



Utah Lake Sediment–Water Nutrient Interactions Report Presentation

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Proposal workplan



- **Rational**

Sediment-phosphorus chemistry of the lake was prioritized for 2019 by the Utah Lake Water Quality Study (ULWQS) Science Panel to determine the sediment-phosphorus equilibrium, release of nutrients from the sediment, sediment oxygen demand, and related sediment chemistry in the lake.

- **Objectives**

- To understand the role of **aerobic/anaerobic** conditions in **phosphorus** release and sediment dynamics over a range of phosphorus concentrations
- To understand the role of **pH** in water column–sediment interactions and nutrient releases
- To estimate the **sediment oxygen demand** and other nutrient release (nitrogen) from sediments under current conditions

Date of experiment

The sediment core collection and incubation experiments were finished in September to minimize the temperature effect; SOD experiment was finished before mid-October.

Site 1: State Park site near DWQ buoy		
Date	# of cores	Experiment
September 12 th , 2019	12	Aerobic and anaerobic experiments
September 26 th , 2019	12+2 (prepared for low pH detect)	pH=9.5
August 14 th , 2019	12	Neutral pH
October 1 st , 2019	3 chambers (1 control +2 experiment)	Sediment oxygen demand
Site 2: Provo Bay		
Date	# of cores	Experiment
September 4 th , 2019	12	Aerobic and anaerobic experiments
September 17 th , 2019	11(1 fewer for control)	pH=9.5
September 27 th , 2019	12(experiment not conducted)	Neutral pH
October 3 rd and 14 th , 2019	3 chambers (1 control +2 experiment)	Sediment oxygen demand

Note: With sediment core collection, surface lake water was taken to replace overlying water in sediment cores

Sediment core collection



Experimental setup



SOD chamber installation



More about experimental Design

Experimental setup

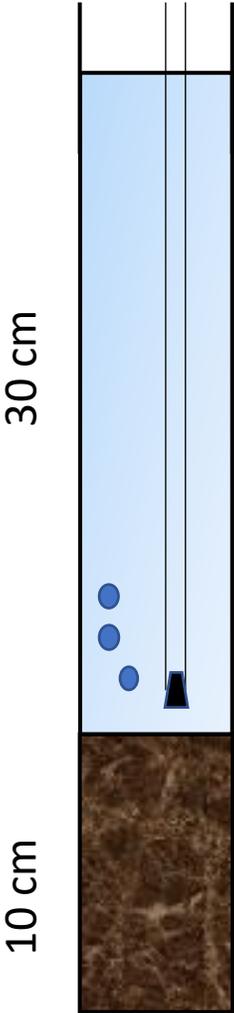


Ambient	0.5X	2X	4X
1 2 3	1 2 3	1 2 3	1 2 3

Total 12 cores

Samples were taken at 0, 12, 24 and 72 hours, pH and DO were measured using a luminescent DO probe at the time of sampling

Tubing



Data analysis

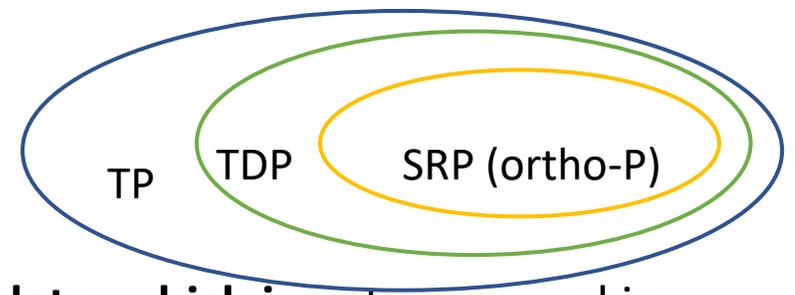
Parameters	Instrument	Sample volume (mL)	Organization
All ions	ICP-OES	7-10	BYU
Ortho-P	Spectrophotometer	3	BYU
Ammonia-N	Hach	5	UofU
Nitrate-N, nitrite-N	IC	7-10	UofU

Note: samples were filtered through 0.45 μm before analysis

Statistical analysis

- The concentrations and difference of concentrations were plotted;
- One-way Anova was used to compare among treatment;
- The rates of nutrient release (nutrient flux) was calculated

Forms of phosphorus

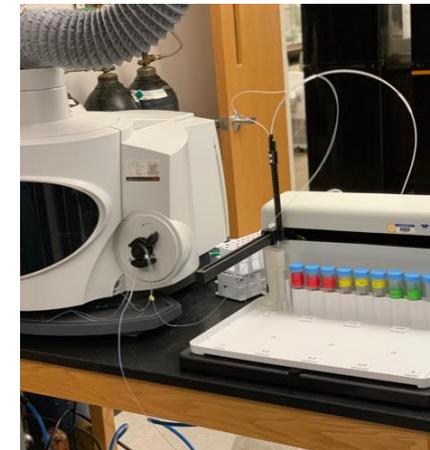


- **Total P (TP)** – All forms of **phosphorus, dissolved or particulate, which is not measured** in the study.
- **Total dissolved P (TDP)**– Dissolved form of TP, both organic and inorganic phosphorus can either be dissolved in the water or suspended, measured in the filtrate.
- **Soluble reactive P (SRP)**- A measure of orthophosphate, the filterable (**soluble, inorganic**) fraction of **phosphorus**. TP can be converted to dissolved orthophosphate with acid, persulfate, and heat.

Parameters	Instrument	Detection limit	Methods
P, Ca, K, Mg, Si, Fe, Pb...	Thermo Fisher iCAP 7400 Duo ICP-OES	Depend on major and minor ions	EPA method 200.7
SRP	Spectrophotometer for 96 well plate	0.6 mg/L	Modified Murphy and Riley, 1962.
Ammonia-N	Hach spectrophotometer Dr5000	0.015 - 2.00 mg/L NH ₃ -N	Hach ammonia TNT 830 Salicylate based ammonia chemistry
Nitrate-N, Nitrite-N	Metrohm 883 Basic IC plus	Depend on calibration curve, 0.1 mg/L in this case	EPA method 300.0 Determination of Inorganic anions by IC



Ion Chromatography



ICP-OES

Results and Discussion

Phosphorus release under

- **Condition:**

- **Aerobic:** DO was maintained above 7.5 mg/L using ...
The water column was well-mixed with aeration and ...
water surface.
- **Anaerobic:** DO was below 0.3 mg/L with pure N₂ pu ...
(We figured that high flowrate when taking samples a ...
maintain anaerobic condition).

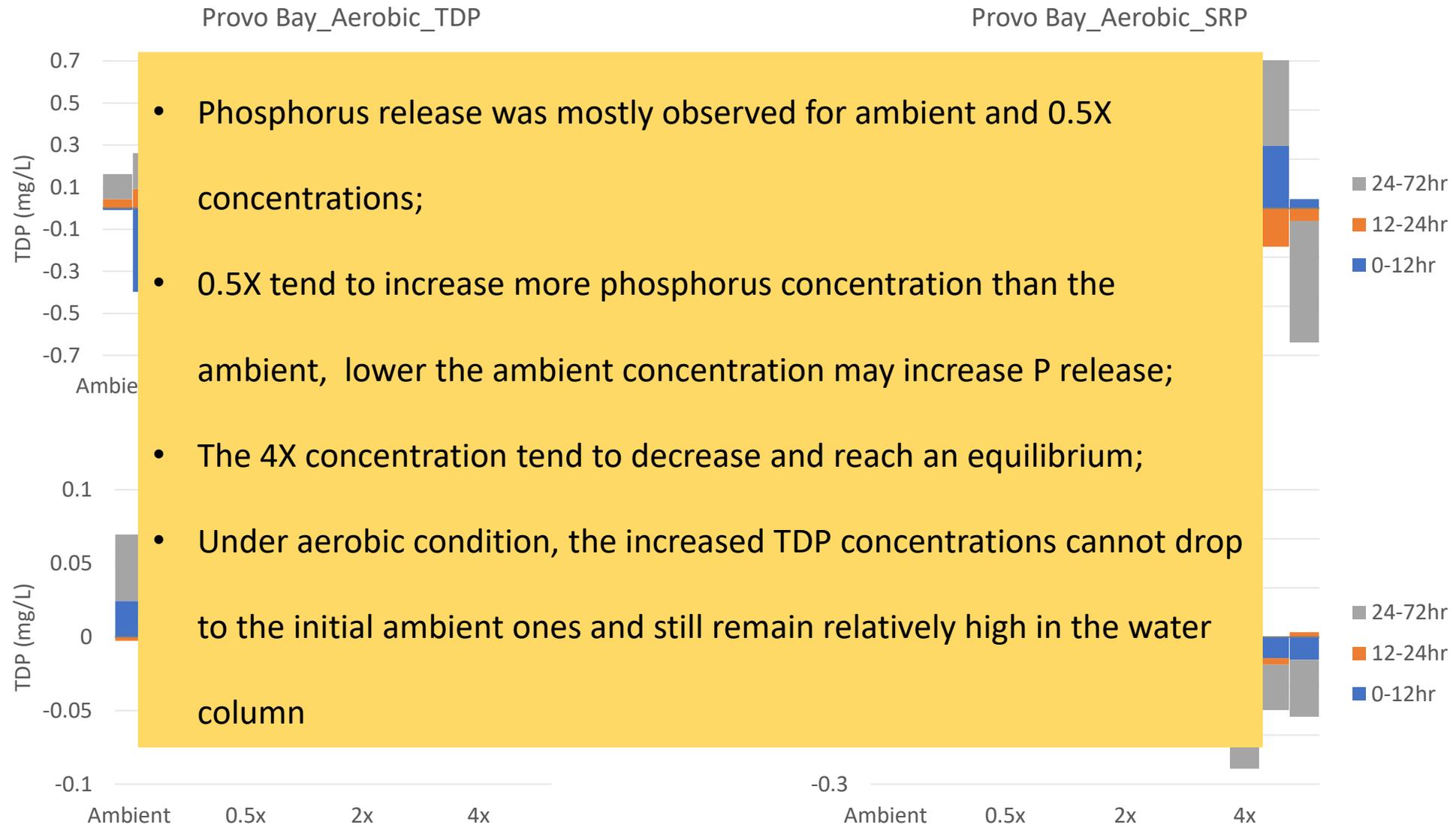
- **Challenges:**

Generally, the sediment at Provo Bay area has a layer of black organic matter that makes the coring tubing difficult to penetrate

- **Aerobic:** The pH stayed closer to the initial ones at around 8.5. No much abnormal changes have been noticed.
- **Anaerobic:** pH increased to above 9.5 at the end of experiment; we hypothesized that the pure nitrogen purged could remove CO₂ from the system and break the initial equilibrium; CaSO₄, Ca(OH)₂ and CaCO₃ could be formed under such condition together with P precipitation.



Phosphorus release under aerobic condition

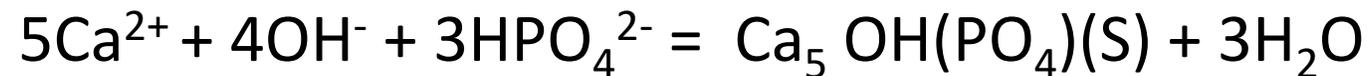


Discussion about results

- Lowering ambient phosphorus concentrations may enhance the release of phosphorus;
- The enhanced phosphorus concentration (4X) would decrease and reach equilibrium, however, the final concentrations were not as low as initial ambient ones, which indicates the increased P in water column would not completely sink into sediment under aerobic condition
- Mechanisms causing the aerobic P release/sink:
 - Usually, P releases more with relatively low dissolved oxygen concentrations;
 - Fe(III) reduction at the sediment-water interface;
 - Phosphorus can bind with Fe^{3+} to form $\text{Fe}_2(\text{PO}_4)_3$; at the same time, dissolved phosphorus in the overlying water can be adsorbed by $\text{Fe}(\text{OH})_3$ in the sediment;
 - Phosphorus release from Polyphosphate accumulating organisms (PAO)

Discussion about results

- Usually, more phosphorus is released under anaerobic conditions;
- Phosphorus bound to $\text{Fe}^{3+}/\text{Al}^{3+}$ can be released from the sediments to the overlying water;
- In our anaerobic experiments, artificially increased (2x, 4x) P concentrations in the water column decreased, likely sinking into the sediment.
- **The sink of phosphorus could be caused by:**
- Phosphorus uptake by Polyphosphate accumulating organisms (PAO);
- Due to increased pH, P could be absorbed on to precipitated CaSO_4 , $\text{Ca}(\text{OH})_2$ and CaCO_3 compounds;
- The following equation could also occur:



The change of Calcium together with Phosphorus

Change for each ion after 72 hours:
The unit of Ca²⁺ is mg/L P is mg/L

Treatment	category	Provo_aerobic	Provo_anaerobic	Buoy_aerobic	Buoy_anaerobic	Provo_high pH	Buoy_high pH	Buoy_low pH
Ambient	P	0.005	-0.692	0.049	-0.008	-0.0624	0.0056	0.1157
	Ca	-6.08	-49.04	1.12	-14.14	14.54	-24.39	-12.08
0.5X	P	0.192	-0.050	0.065	-0.017	-0.0848	0.0345	0.1420
	Ca	2.08	-36.42	0.98	-28.69	-22.91	-18.36	-5.38
2X	P	-0.014	-0.161	-0.004	-0.076	0.0232	0.0031	0.0516
	Ca	-6.61	-45.08	0.65	-8.60	-19.33	-13.16	-10.62
4X	P	-0.180	-0.354	-0.002	-0.014	-0.0461	-0.0549	-0.2573
	Ca	-2.81	-47.35	0.16	-10.72	-32.29	-26.53	-8.18

- Calcium sink occurred mostly under anaerobic conditions
- Most calcium could precipitate as some insoluble compound **with high pH and/or anaerobic condition.**
- Calcium sink was relatively more at high pH than low pH, however, they were lower than the anaerobic conditions.
- Low pH also observed relative high P release except for the 4X concentration

Calcium sink **anaerobic Provo Bay** > **anaerobic Buoy**
Calcium sink **high pH Buoy** > **high pH Provo Bay**

Calcium sink anaerobic > high pH > low pH > aerobic

Phosphorus release under alkaline and neutral pH

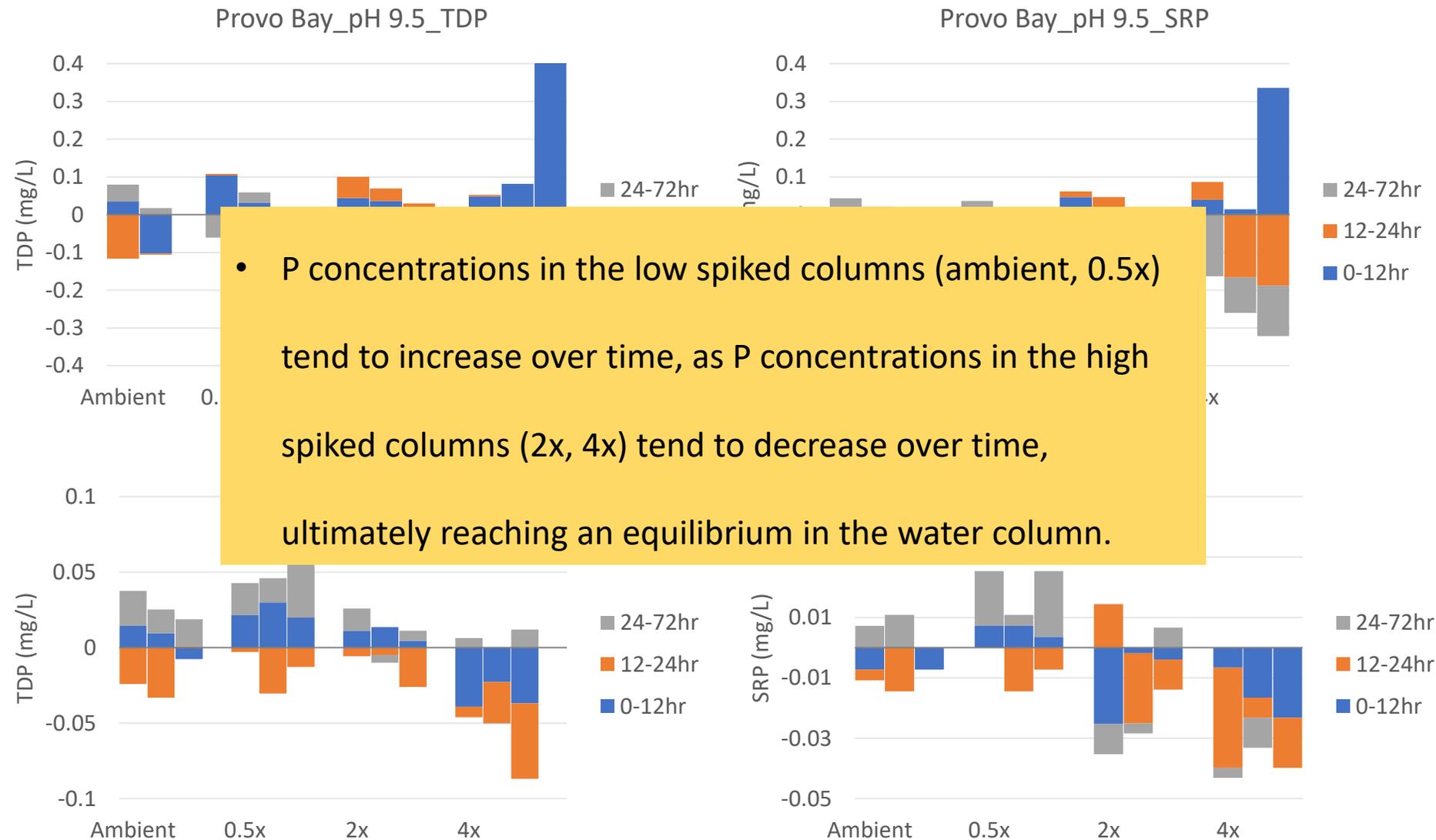
- **Conditions:**

- Similar to aerobic condition, DO was maintained above 7.5 mg/L
- The pH was adjusted initially in the replacement water before adding to the sediment cores

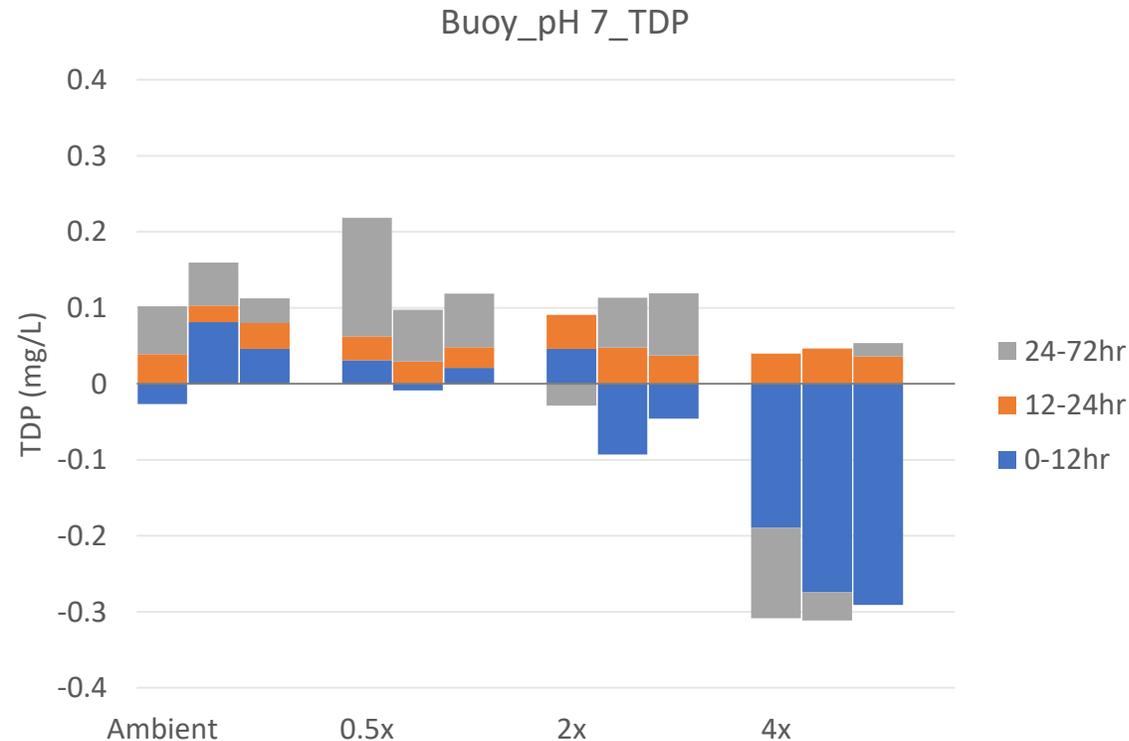
- **Challenges:**

- At both pH conditions, pH is returned to initial conditions by the strong buffering system of the ecosystem
- The alkaline condition is better maintained
- Continuous adding of acid or base is required to maintain desired pH

Phosphorus release under alkaline condition



Phosphorus release under neutral condition



- Only the columns with P increased by a factor of four see significant decrease in P concentration over time.
- Lower pH may affect the particles aggregation/cohesion behavior and release more P from the sediment.

Discussion about results

- Previous study found that the variation of pH can change the particles aggregation/cohesion behavior by altering their surface charge properties.
- The combination form of Fe-P and Al-P could exist in the sediment. At pH = 7–9, a layer of $\text{Fe}(\text{OH})_3$ protective film is formed on the surface of Fe-P, which have Fe-P stabled relatively.
- The reduction of Fe^{3+} to Fe^{2+} that results in P release from sediment occurs more strongly under extremely low redox potential and low pH (5.5) conditions.
- Fe phosphate precipitation or adsorption of P by Fe oxides or hydroxides results in low P solubility.
- Changes of pH during incubation could be due to the photosynthetic and denitrification processes.

Anova analysis

Pvalue <0.05 indicate significant difference

Site	Groups	Concentration	Mean	Standard Deviation	Standard Error	Age	Variance	Pvalue	
Provo_aerobic	Ambient					423333	0.01655457	2.5826E-19	
	0.5x					0.2495	0.01572943		
	2x					814167	0.00040637		
	4x					056475	0.0003853		
Provo_anaerobic	Ambient					254125	0.0023154		
	0.5x					0.0597	0.00019669		
	2x					174925	0.00253657		
	4x					0.5153	0.01718264		
Buoy_aerobic	Ambient					0.1754	0.00644953		9.2983E-26
	0.5x					711667	0.00073819		
	2x					789167	0.00017491		
	4x					246667	0.01019863		
Buoy_anaerobic	Ambient					113333	0.00028186		
	0.5x					164167	0.00433816		
	2x					166667	0.05753105		
	4x					656667	0.0458481		
Provo_high pH	Ambient					656667	0.0006166	7.4238E-26	
	0.5x					611667	0.00078352		
	2x					323333	0.00085409		
	4x					0.051	9.0633E-05		
Buoy_high pH	Ambient					209275	0.00225671		
	0.5x					906667	0.04642433		
	2x					0.4547	0.11264093		
	4x					270833	0.00044862		
Buoy_low pH	Ambient					933333	0.00402462		5.9849E-27
	0.5x					0.3508	0.01691459		
	2x					0.0796	0.00071613		
	4x					328825	0.01424022		

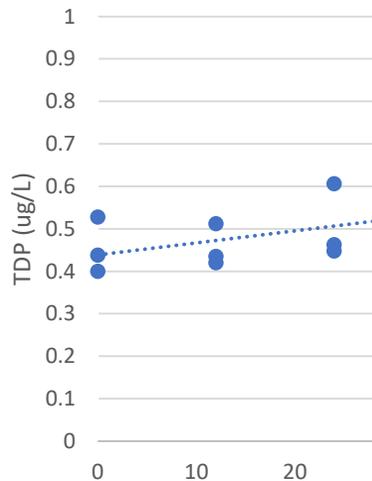
- Using one-way anova, significant differences were observed for treatment with different initial concentrations or other environmental factors (aerobic, anaerobic) (p<0.05 anova);
- P concentrations were higher for aerobic (0.08 - 1.22 mg/L) than anaerobic condition (0.06 – 0.45 mg/L);
- The Provo Bay site has higher P concentrations (0.18-1.22 mg/L) than the buoy site (0.06 – 0.31 mg/L).
- For the pH effect, Buoy site has higher P concentrations with decreased pH (0.17 – 0.32 mg/L) than increased pH(0.04 -0.08 mg/L).

Nutrient flux

Nutrient flux

Nutrient flux (g)

Where, dC_e/dt = change in experimental chamber
 $D = \frac{V}{A}$ = depth of ambient

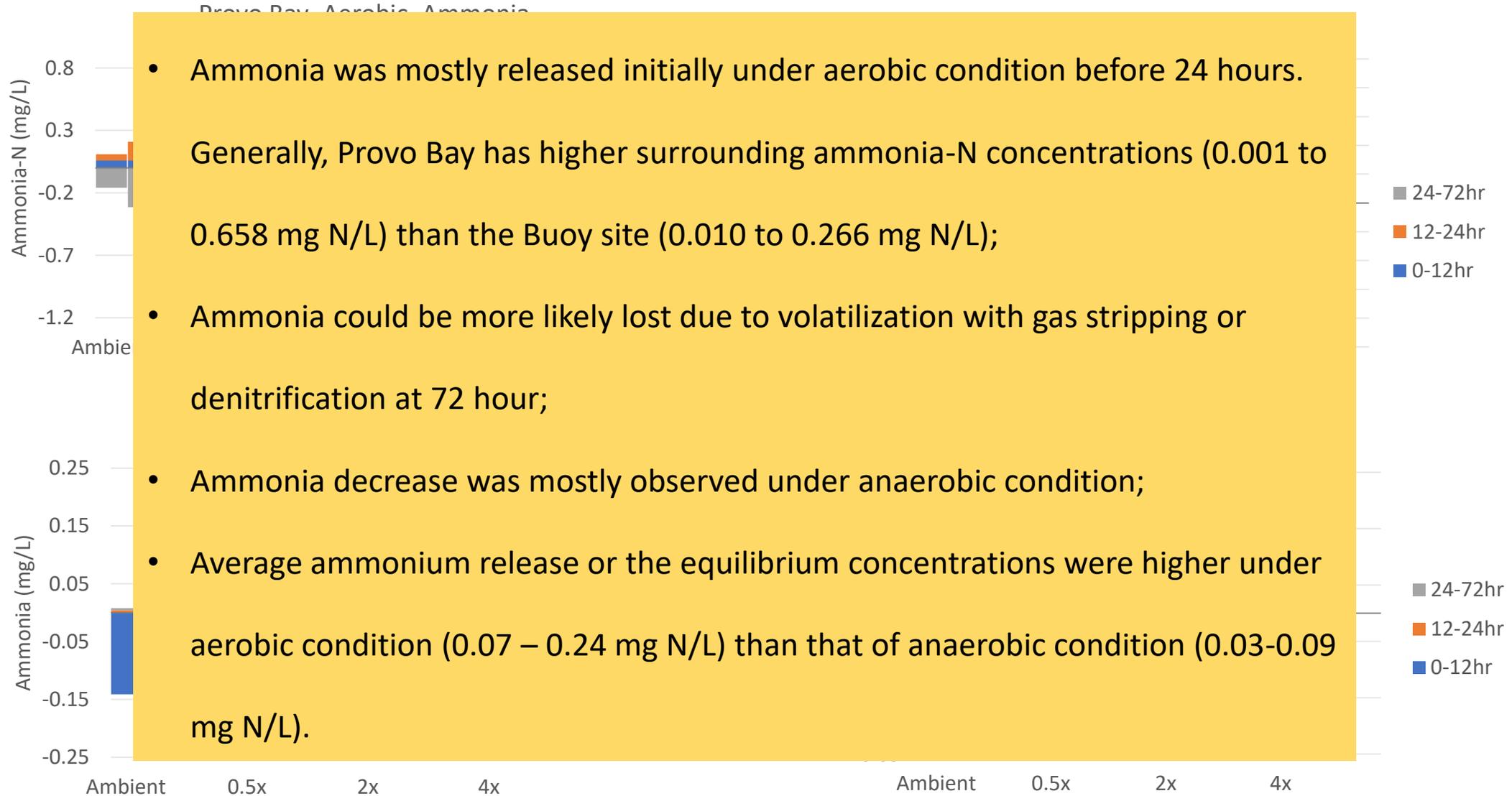


- Phosphorus sink was observed more under anaerobic than aerobic condition;
- Provo Bay generally observed higher release/sink flux (-51.84 to 201.6 mg/m³/d) than the buoy site (-5.76 to 5.76 mg/m³/d);
- The highest release and sink were observed at Provo_aerobic_0.5X (201.6 mg/m³/d) and Provo_anaerobic_4X (-51.84 mg/m³/d), respectively.
- Sediment has high potential to release P at lower pH; The buoy site has the highest P release at 0.5X_low pH than any other conditions for the same site.

value	R square	nutrient flux (mg/m ³ /d)
0.0007	0.0248	5.04
0.028	0.381	201.6
0.0008	0.0087	5.76
-0.0019	0.0649	-13.68
-0.0013	0.0837	-9.36
0.0002	0.0077	1.44
-0.0038	0.263	-27.36
-0.0072	0.3744	-51.84
0.0006	0.7332	4.32
0.0008	0.7599	5.76
-0.0002	0.035	-1.44
-0.0002	0.0493	-1.44
0.00005	0.0057	0.36
-0.00007	0.0228	-0.504
0.000007	5.00E-05	-0.0504
-0.0008	0.1191	-5.76
-0.0007	0.1679	-5.04
-0.001	0.0803	-7.2
0.0001	0.0156	0.72
-0.0018	0.1487	-12.96
7.00E-05	0.0205	0.504
0.0004	0.4436	2.88
3.00E-07	6.00E-07	-0.00216
-0.0006	0.4108	-4.32
0.0015	0.7319	10.8
0.002	0.7687	14.4
0.0009	0.3065	6.48
-0.0024	0.3296	-17.28

The water column depth is around 0.5m

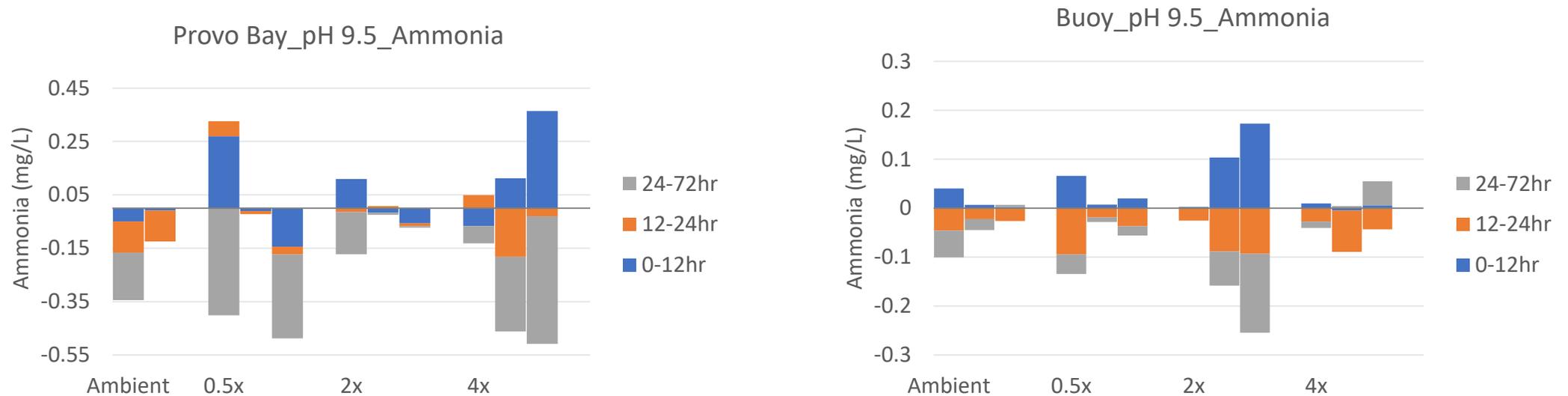
Ammonia release under aerobic condition



Discussion about results

- Like Phosphorus release, ammonia-N release is also correlated with trophic status;
- Higher DO levels could activate nitrifying bacteria, leading to high rates of biological ammonia oxidation and coupled nitrification–denitrification;
- However, the nitrate concentration does not change significantly. The volatilization of ammonia could be another way of it losing from the system;
- Under aerobic condition, it is commonly realized that hypoxic conditions ($\text{DO} < 2.0 \text{ mg L}^{-1}$) can trigger the release of ammonium due to anaerobic fermentation from nitrogen-rich sediments to the overlying water;
- Struvite formation may occur, which is $1:1:1 \text{ Mg:NH}_4:\text{PO}_4$.

Ammonia release under high pH



Results and discussion

- For pH changes, the ammonia-N release was also higher for Provo Bay (0.06-0.21 mg N/L) than that of the Buoy site (0.05-0.08 mg N/L) probably due to different mineralogy compositions.
- Similar to aerobic condition, the ammonia release slightly increased and then decreased.
- Percentage of un-ionized ammonia and toxicity were increased under high pH.
- The increased pH and toxicity may inhibit bacterial activities and cause more ammonia volatilization.

Ammonia volatilization



- High pH is an important factor causing volatilization

pH	8.0	8.4	8.8	9.2	9.6	10.0
Percent	3.81	9.04	19.98	38.55	61.17	79.83

Temperature was at 20 °C for percentage of unionized-ammonia

Emerson, Kenneth, et al. "Aqueous ammonia equilibrium calculations: effect of pH and temperature." *Journal of the Fisheries Board of Canada* 32.12 (1975): 2379-2383.

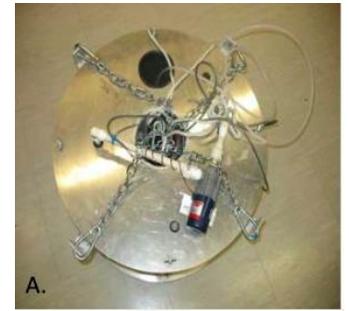
Some percentages of ammonia loss were higher than listed in the table.

It could be due to continuous air stripping or other discussed pathways.

Percentage of ammonia removal

Treatment	Ambient	0.5X	2X	4X
Provo_aerobic	97.092	96.525	96.174	97.441
Provo_anaerobic	91.879	70.864	69.723	90.775
Buoy_aerobic	73.795	88.013	81.248	47.144
Buoy_anaerobic	-34.417	55.856	28.566	38.618
Provo_high pH	90.932	80.671	69.375	90.062
Buoy_high pH	64.833	74.230	76.292	42.772

Sediment oxygen demand



- **Definition:** Rate of oxygen removed from sediment due to the decomposition of organic matter in sediment.

- SOD chamber:

$$SOD = 1.44 \left(\frac{V}{A}\right)b$$

Where, SOD = sediment oxygen demand (g/m²day)

V = volume of SOD and WC chambers

A = sediment area within the chamber (0.16 m²) (Hogsett, 2015)

b = slope of oxygen depletion curve (mg/L min)

- Measured SOD can be corrected to 20 °C:

$$SOD_{20} = \frac{SOD}{1.065^{(T-20)}}$$

Chambers	SOD (g/m ² day)	Corrected SOD at 20 C
Site 1: State Park site near DWQ buoy		
Water column	-0.356	-0.488
SOD	-2.086	-3.065
	Final SOD	
Site 2: Provo Bay		
Water column	0.0396	0.060
SOD	-1.197	-1.822
	Final SOD	-1.882

It's surprising that the open water site has higher SOD results than the Provo Bay site since Provo Bay is known for higher organic content. More sampling needs to be conducted to have an accurate SOD estimate.

Questions?



Special thanks to DWQ's sampling team for lending us the boat and assisting with core collection.