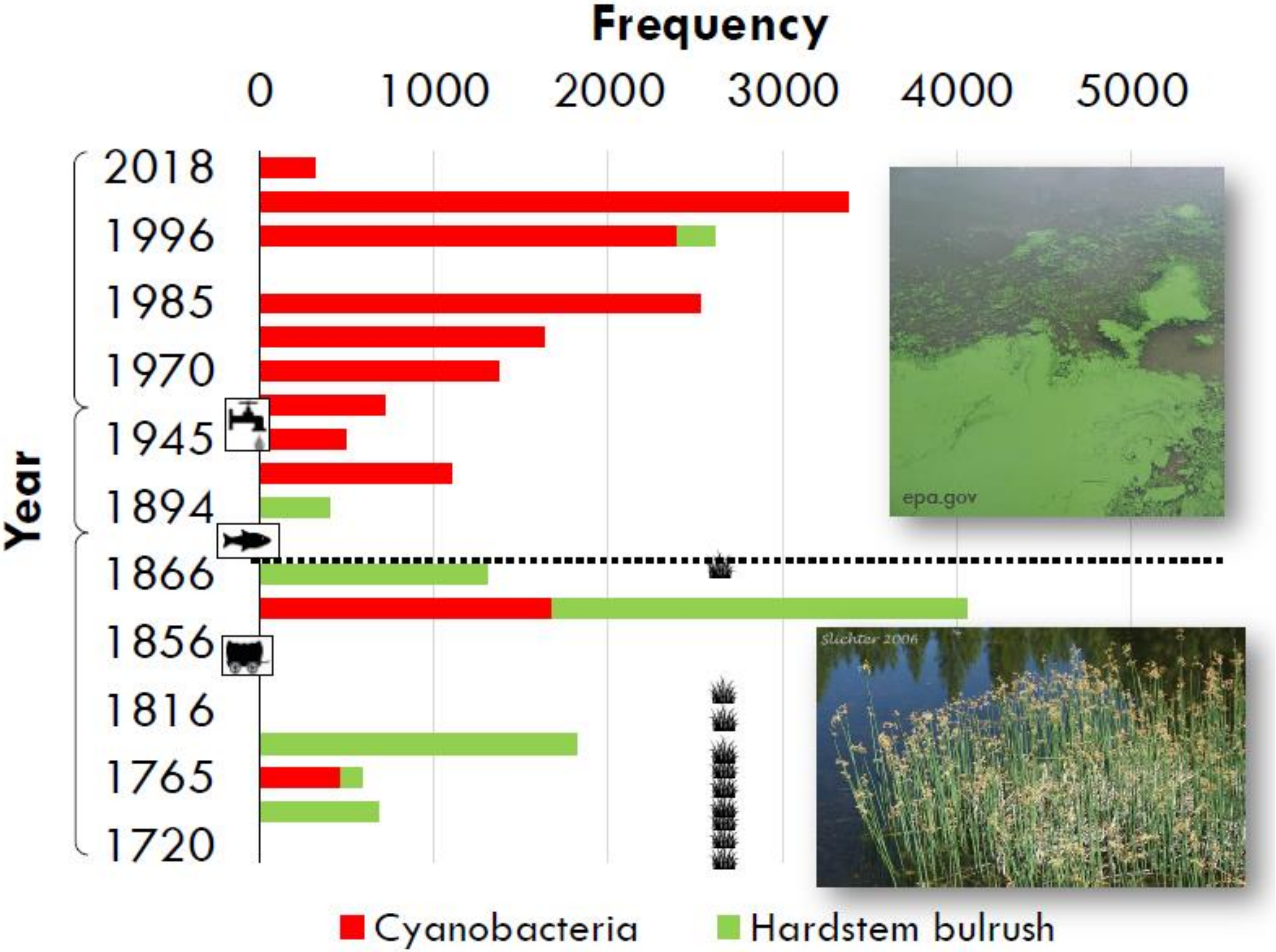




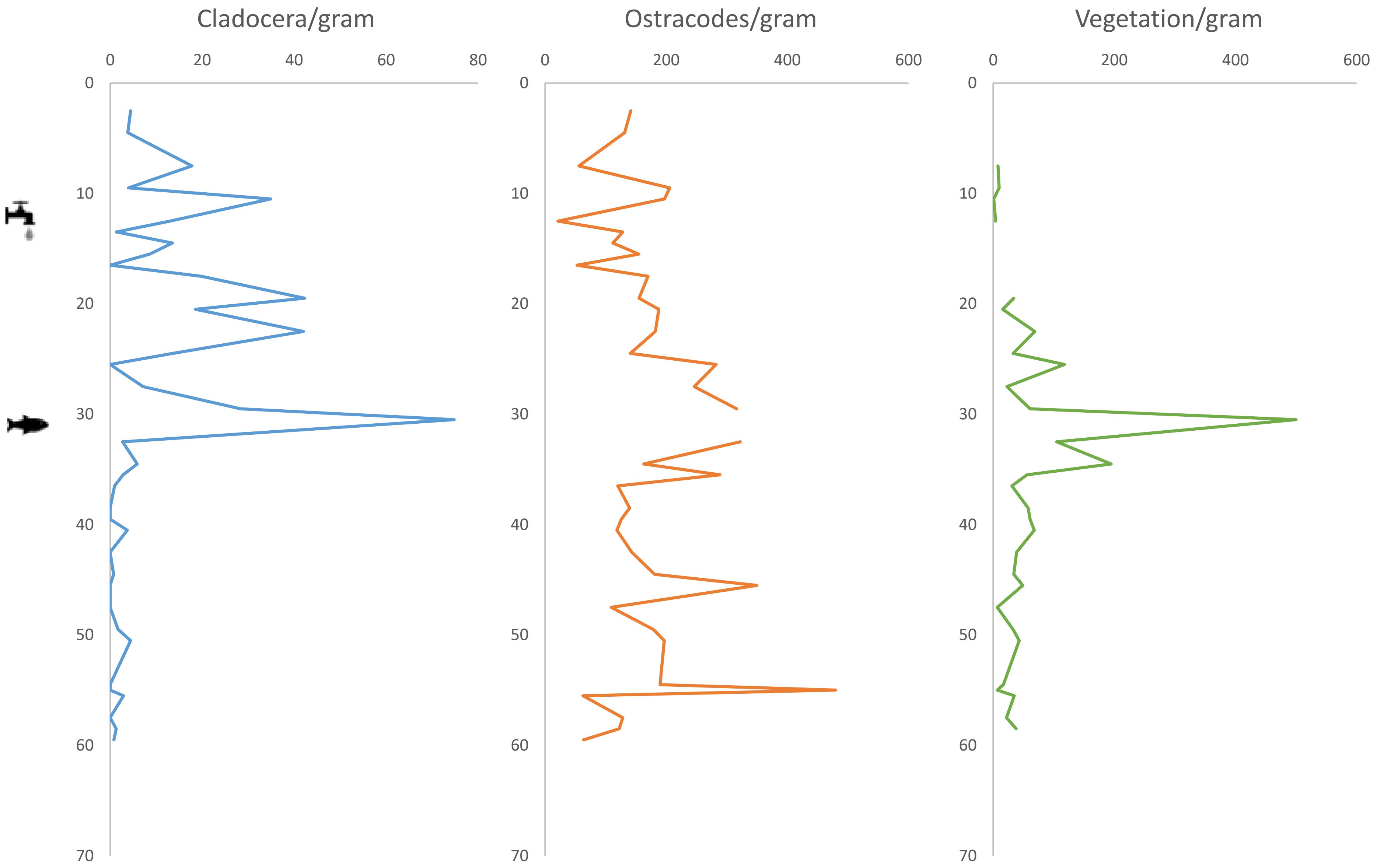
RESULTS:

E-DNA
CYANOBACTERIA
AQUATIC PLANTS

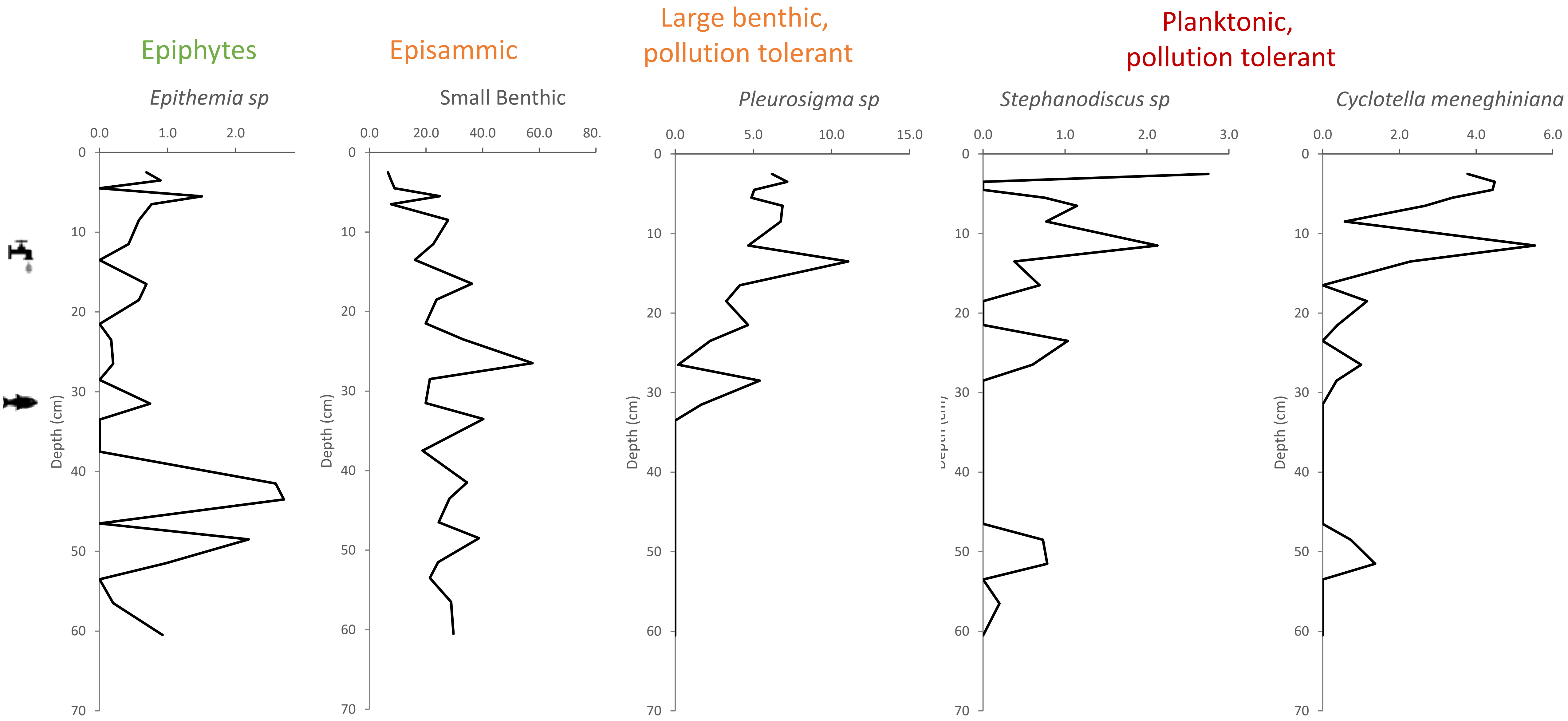
= Plant remains



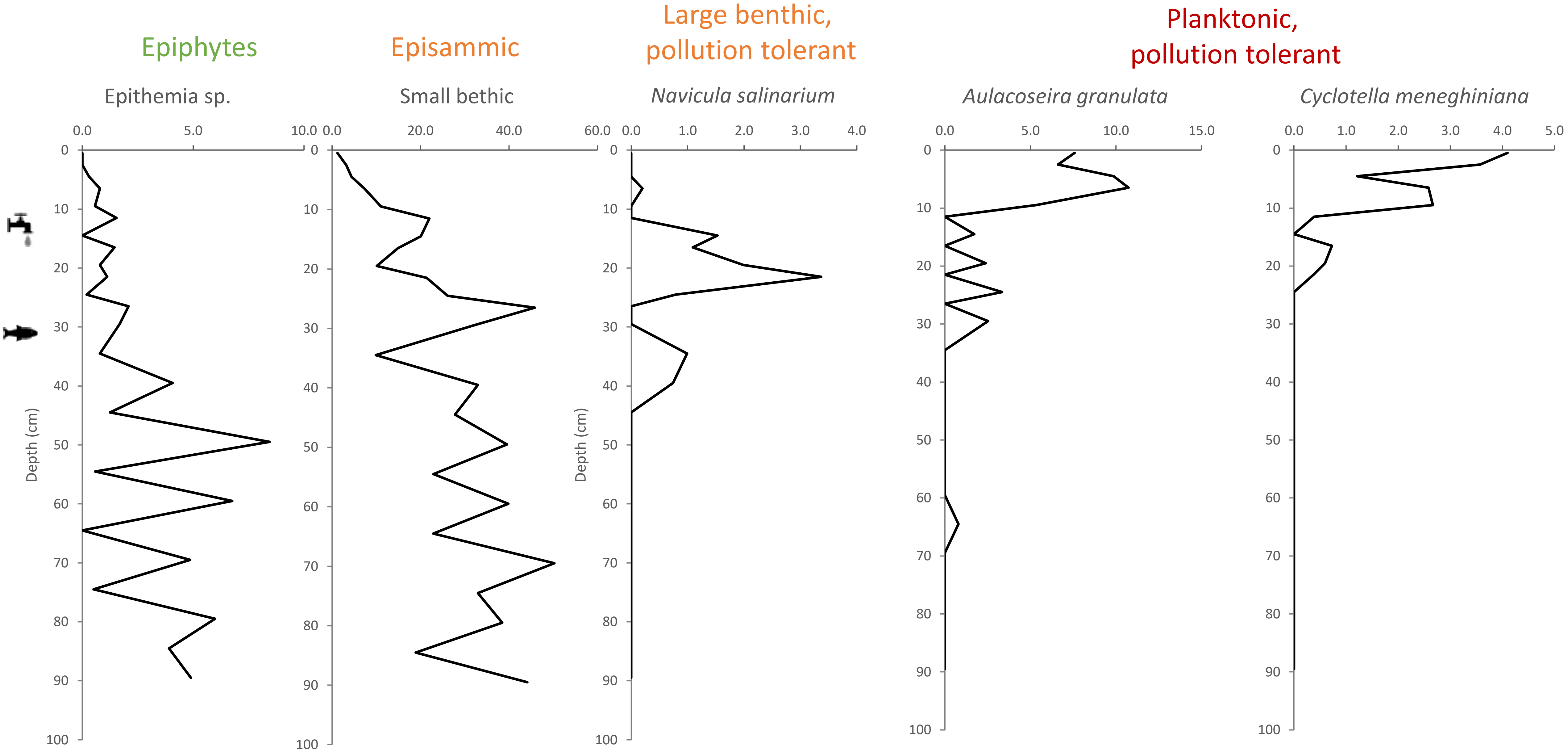
Goshen Bay - Fossils



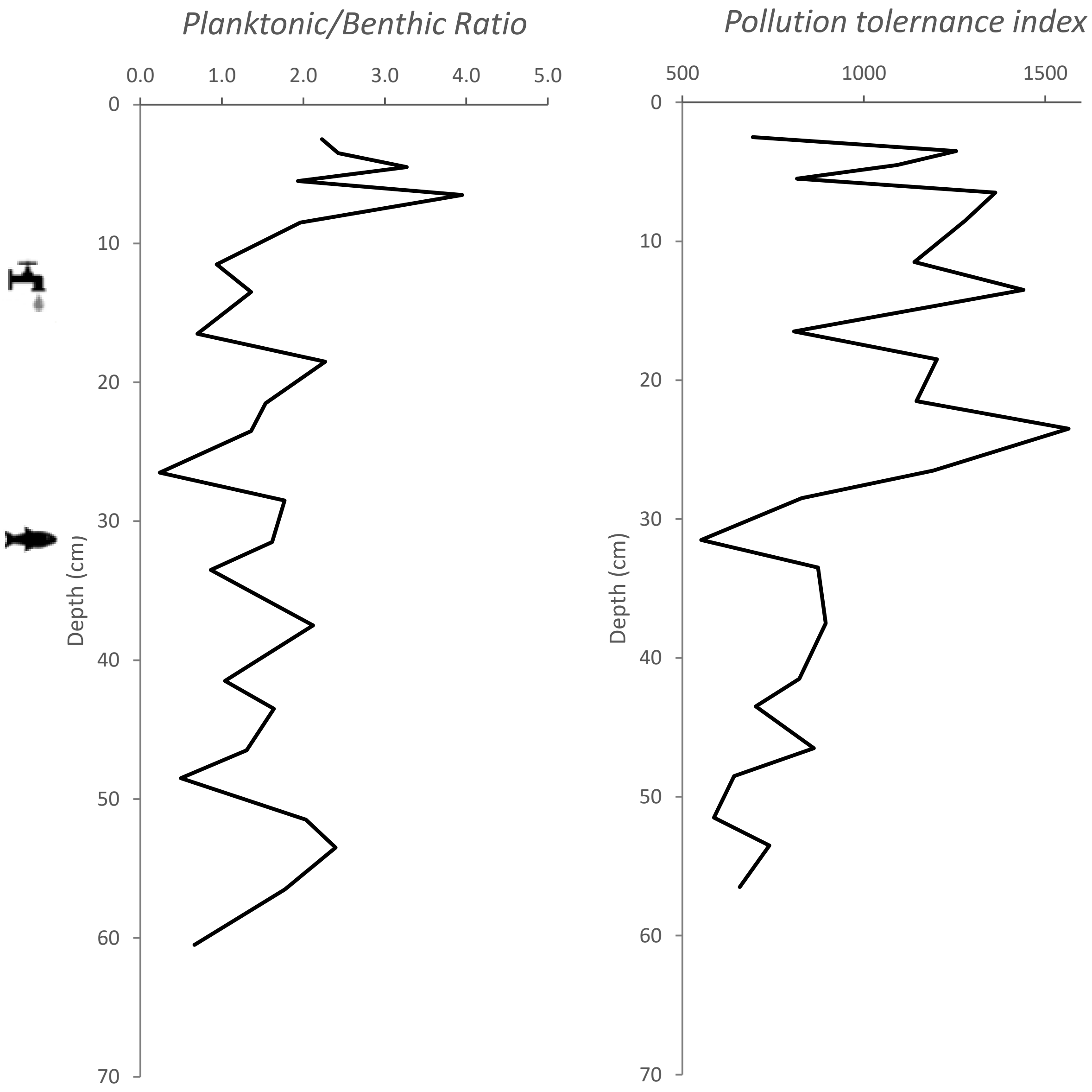
Goshen Bay- Diatoms



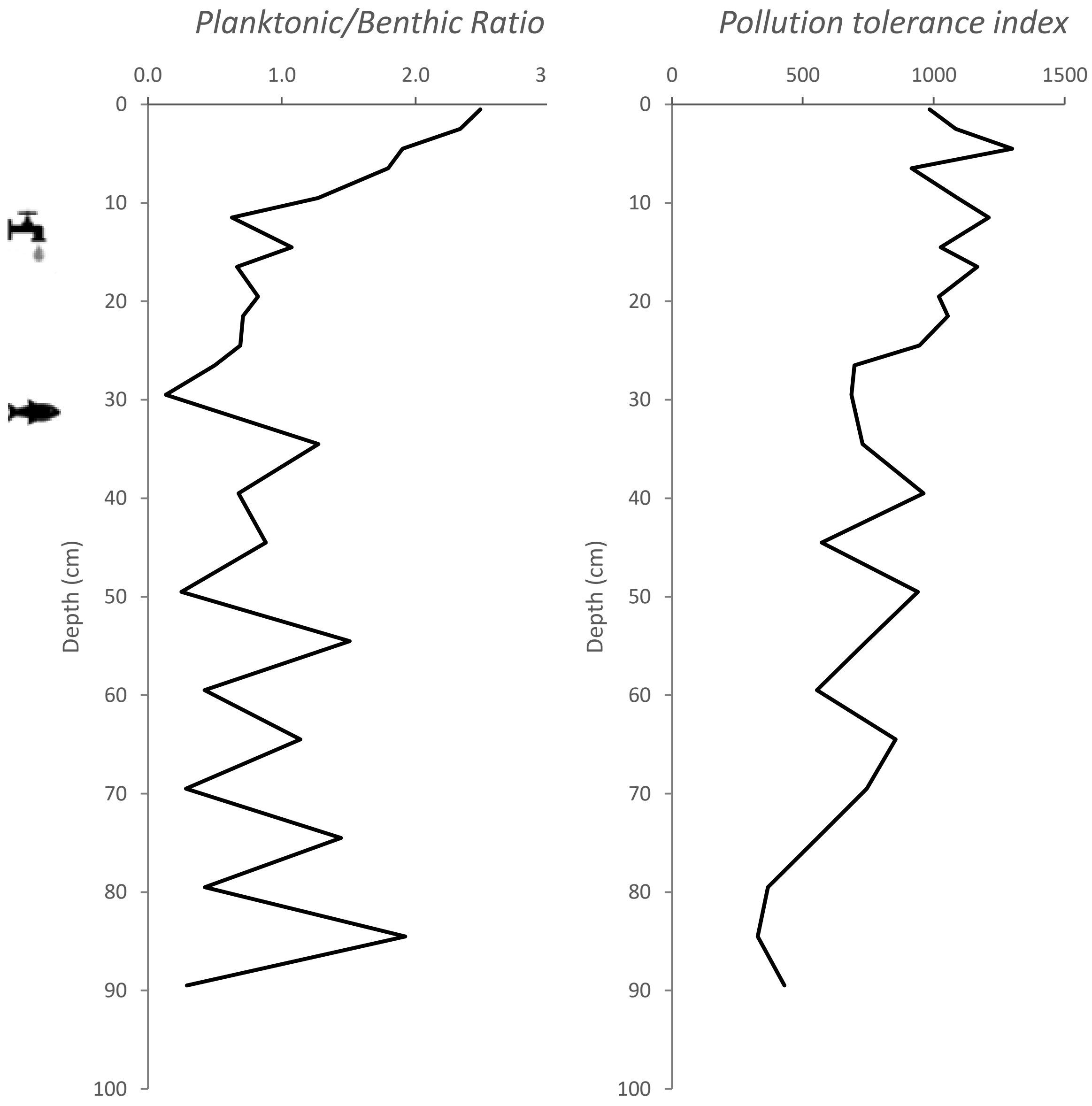
Bird Island- Diatoms



Goshen Bay -Diatoms

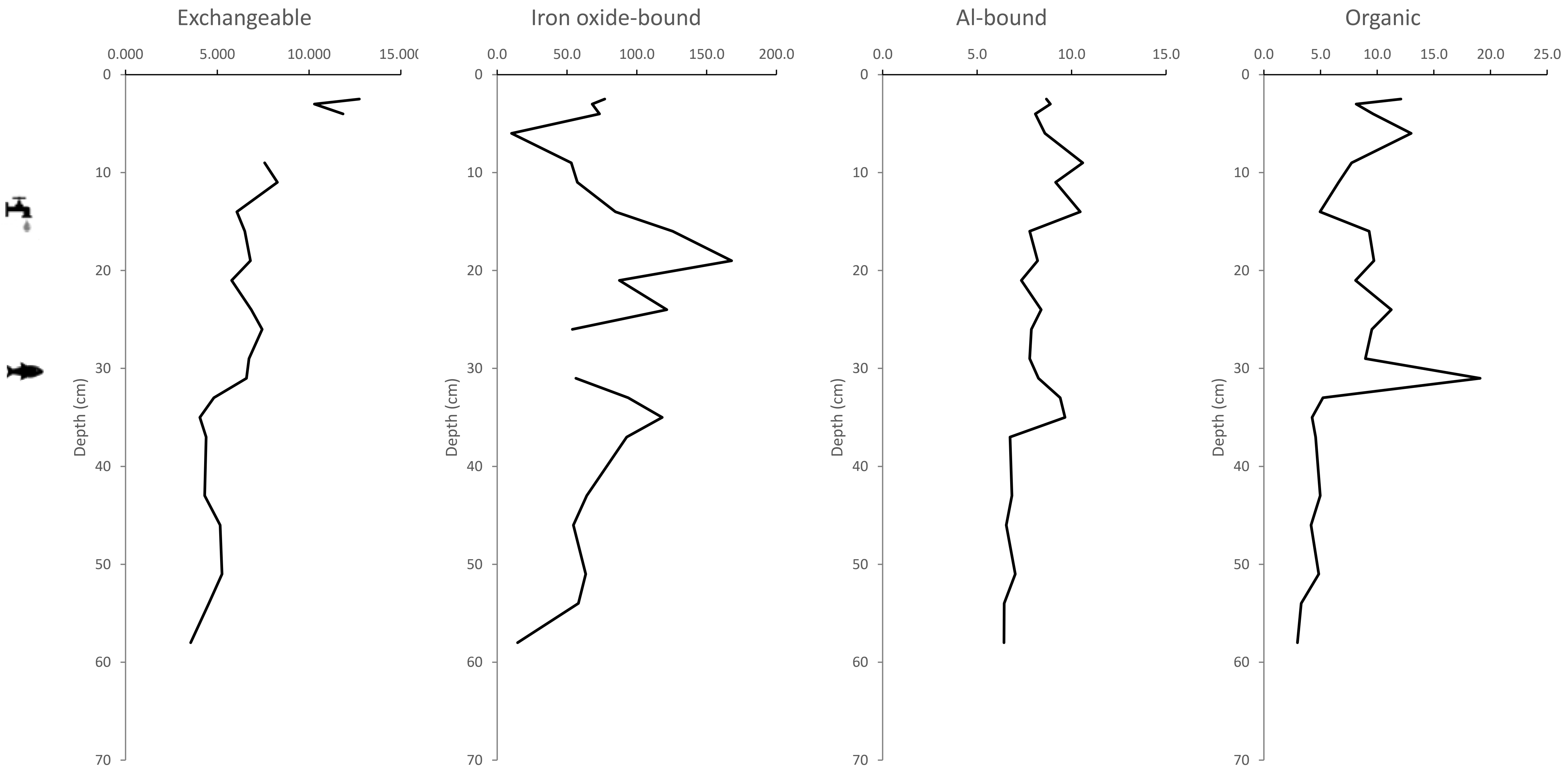


Bird Island- Diatoms



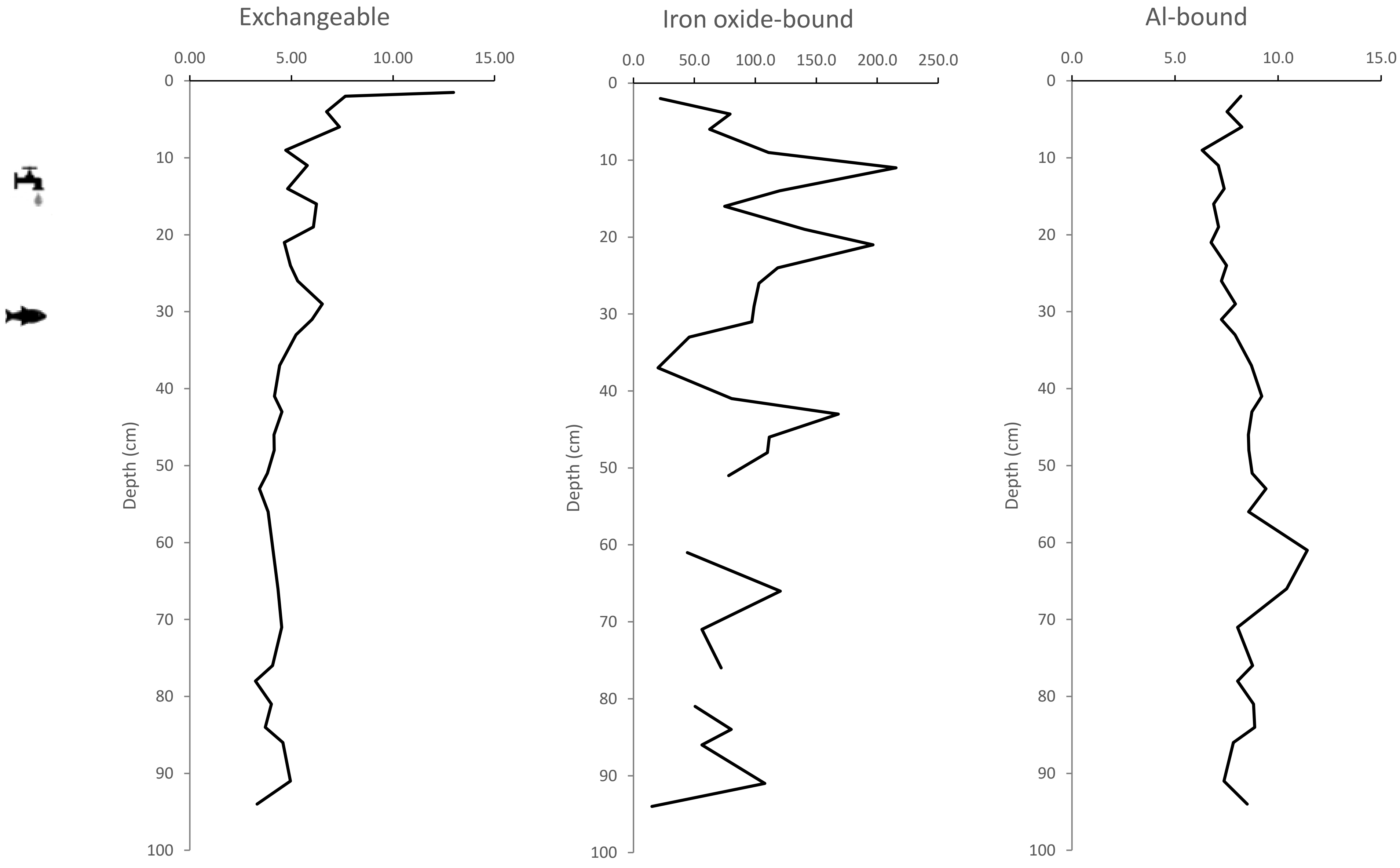
Goshen Bay- Sequential Extractions

+ Calcite, + Recalcitrant



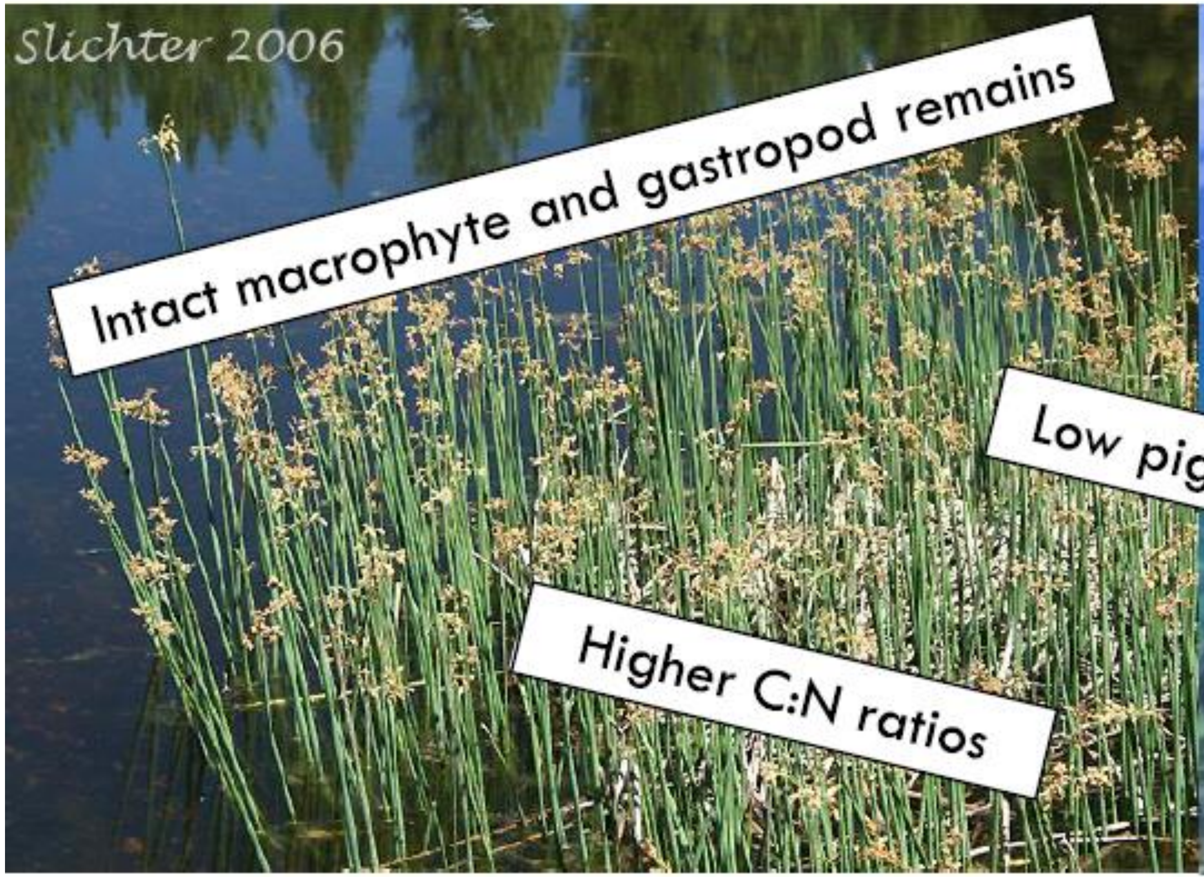
Bird Island - Sequential Extractions

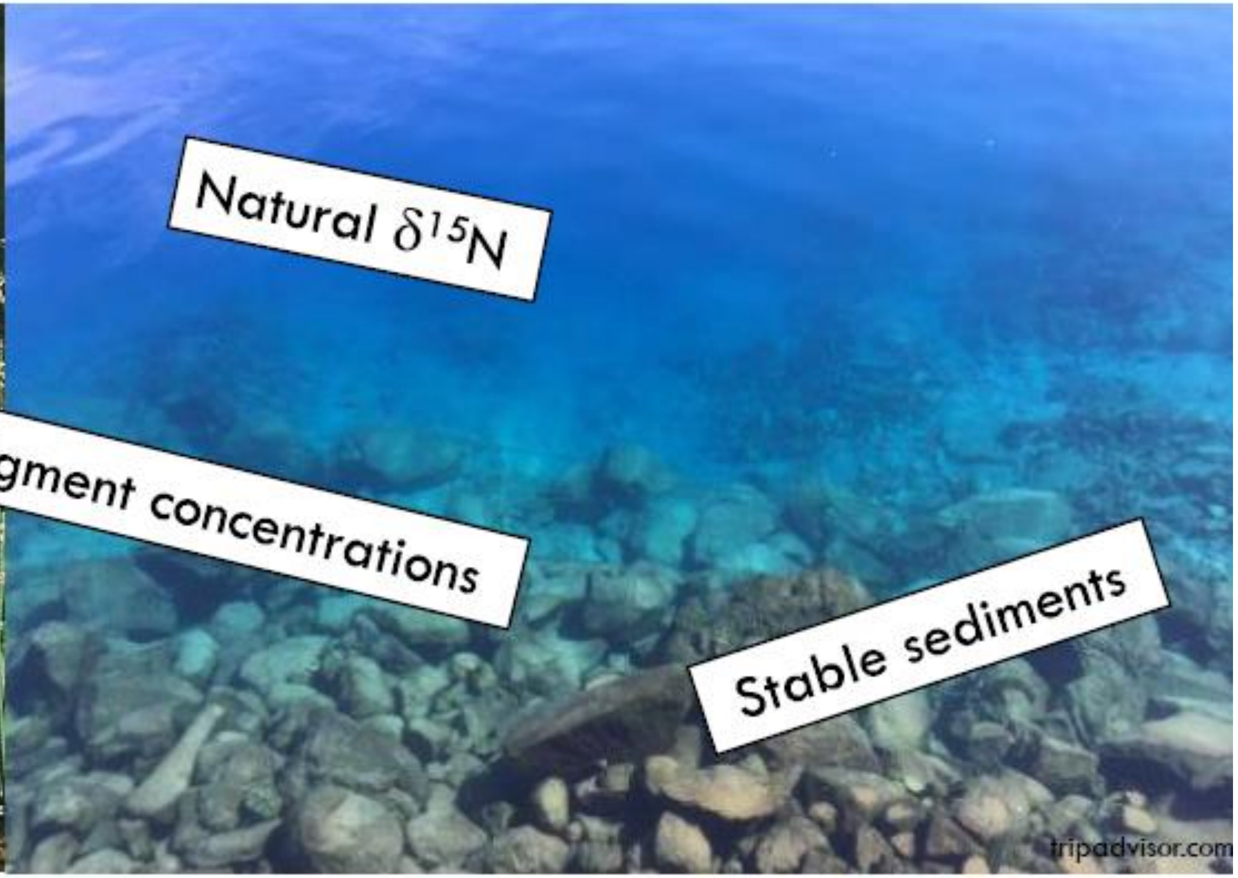
+ Organic, + Calcite, + Recalcitrant



TIME PERIODS IDENTIFIED

1. Pre-regime shift (~1640-1869)



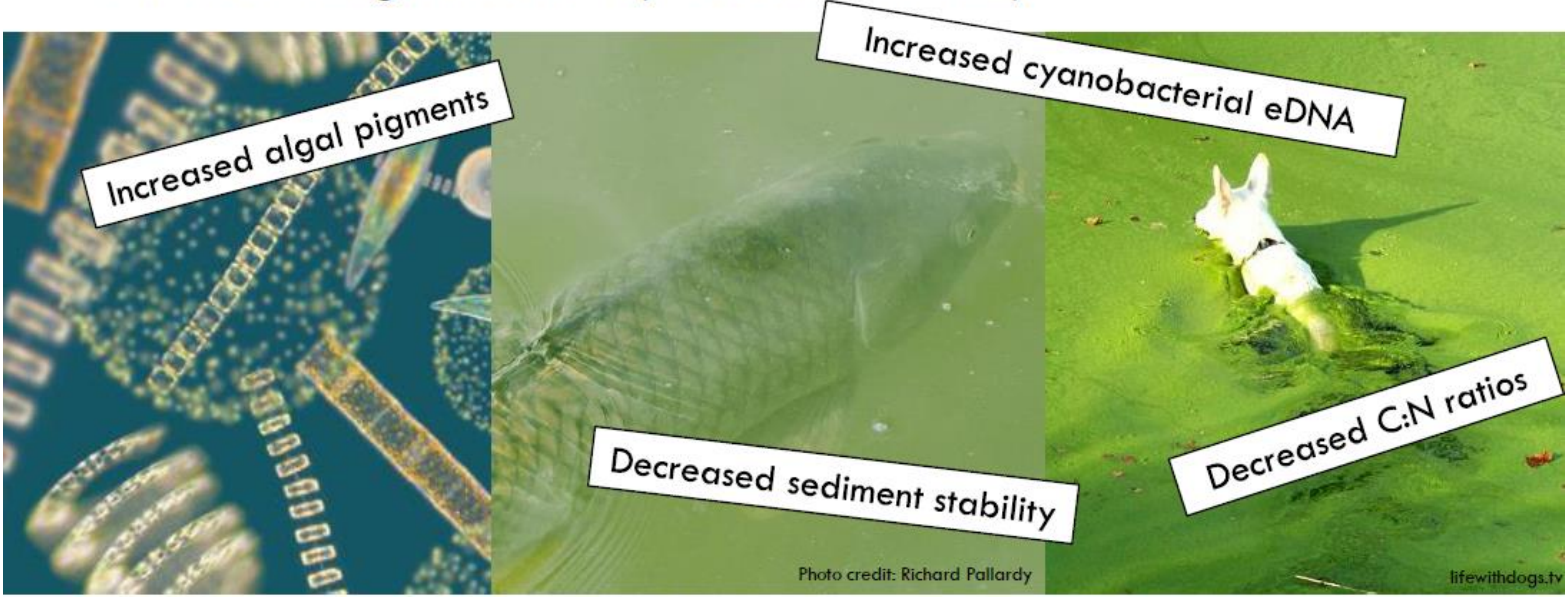


Macrophyte presence

Clearer water

TIME PERIODS IDENTIFIED

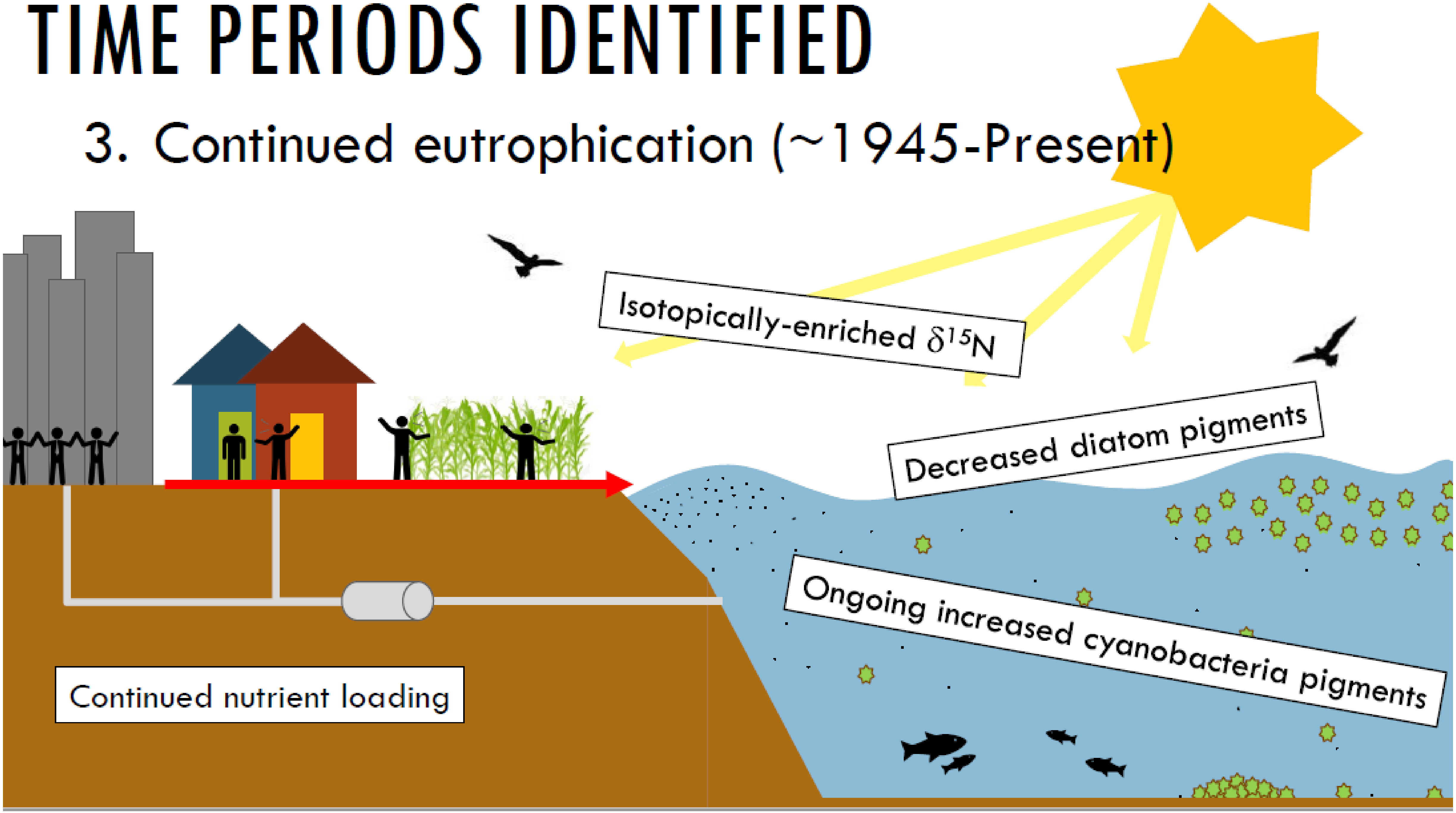
2. Post-regime shift (~1869-1945)



Eutrophic, turbid conditions featuring harmful algal blooms

TIME PERIODS IDENTIFIED

3. Continued eutrophication (~1945-Present)



Utah Lake Paleolimnology: Update December, 2019

Brahney et. al.

Current and Next Steps

<u>Samples submitted</u>

- **Carbon and Nitrogen isotopes – Provo Bay or North**

- **Diatoms community composition North or New Provo (BSA?)**
  - **They do not analyze absolution counts**
  - **Can use amorphous silica as an additional proxy?**

- **Algal pigments – (Leavitt Lab) Provo Bay (new) or North**

- **Zooplankton (Brahney Lab) Identify species, measure**

- **Chironomid (Axford Lab)**

- **Charcoal and pollen (Power Lab)**

- **Phosphorus fractionations and calcite bound (Brahney Lab) ongoing**

Littoral-Benthic Primary Production in Utah Lake

Soren Brothers, Leighton King, Angelia Klein, Janice Brahney

soren.brothers@usu.edu
Dept. of Watershed Sciences & Ecology Center, Utah State University

UtahStateUniversity

Summary / Key findings

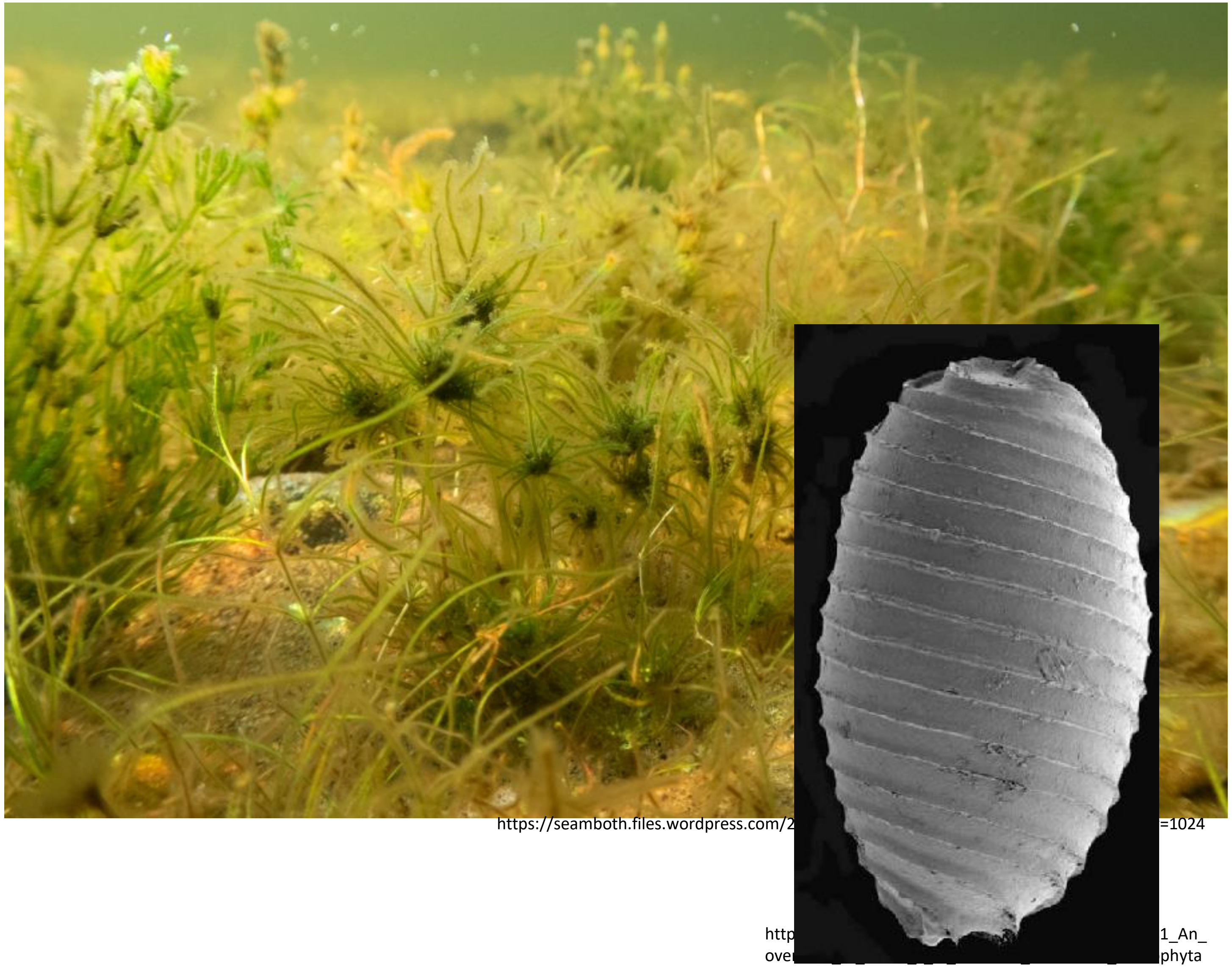
- **Utah Lake primary production in 2018 was ~550 gC/m2, 99% planktonic**
- **A stable clear-water macrophyte community would likely require mean Secchi depths of ≥1 m (2018 mean = ~0.2 m) and chl *a* concentrations of ≤20 μg/L (2018 mean = ~40 μg/L)**
- **Under these conditions, primary production may still have been dominated by phytoplankton, and total PP may have been ~10-20% greater than 2018 rates**
- **Higher primary production with clear waters may feature lower algal biomass accumulation in the water column due to higher grazing**

Goals

- **Determine current and historical rates of primary production in Utah Lake**
- **Locate sediment macrofossil remains of *Chara aspera* oospores in nearshore sediment cores**

Oospore Analysis - Approach

- ***C. aspera*** **(stonewort) is a clearwater indicator algal species reported to historically exist in Utah Lake (Miller and Crowl, 2006)**
- **Especially common in hardwater lakes (common name comes from calcium carbonate deposits that cover them)**
- **Oospores are often discernible in sediment remains, typically buried directly at the location of plant growth**



https://seamboth.files.wordpress.com/2 =1024

http 1_An_
ove phyta

Oospore Analysis - Approach

- **Sediment cores retrieved from the periphery of Utah Lake to confirm the presence and extent of *C. aspera***
- **Two field campaigns carried out in August and October 2019 (20 cores retrieved, sieved, and analyzed by dissecting microscope)**

Oospore Analysis - Results

- **Maximum near-shore retrievable core length was 10-30 cm (separate methods used in each campaign)**
- **No oospore remains identified in any cores**
- **Likely reasons include:**

- Our cores were not deep enough to reach the time period of *C. aspera* presence

- Our cores were not in the same physical location as historical *C. aspera* communities

Oospore Analysis – Next step/Recommendations

- **Off-shore, longer sediment cores contain visible macrophyte vegetation remains**
- ***C. aspera*** **frequently inhabits deeper waters in bands corresponding to lower light limitation depths**
- **Coring transect by boat from shore to center would provide more conclusive analysis to determine presence of *C. aspera***

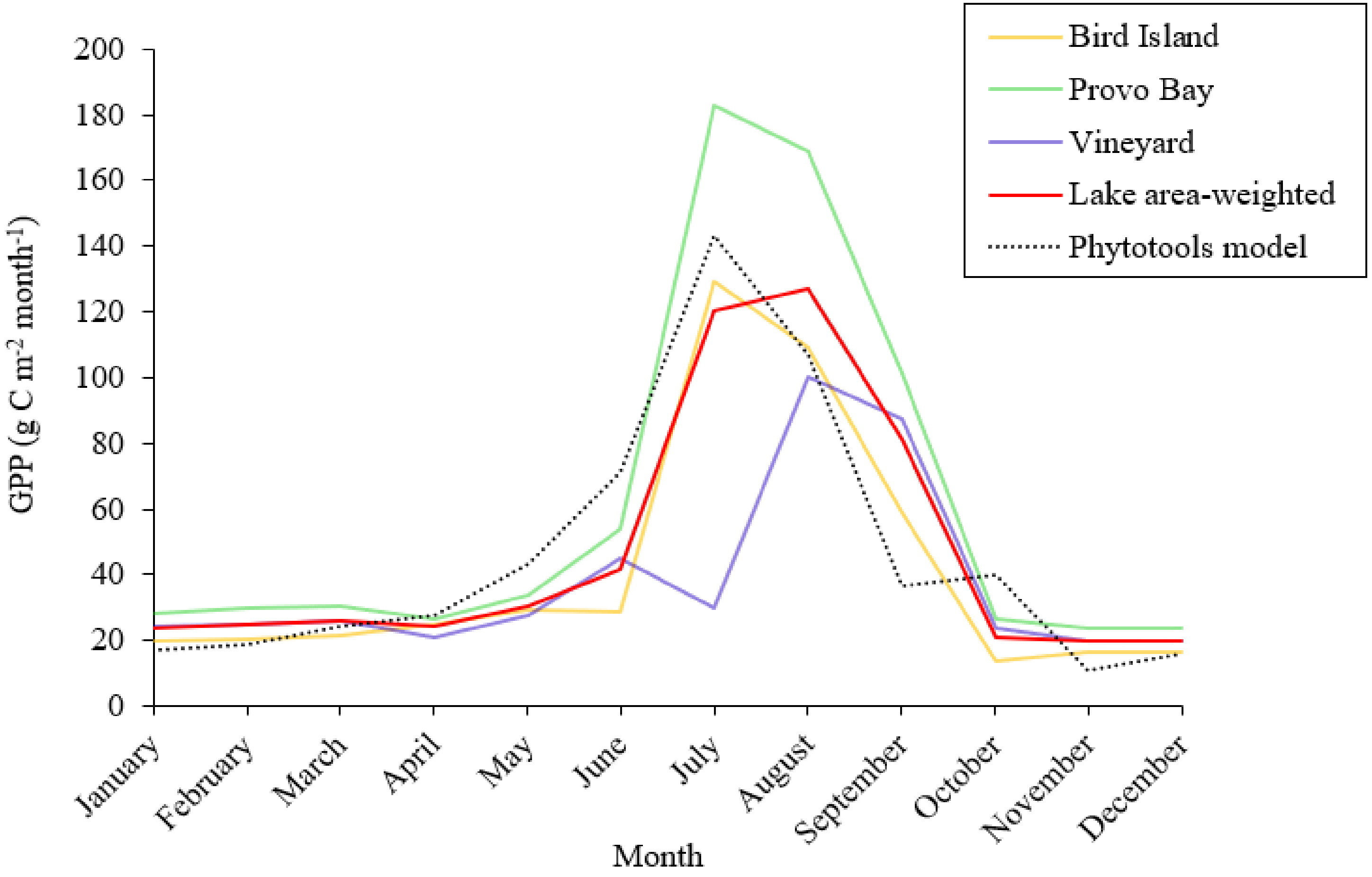
Primary Production - Approach

- **Phytoplankton primary production model (Phytotools) based on water clarity (accounting for high resuspension) and chl *a* concentrations**
- **Photosynthesis-irradiance (P-I) curve parameters determined from literature and in-lake measurements**
- **Periphyton primary production models based on water clarity**
- **Diel dissolved oxygen curves (offshore and nearshore)**

Landom et al., 2019

Primary Production –Results

- **Good agreement between seasonal modeled and measured primary production (~550 gC/m2y, 99% planktonic)**
- **Literature review indicated that >70% of sediment surface area is required to significantly reduce resuspension**
- **Associated with Secchi depths ≥1 m, chl *a* concentration of ≤20 µg/L**

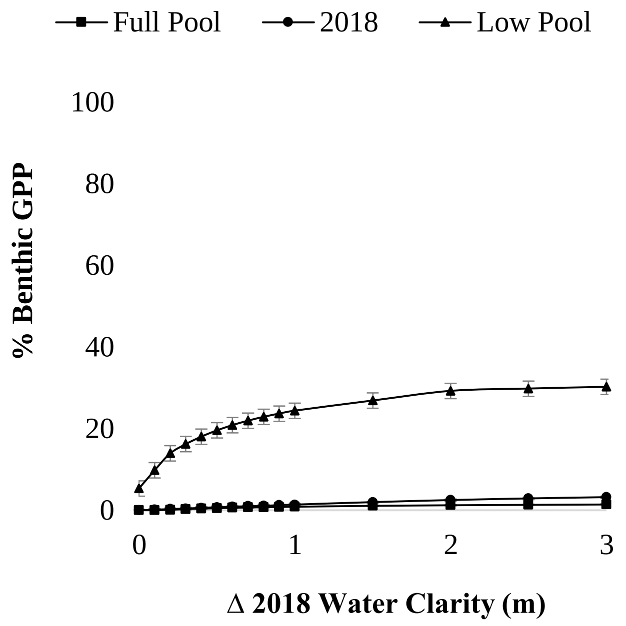


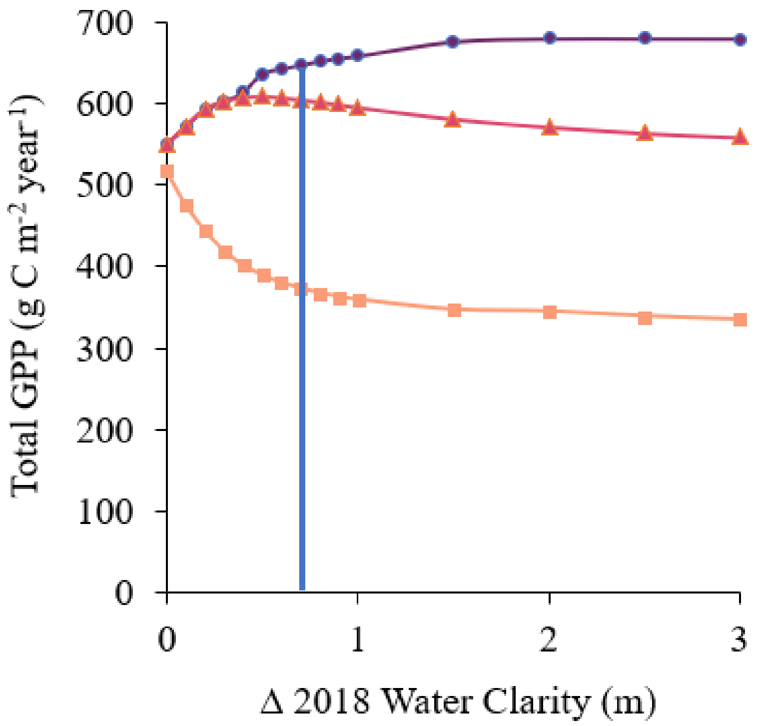
King et al. (*in review*)

Primary Production – Model Results

- **Modeled total productivity rises with initial water clarity increase at 2018 and full-pool water levels**
- **Lake remains generally dominated by phytoplankton productivity**

https://ksltv.com/wp-content/uploads/2018/05/june-sucker-fish-620x359.jpg

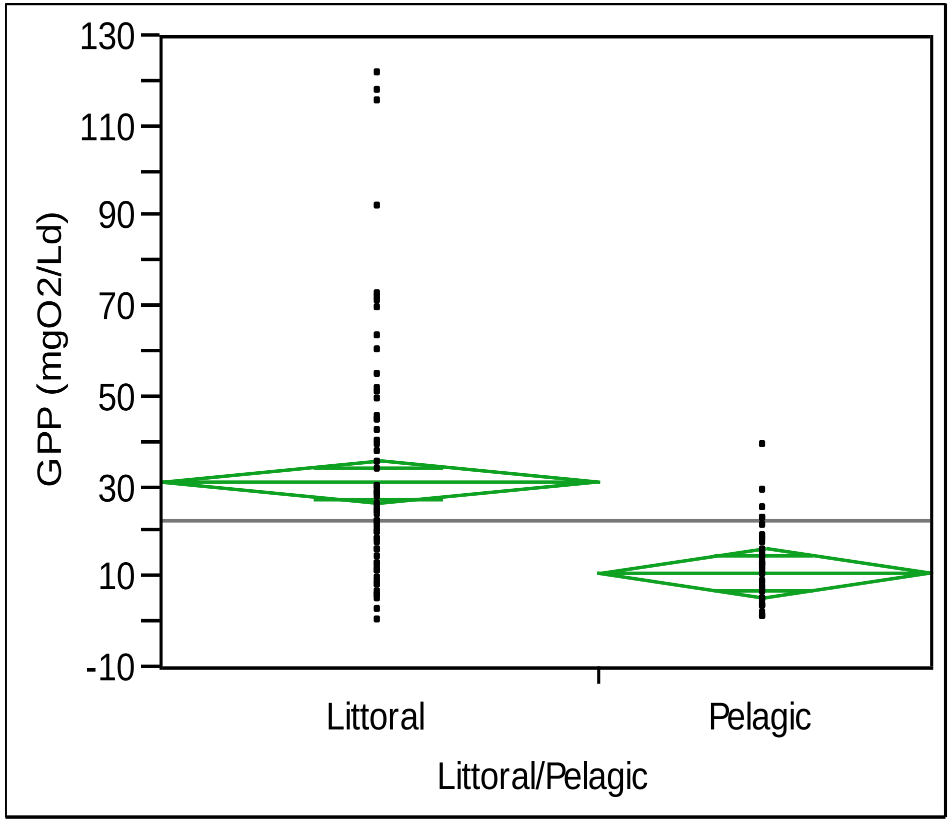




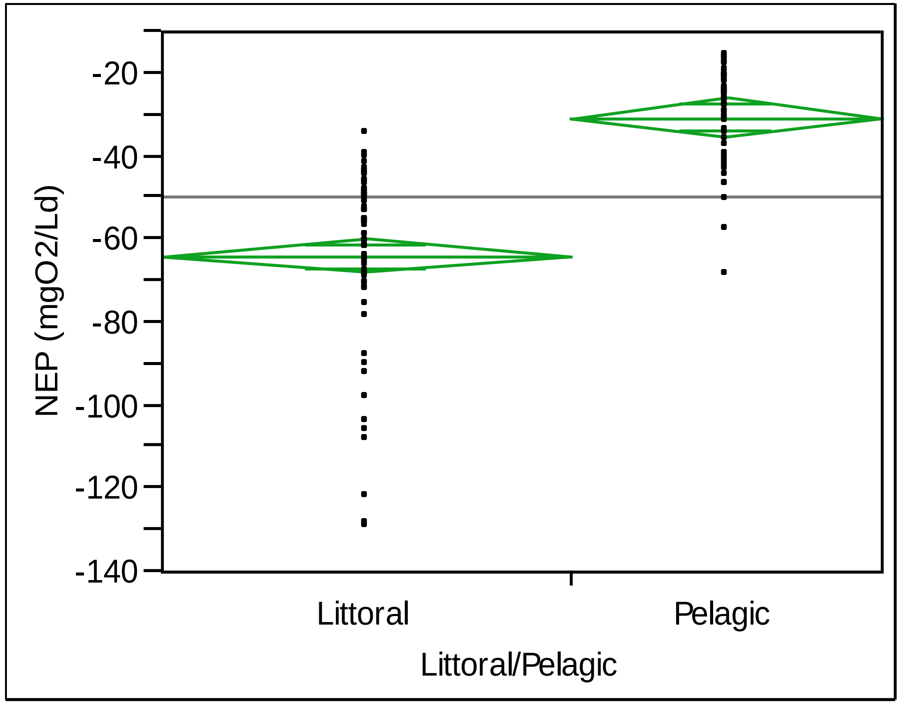
King et al. (*in review*)

Primary Production – Aquatic Metabolism Results

- **Littoral GPP significantly greater than concurrent off-shore measured rates**



Primary Production – Aquatic Metabolism Results



- **Net ecosystem production significantly more negative in the nearshore zone**
- **Net heterotrophy (NEP < 0) is associated with non-local organic matter mineralization**
- **Typically attributed to terrestrial loading, but can be macrophytes, sloughed periphyton and/or a temporal "legacy" effect**

Primary Production – Aquatic Metabolism Results

Vadeboncoeur and Power, 2017

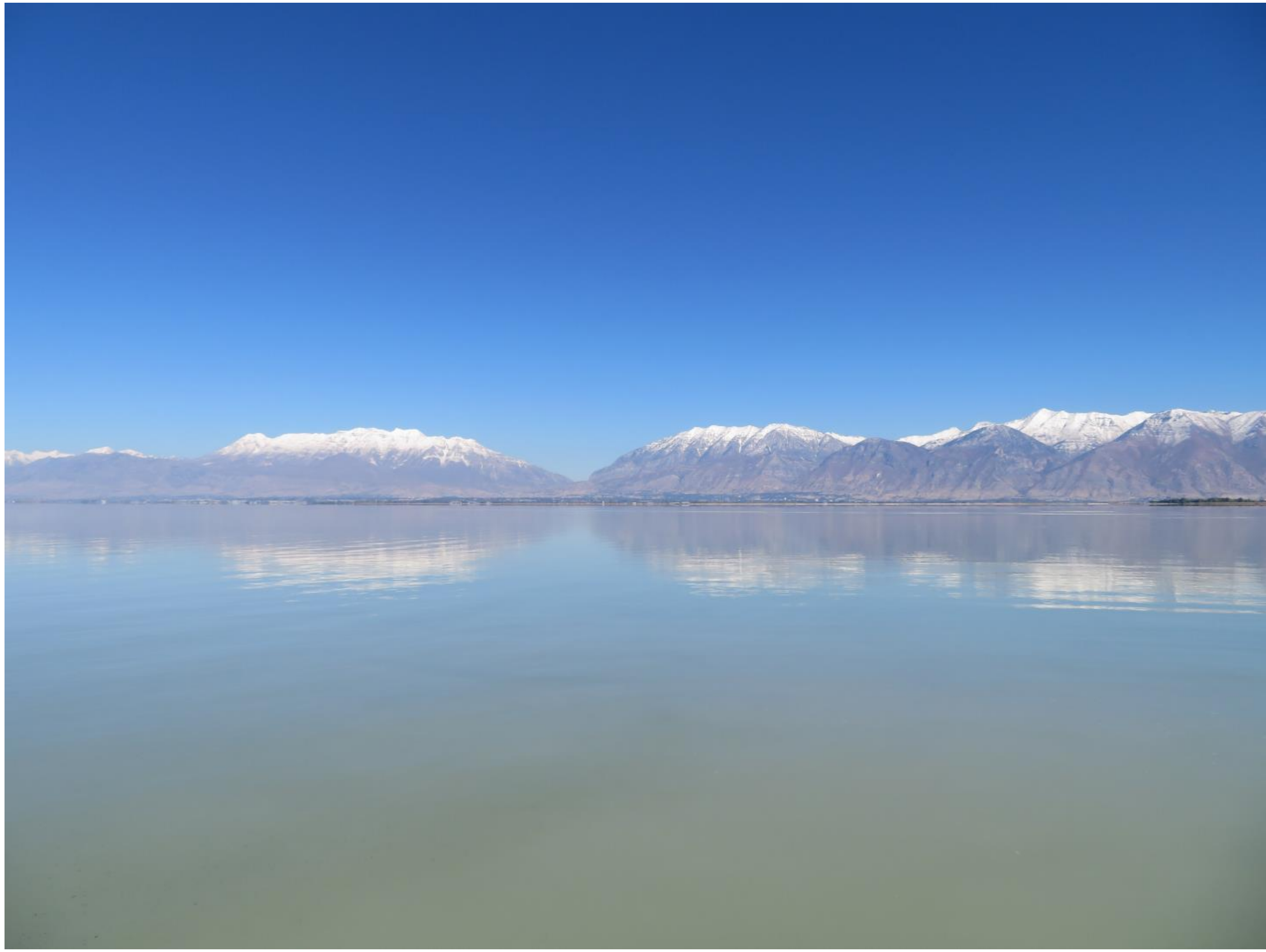
- **More negative NEP paired with higher GPP may indicate more efficient use of primary production by food web**
- **Inverted trophic pyramid is often associated with healthy benthic primary producer communities**
- **Production does not necessarily scale to biomass (i.e., a more productive ecosystem is not necessarily more "swampy")**

Primary Production – Next Steps/Recommendations

- **Longer time series of littoral vs. off-shore aquatic metabolism rates (full year, multi-year, multi-location)**
- **Investigations into periphyton – submerged macrophyte dynamics**
- **Detailed measurements of P-I parameters for Utah Lake algal communities**

Summary

- **Utah Lake's current primary productivity is typical/high-end of eutrophic shallow lakes**
- **Models indicate that an 80 cm increase in mean Secchi depth would result in higher total PP, and maintain phytoplankton dominance**
- **The conditions required for self-stabilizing clear-water feedback effects via benthic GPP may be associated with lower algal biomass, greater food web use of organic matter**



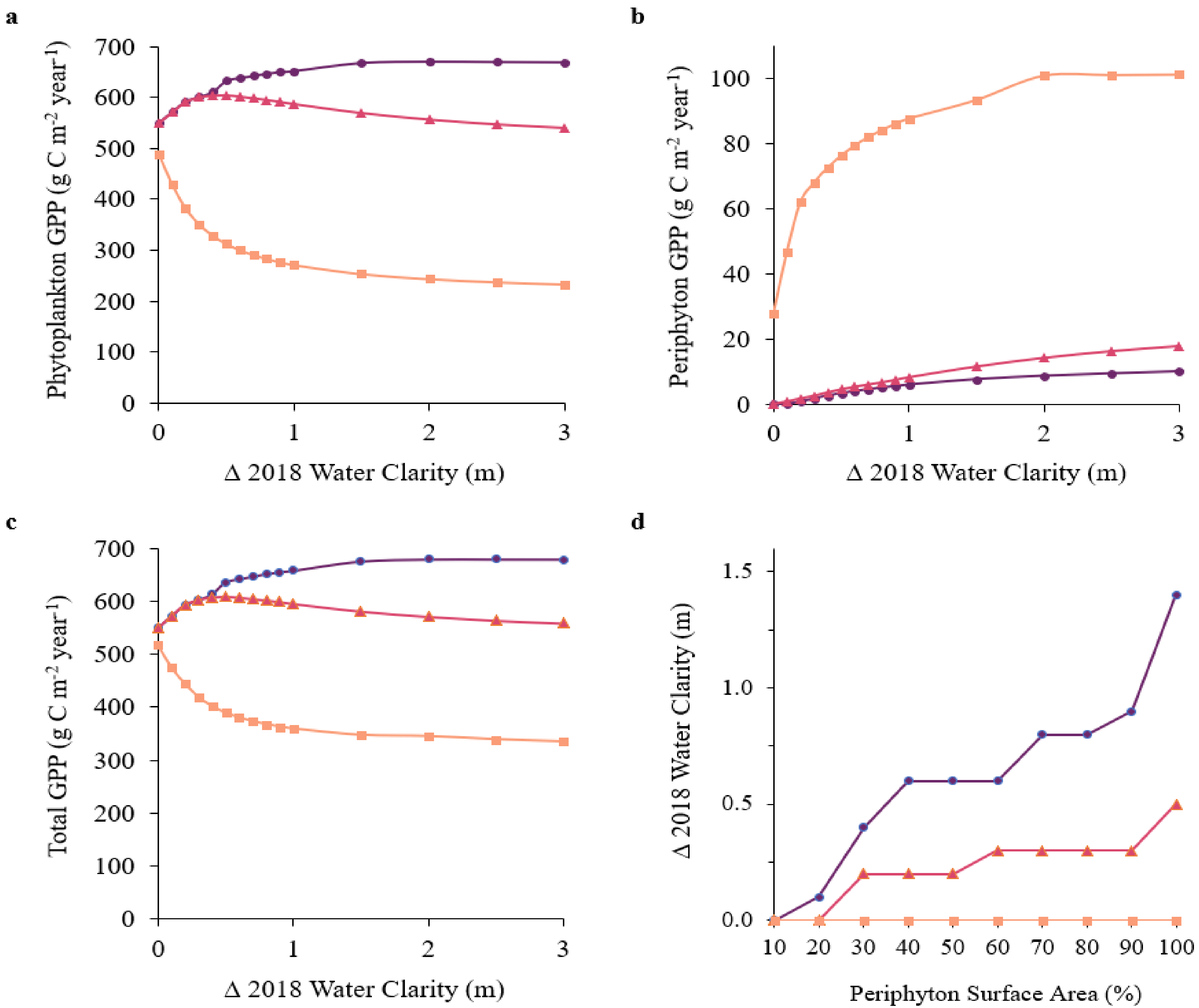
Thank You!

Utah Division of Water Quality

Central Utah Water Conservancy District

Utah State University

Kevin Landom, Kateri Salk, Michael Paul, Ryan West


a
Phytoplankton GPP (g C m-2 year-1)
0
100
200
300
400
500
600
700
0
1
2
3
Δ 2018 Water Clarity (m)
b
Periphyton GPP (g C m-2 year-1)
0
20
40
60
80
100
Δ 2018 Water Clarity (m)
c
Total GPP (g C m-2 year-1)
Δ 2018 Water Clarity (m)
d
Δ 2018 Water Clarity (m)
0.0
0.5
1.0
1.5
10
20
30
40
50
60
70
80
90
100
Periphyton Surface Area (%)

STRATEGIC RESEARCH PLAN

Utah Lake Water Quality Study
Science Panel Call
March 15, 2021

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY

GOALS

- Review Progress on Research
  - Charge Questions and Priorities

- What should be the next RFP?

Utah Lake Water Quality Study—
Strategic Research Plan
DRAFT

August 18, 2020
Version 4.3

PRESENTED TO

Utah Department of Environmental Quality
Division of Water Quality
PO Box 144870
Salt Lake City, UT 84114

PREPARED BY

Tetra Tech
1 Park Drive, Suite 200
Research Triangle Park, NC 2709

STRATEGIC RESEARCH PLAN (SRP): PAST AND PRESENT

- Strategic Plan:
  - Fill knowledge gaps
  - Target initial charge questions/conceptual model
  - Lays out future
  - Living document
- Exploratory Research Plan: Ignite research
  - Paleo, Sediment, Bioassays
- Current Priorities:
  - Littoral Sediment, CNP Budgets and P-Binding

CHARGE QUESTION PROGRESS

Question 1. What was the historic ecological and nutrient condition of Utah Lake pre-settlement and how has it changed?

- Solid Coverage
  - Paleo Study
  - Ongoing Analysis
  - EFDC/WASP in Retro Mode

See Handout

CHARGE QUESTION PROGRESS

Question 2. What is the current ecological and nutrient condition?

- Solid Coverage
  - HAB locations, limitation
    - Bioassay, Analysis Report, Models
  - Sediment and Cycling
    - Sediment, P Binding, Mass Balance, Models
  - Early Life Stages
    - June Sucker Recovery

utah.com

See Handout

CHARGE QUESTION PROGRESS

Question 2. What is the current ecological and nutrient condition?

- In Part
  - Carp and Macrophyte
    - Analysis Report, Literature
- Missing
  - What species are sensitive?

utah.com

See Handout

CHARGE QUESTION PROGRESS

Question 3. What additional information is needed for setting NNC that support Utah Lake's Beneficial Uses?

- Solid Coverage
  - Framework Document
  - Assessment Endpoints linked to ongoing or planned work

utah.gov

See Handout

CHARGE QUESTION PROGRESS

Question 4. Is there an improved stable state that can be reached under the constraints of current water and fishery management?

- Solid Coverage
  - Models
  - Synthesis of existing knowledge
  - Forecasting Limitations

cnr.usu.edu

See Handout

RESEARCH PRIORITY PROGRESS

- Solid Coverage
  - Budgets, Calcite, Modeling
- In Part
  - Toxin Production and N fixation
- Lots of Gaps

Research ideas		Mean Ranking - Feb 2020	Relevant Funded Studies	Limnocorrals or Littoral?
5*	Carp effects on nutrient cycling	7.3		**Limnocorrals?**
6*	Lake level (effect on macrophytes)	9.2		**Littoral?**
7*	Bioassays that incorporate sediment (next phase mesocosms)	9.4		**Limnocorrals?**
8*	Macrophyte recovery potential (Provo Bay demo)	10.0		**Littoral?**
9	Lake-level effects on biogeochemistry and nutrient cycling	10.2		
11*	Turbidity effect on primary producers	11.2		**Limnocorrals?**
12*	Resuspension rates from bioturbation	11.7		**Limnocorrals?**
13*	Carp effects on zooplankton (and does this influence algal response)	11.8		**Limnocorrals?**
14*	Carp effects on macrophytes	12.1		**Limnocorrals?**
17*	Macrophyte role (to biogeochemistry)	14.0		**Limnocorrals?**
19	Alternative models (PCLake – cyano/macrophyte state change)	14.9		

See Handout; And * means TSSD team sees potential for limnocorral application

UTAH LAKE MESOCOSM RESEARCH

Jeff Holt, YouTube

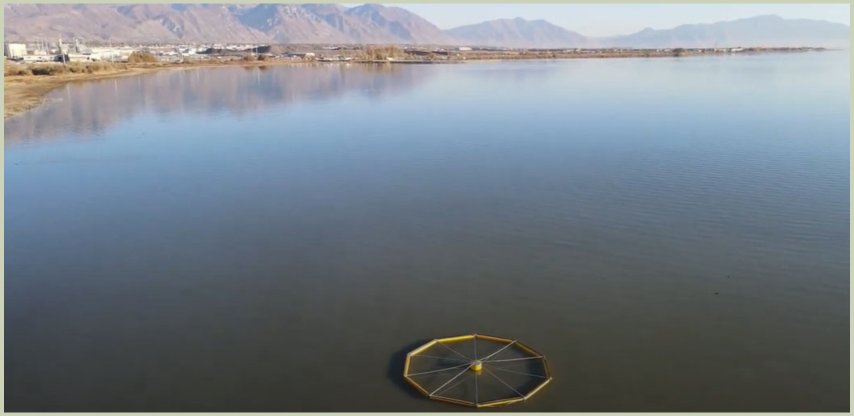
- Mesocosms could address many areas
  - Calcite Binding
  - Carp Effects
  - Macrophyte Recovery/Effects
  - Lake Level Effects
  - Nutrient Limitation and Toxin Controls
  - Turbidity Effects

WHAT SHOULD BE THE NEXT RFPS?

Address Gaps?

- Carp Effects Missing
- Macrophyte Effects Missing
- Fish Species Sensitivity Missing

Strengthen Other Areas?



QUESTIONS/DISCUSSION

Addressing

In Part

CHARGE QUESTION PROGRESS

What was the historic ecological and nutrient condition of Utah Lake pre-settlement and how has it changed?

Charge Question #1 - Historical Condition

Questions	Being addressed
1.1. What does the diatom community and macrophyte community in the paleo record tell us about the historical trophic state and nutrient regime of the lake?	Paleo Study
i. Can diatom (benthic and planktonic) and/or macrophyte extent or presence be detected in sediment cores? And if so, what are they?	Paleo Study
ii. What were the environmental requirements for diatoms and extant macrophyte species?	Analysis Report
iii. How have environmental conditions changed over time?	Paleo Study; Analysis Report; EFDC/WASP
1.2. What were the historic phosphorus, nitrogen, and silicon concentrations as depicted by sediment cores? (add calcium, iron, and potentially N and P isotopes)	Paleo Study
1.3. What information do paleo records (eDNA/scales) provide on the population trajectory/growth of carp over time? What information do the paleo records provide on the historical relationship between carp and the trophic state and nutrient regime of the lake?	Paleo Study; Contemporary data gathered by carp monitoring program
1.4. What do photopigments and DNA in the paleo record tell us about the historical water quality, trophic state, and nutrient regime of the lake?	Paleo Study

Addressing

In Part

CHARGE QUESTION PROGRESS

What is the current ecological and nutrient condition?

Charge Question #2 - Current Conditions

Questions	Being addressed
2.1. What are the impacts of carp on the biology/ecology and nutrient cycling of the lake and how are those impacts changing with ongoing carp removal efforts?	
i. What contribution do carp make to the total nutrient budget of the lake via excretion rates and bioturbation? How much nutrient cycling can be attributed to carp?	Analysis Report
ii. What is the effect of carp removal efforts on macrophytes, nutrients, secchi depth, turbidity, and primary productivity?	Literature; Proposed Work
iii. How much non-algal turbidity and nutrient cycling is due to wind action versus carp foraging? How much does sediment resuspension contribute to light limitation, and does wind resuspension contribute substantially in the absence of carp?	Analysis Report; EFDC
2.2 What are the environmental requirements for submerged macrophytes currently present at Utah Lake?	
i. What is the role of lake elevation and drawdown in macrophyte recovery? Are certain species more resilient to drawdowns and nutrient related impacts? Can some species establish/adapt more quickly?	Landom et al. (2019); EFDC/WASP
ii. What is the relationship between carp, wind, and macrophytes on non-algal turbidity and nutrient cycling in the lake? What impact could macrophyte reestablishment have?	Analysis Report; EFDC/WASP

Carp and Macrophyte Effects Missing From Current Science Panel Research

Addressing

In Part

CHARGE QUESTION PROGRESS

What is the current ecological and nutrient condition?

Charge Question #2 - Current Conditions

Questions	Being addressed
2.3. What are the linkages between changes in nutrient regime and Harmful Algal Blooms (HABs)?	
i. Where do HABs most frequently start/occur? Are there hotspots and do they tend to occur near major nutrient sources? Data analysis	Analysis Report
ii. Which nutrients are controlling primary production and HABs and when?	Bioassay; Analysis Report; EFDC/WASP
iii. If there are linkages between changes in nutrient regime and HABs, what role if any does lake elevation changes play?	Analysis Report; EFDC/WASP
iv. How do other factors affect HAB formation in Utah Lake (e.g., climate change; temperature; lake stratification; changes in zooplankton and benthic grazers and transparency)	Analysis Report; EFDC/WASP
v. What is the role of calcite “scavenging” in the phosphorus cycle?	P Binding; Sediment
vi. What is the relationship between light extinction and other factors (e.g., algae, TSS, turbidity)?	Analysis Report; EFDC/WASP

Addressing

In Part

CHARGE QUESTION PROGRESS

What is the current ecological and nutrient condition?

Charge Question #2 - Current Conditions

Questions	Being addressed
2.4. How do sediments affect nutrient cycling in Utah Lake?	
i. What are current sediment equilibrium P concentrations (EPC) throughout the lake? What effect will reducing inputs have on water column concentrations? If so, what is the expected lag time for lake recovery after nutrient inputs have been reduced?	Sediment; CNP Budgets
ii. What is the sediment oxygen demand of, and nutrient releases from, sediments in Utah Lake under current conditions?	Sediment; Literature; EFDC/WASP
iii. Does lake stratification [weather patterns] play a result in anoxia and phosphorus release into the water column? Can this be tied to HAB formation?	Analysis Report; Sediment; EFDC/WASP
2.5. For warm water aquatic life, waterfowl, shorebirds, and water-oriented wildlife:	
i. Where and when in Utah Lake are early life stages of fish present?	June Sucker Recovery Program
ii. Which species are most sensitive and need protection from nutrient-related impacts?	No – literature?

Fish Species Sensitivity Missing From Current Science Panel Research

Addressing

In Part

CHARGE QUESTION PROGRESS

What additional information is needed for setting NNC that support Utah Lake's Beneficial Uses?

Charge Question #3 – Additional Information

Questions	Being addressed
3. What additional information is needed to define nutrient criteria that support existing beneficial uses?	
3.1 For warm water aquatic life, waterfowl, shorebirds, and water-oriented wildlife	Framework Document Links these to Assessment Endpoints Being Measured
3.2 For primary contact recreation	
3.3 For agricultural uses including irrigation of crops and stock watering	

Addressing

In Part

CHARGE QUESTION PROGRESS

Is there an improved stable state that can be reached under the constraints of current water and fishery management?

Charge Question #4 – High Level Question

Questions	Being addressed
4. What additional information is needed to define nutrient criteria that support existing beneficial uses?	
4.1 What would be the current nutrient regime of Utah Lake assuming no nutrient inputs from human sources?	EFDC/WASP (in part) Synthesis of Modeling and Empirical Analysis to Inform SP Judgment
4.2 Assuming continued carp removal and current water management, would nutrient reductions support a shift to a macrophyte-dominated state within reasonable planning horizons (i.e., 30- 50 years)?	
4.3 If the lake stays in a phytoplankton-dominated state, to what extent can the magnitude, frequency, and extent of harmful and nuisance algal blooms be reduced through nutrient reductions?	

Addressing

In Part

PRIORITY PROGRESS

	#	Research ideas	Mean Ranking - Feb 2020	
	1	**How large is internal vs external loading (how long would recovery take?)**	**2.3**	CNP Budgets, Sediment
	2	**Sediment budgets (C, N, and P; nutrient flux chambers)**	**3.6**	CNP Budgets, Sediment
	3	**Calcite scavenging (how bioavailable is SRP – does bioassay address?)**	**4.3**	P Binding, Bioassay
	4	**Adding modules to the WQ models (sediment diagenesis, calcite scavenging)**	**4.3**	P Binding, Sediment
Limnocorrals/Mesocosms?	5	Carp effects on nutrient cycling	7.3	
	6	Lake level (effect on macrophytes)	9.2	Littoral*
Limnocorrals/Mesocosms?	7	Bioassays that incorporate sediment (next phase mesocosms)	9.4	
?	8	Macrophyte recovery potential (Provo Bay demo)	10.0	
	9	Lake-level effects on biogeochemistry and nutrient cycling	10.2	Littoral*
	10	Environmental controls on toxin production	11.1	Bioassay
Limnocorrals/Mesocosms? (11–14)	11	Turbidity effect on primary producers	11.2	
	12	Resuspension rates from bioturbation	11.7	
	13	Carp effects on zooplankton (and does this influence algal response)	11.8	
	14	Carp effects on macrophytes	12.1	
	15	Toxin Production and N Species	13.7	Bioassay
	16	Recreational surveys	13.8	Steering Committee
Limnocorrals/Mesocosms?	17	Macrophyte role (to biogeochemistry)	14.0	
	18	Additional atmospheric deposition data	14.6	WFWQC
	19	Alternative models (PCLake – cyano/macrophyte state change)	14.9	

FUTURE DIRECTION

Limnocorrals/Mesocosms?

Carp Effects Missing

Macrophyte Effects Missing

Fish Species Sensitivity Missing

Note	#	Research ideas	Mean Ranking - Feb 2020	Topic
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