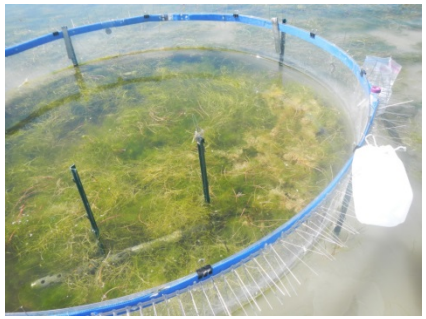
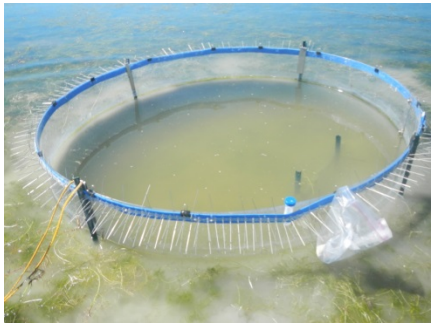
Willard Spur: Nutrient Uptake and Cycling





Science Panel

October 22, 2015

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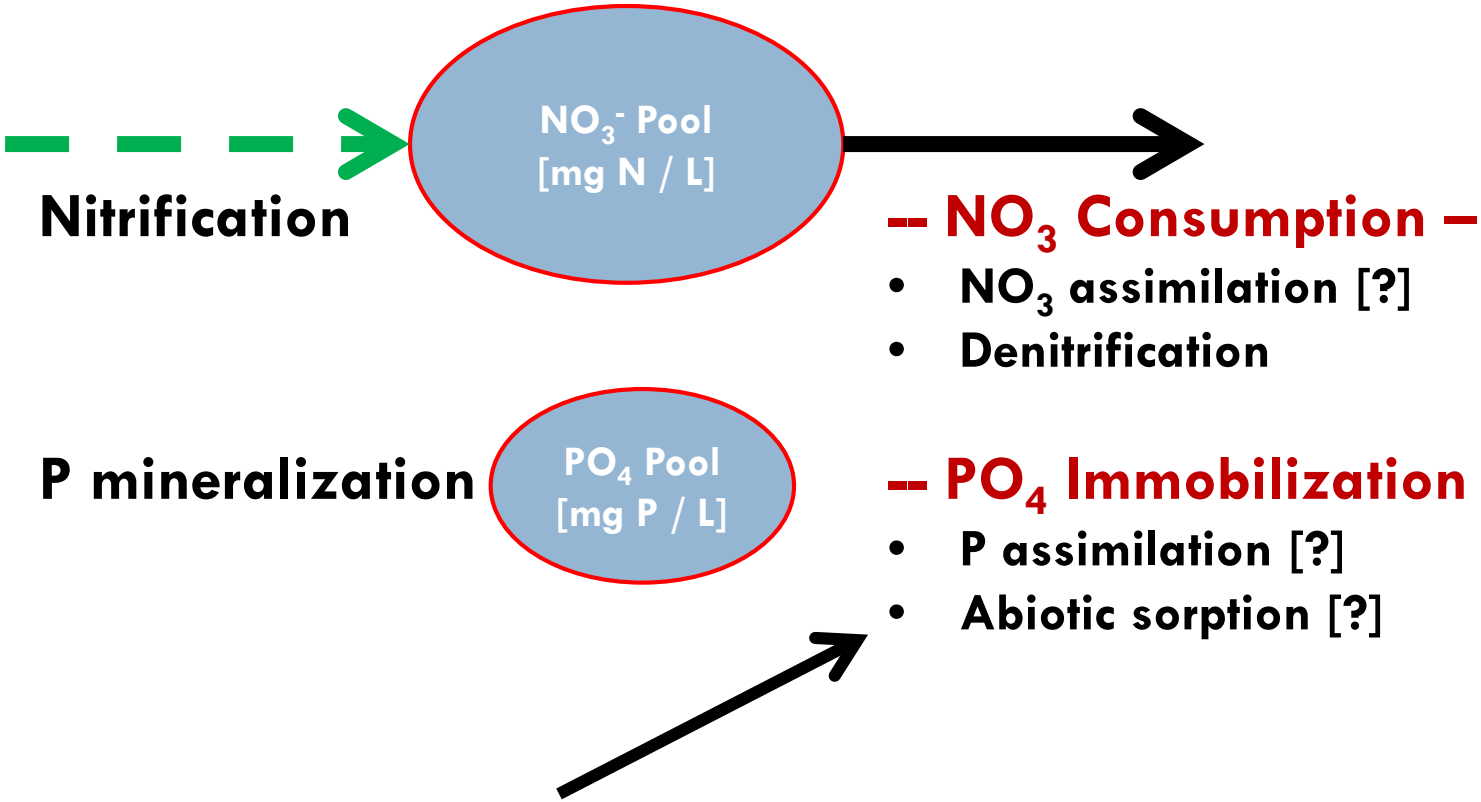
Study Objectives

What is the role of SAV (plus their epiphytes) relative to phytoplankton on nutrient uptake and cycling in Willard Spur?

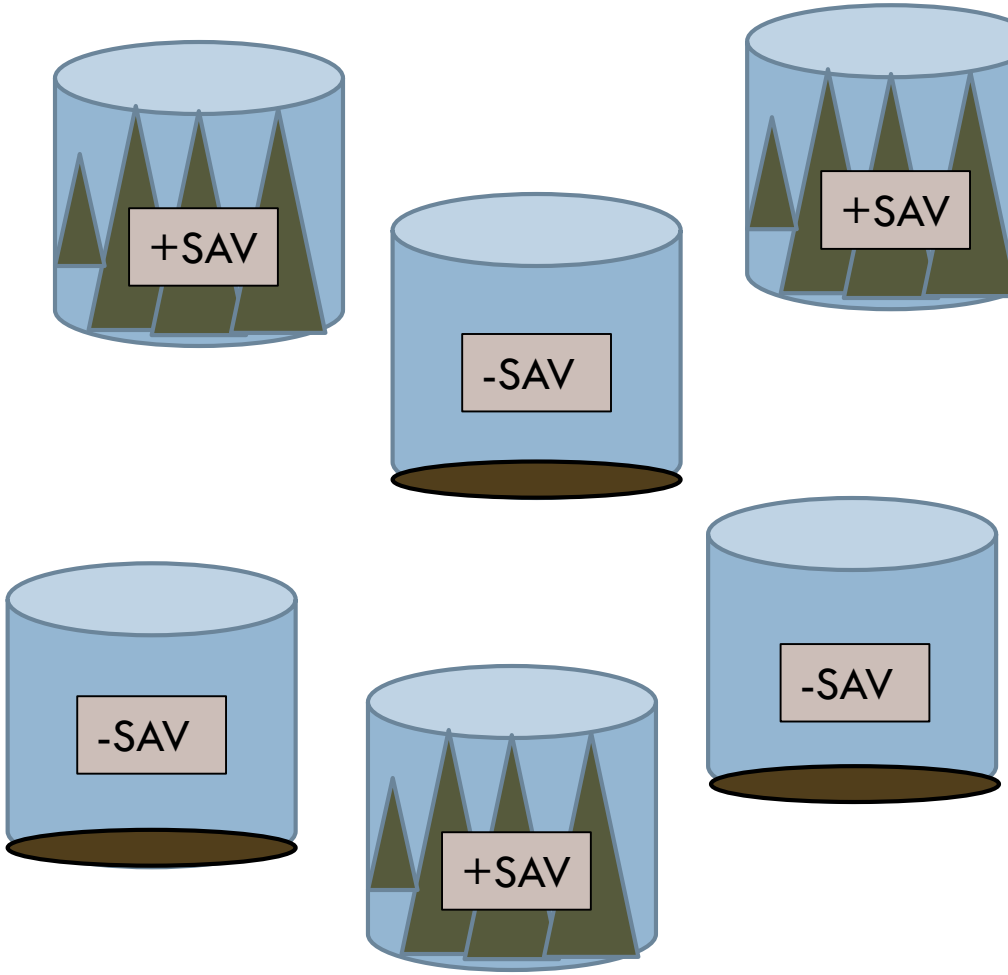
- What is the uptake rate of nitrate and phosphate?
- How does uptake vary seasonally?
- Can we use these uptake measurements to estimate the assimilative capacity of the Spur?
  - Is so, what is the remaining assimilative capacity?
  - Are there circumstances where the discharge contributes to exceeding the assimilative capacity?
- What is the evidence for N vs. P limitation? Does nutrient deficiency vary seasonally?

Background



Collectively = Uptake

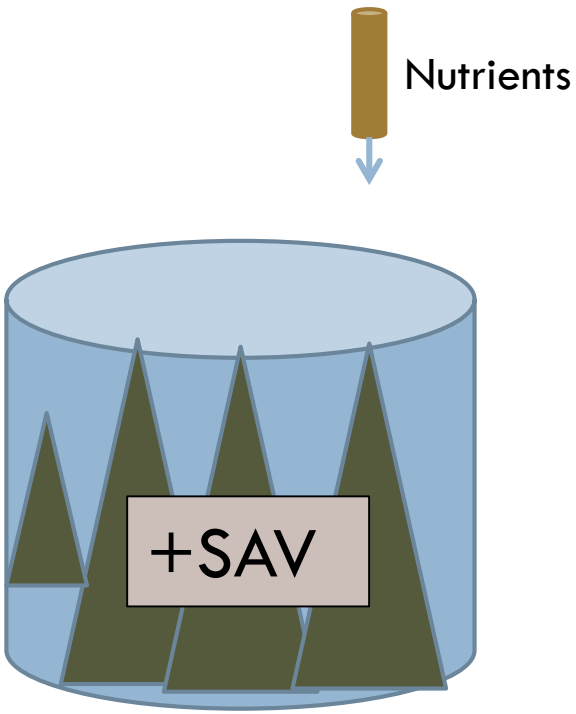
Methods: Experimental Design



- Treatment = -SAV (N=3)
- Control = +SAV (N=3)

- Clear Water Phase
- Green Water Phase
  - *SAV not physically removed*

Methods: Experimental Design



Water Samples

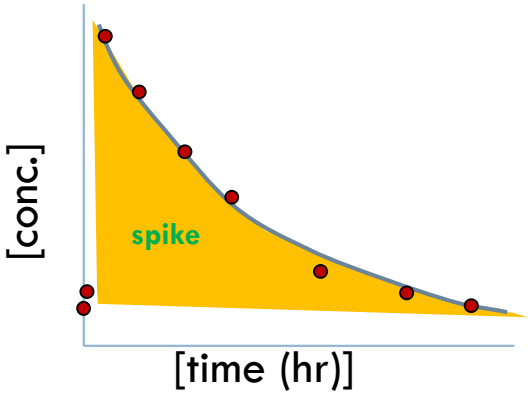
- Time zero (T0) X 2
- Every 15-minutes for 2 hours
- Every 30-minutes for 4 hours

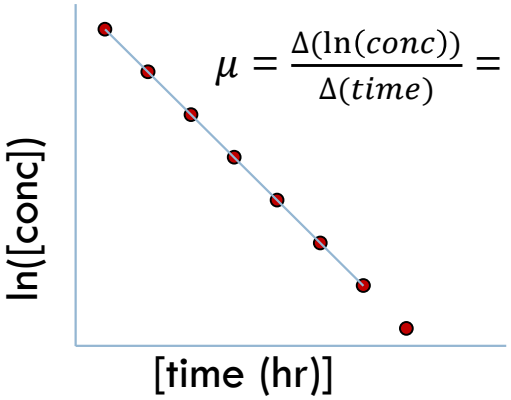
Photosynthetic Organic Matter

- Composites @ end of experiments
- Separated:
  - *Seston (periphyton)*
  - *SAV*
  - *SAV epiphytes*
  - *Phytoplankton (Flocc)*

Methods: Uptake Rates

Calculate Uptake Rate Constants





$$\mu = \frac{\Delta(\ln(conc))}{\Delta(time)} = \text{- Rate} = \text{-k}$$

Then…

$$Rate = \frac{(-k) \cdot Vol \cdot (T_0 Pool)}{Area} = \frac{1}{hour} \cdot \frac{m^3}{m^2} \cdot \frac{g(X)}{m^3} = \frac{g(X)}{m^2 \cdot hour}$$

Uptake: Clear Water Phase

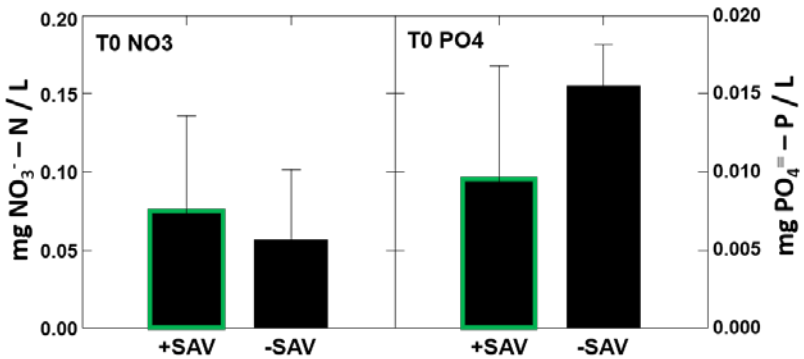
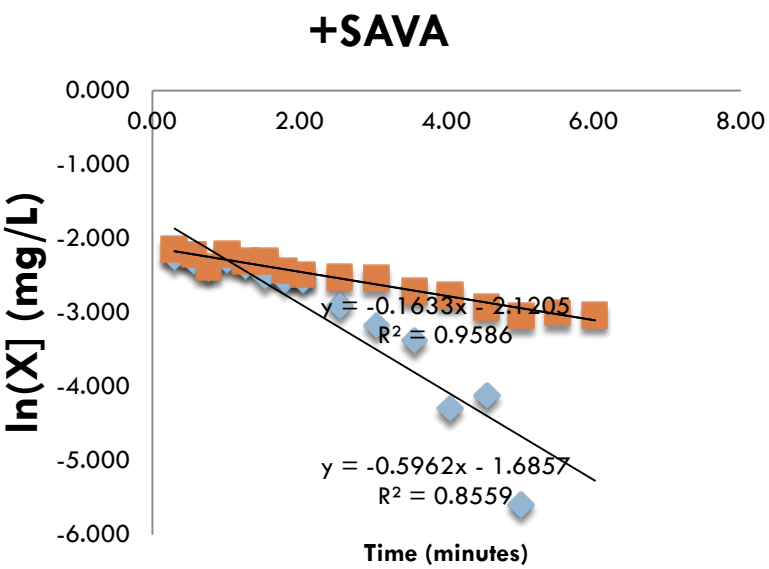


Figure 4. Initial (T0) nitrate (Panel A) and phosphate (Panel B) concentrations showing nonsignificant difference in background nutrient concentrations between treatment (-SAV) and control (+SAV) mesocosms.

- Initial (background) nutrient concentrations were very low:
  - PO_4: 0.011 (±0.006) mg-P/L
  - NO3: 0.048 (±0.022) mg-N/L

- ***Better fits for +SAV than –SAV***
  - +SAV, r^2 = 0.86-0.89
  - -SAV, r^2 = 0.45-0.62



Uptake: Clear Water Phase

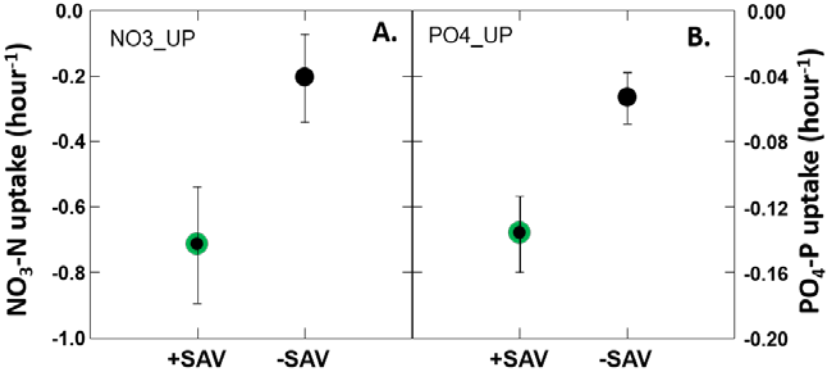


Figure 5. A comparison of clear water uptake rate constants (more negative = more rapid uptake) observed between controls (+SAV) and controls (-SAV) for both nitrate (Panel A) and phosphate (Panel B).

- Uptake was 3X faster with SAV
- Nitrate uptake was faster (3-4X) than phosphate

	NO_3		PO_4	
	k	MRT	k	MRT
+SAV	-0.72/day	1 day	-0.14/day	5.1 days
-SAV	-0.21/day	3.4 days	-0.05/day	13 days

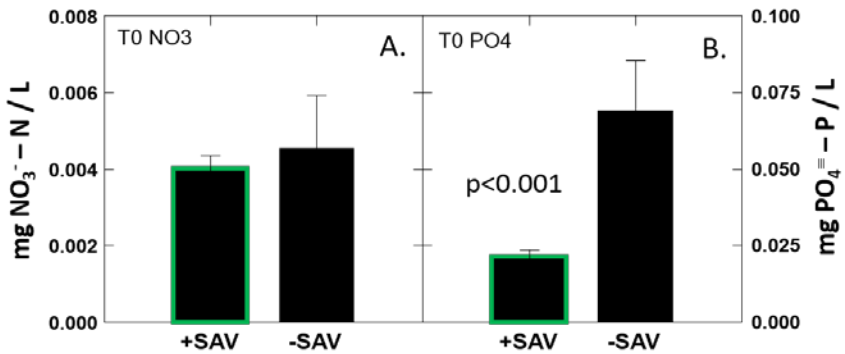
Green Water Phase

Different Experimental Conditions

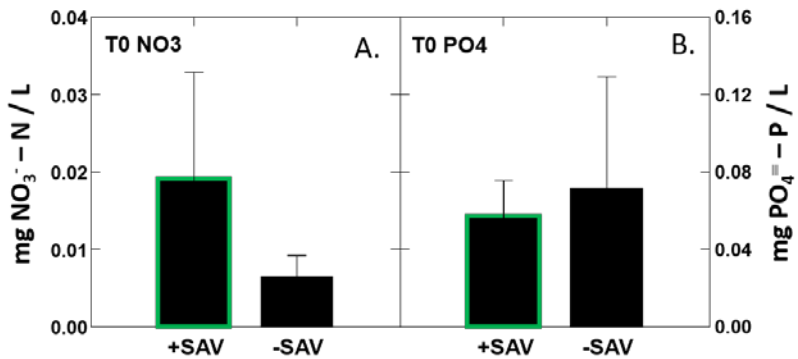
Different Beneficial (if not designated) Use

Uptake: Green Water Phase

Daytime, Green Water Phase: Initial Nutrient Pools



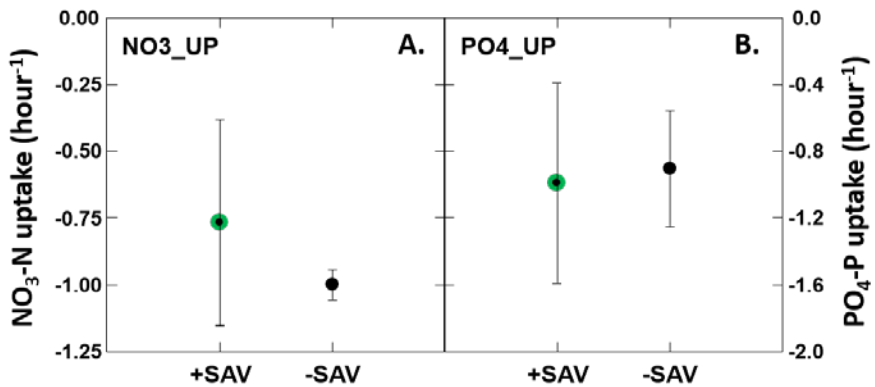
Nighttime, Green Water Phase: Initial Nutrient Pools



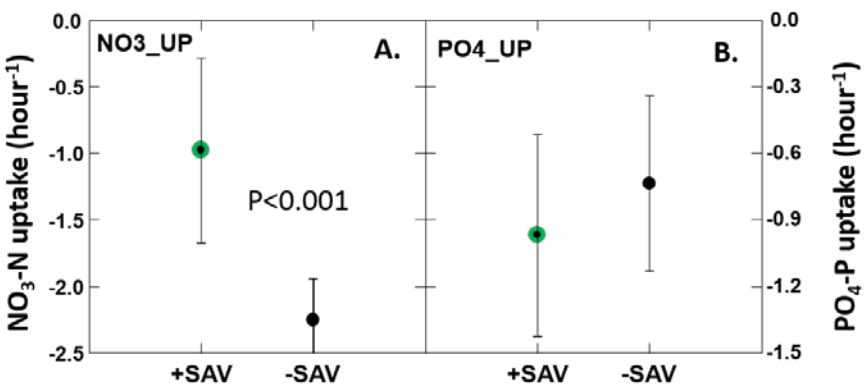
- Both NO_3 and PO_4 were higher later in the year
  - *N still very low*
  - *P is moderate (Hoven, et al. 0.05-0.06 mg/L)*
- During the **day,** PO_4 was lower in +SAV
- During the **night,** NO_3 was lower in -SAV

Uptake: Green Water Phase

Daytime, Green Water Phase: Uptake Rates

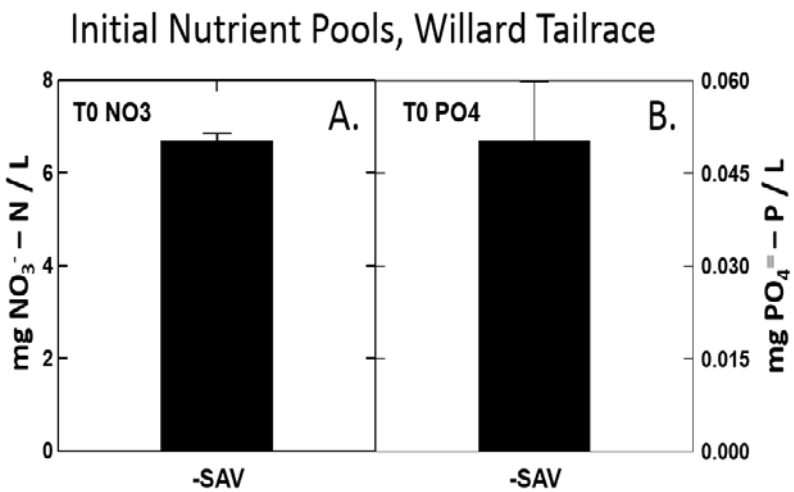


Nighttime, Green Water Phase: Uptake Rates



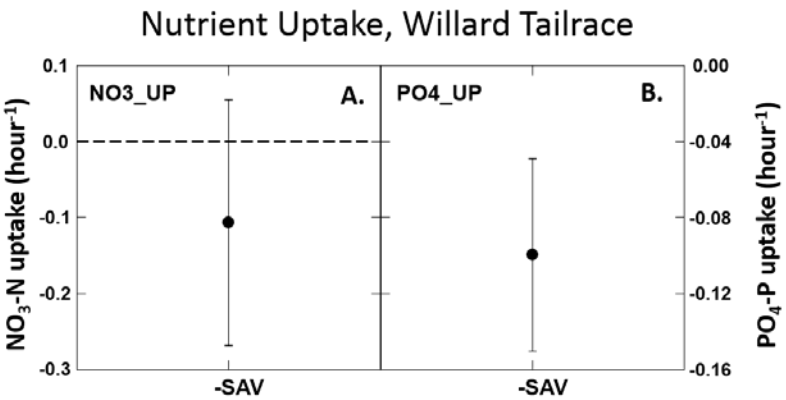
- Uptake was generally faster later in the year
- Rates were similarly fast for N and P, except…
- Nitrate rates at night were smoking fast!

Uptake: Tailrace



- Background phosphate was about the same as the open waters, but nitrate was wicked high!
  - NO_3 = 6.7 mg-N/L
- Consequently, we did not get much of a bump with additions (~5%)

Uptake: Tailrace



- Only one nitrate showed a statistically significant decline over time
- Uptake was generally slower for both N and P than in the open water

Does SAV also play a role in keeping carp-related turbidity under control?

Uptake Summary

Table 3. Summary of experimental conditions for each uptake experiment and uptake velocity estimate for nitrate and phosphate.

			Phosphate		Nitrate	
Phase	Treatment	Volume	Rate Constant	MRT	Rate Constant	MRT
		m3	/day	days	/day	days
Clear Water	+SAV	1.24	-0.137	5.1	-0.716	1.0
Clear Water	-SAV	1.24	-0.054	13.0	-0.206	3.4
Green Water, Daytime	+SAV	0.14	-0.991	0.7	-0.768	0.9
Green Water, Daytime	-SAV	0.14	-0.904	0.8	-0.999	0.7
Green Water,Nighttime	+SAV	0.09	-0.969	0.7	-0.978	0.7
Green Water,Nighttime	-SAV	0.09	-0.735	0.9	-2.25	0.3
Tailrace	-SAV	1.74	-0.0995	7.0	-0.106	6.5

- Early, SAV probably primarily plays a role via primary production
- Later in the year, SAV plays a role with the release of nutrients
  - Increased importance of heterotrophic uptake?

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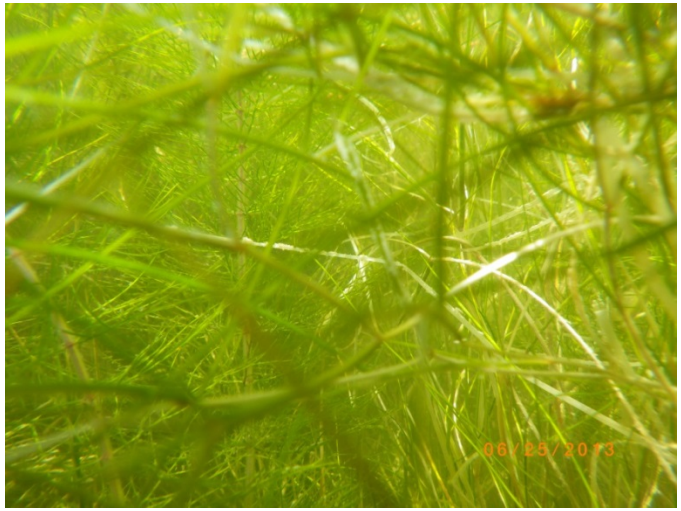
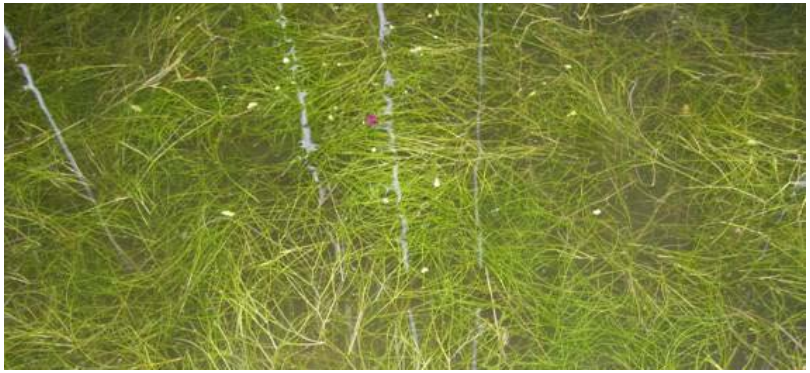
- What are the potential consequences of losing SAV?

Photosynthetic Organic Matter



- Proportion of epiphytes on SAV was greater in later (18%) as opposed to earlier (3%) experiments
- The sediment (phytoplankton) samples were equally abundant
- Phytoplankton did not differ between +SAV and -SAV

Photosynthetic Organic Matter



- C:N and C:P in SAV tissue was much higher in the Green Water Phase
  - Evidence of sequestration to tubers?

- The N in periphyton increases while P decreases
  - P-limitation? (next slide)

Nutrient Limitation

Ranges from literature:

Table 1. Published rates for using molar C:N:P from phytoplankton to infer algae growth rates and nutrient limitation and water column ratios as supporting evidence.

		Nutrient Limitaton[1]					Algae Growth Rate[2]	
Molar Ratio	Medium	Nutrient	No Deficiency	Moderate Deficiency	Extreme Deficiency	Deficient	Low	High
C:N	Algae	N	<8.3	8.3-14.6	>14.6		20-25	5-7
C:P	Algae	P	<129	129-258	>258		500-1000	75-150
N:P	Algae	P	<22			>22	100-150	10-20
N:P	Water[3]	N	>30	8-30	<8			
N:P	Water[3]	P	<8	8-30	>30			

[1]In Gilford and Hecky 2000 from Healy 1995, [2]In Hecky and Kilham 1988, from Goldman 1980,

[3]Moss et al. 2013

Nutrient Deficiency

Table 2. A comparison of measured C:N:P in organic matter pools against literature screening values (see Table 2) for nutrient limitation and algae growth rates.

Pool	Molar Ratio	Clear Water Phase		Green Water Phase		Comment
		+SAV	-SAV	+SAV	-SAV	
Seston (phytoplankton)	N:P	4.29 (±1.31)	6.21 (±0.41)	45.[illegible] (±12.[illegible]8)	38.37 (±8.76)	P deficient
	C:N	12.5 (±2.74)	10.55 (±1.53)	9.67 (±1.25)	8.40 (±1.06)	N deficient
	C:P	51.33 (±6.77)	65.61 (±11.33)	434.62 (±93.62)**	317.67 (±59.83)**	P deficient
Epiphytes	N:P	14.72 (±2.74)++		10.36 (±6.04)++		High Growth Rate
	C:N	11.78 (±0.45)		37.30 (±2.20)**		N deficient
	C:P	173.29 (±23.12)		379.97 (±18.45)**		P deficient
SAV[1]	N:P	78.94 (±22.[illegible]7)		51.04 (±15.79)		P deficient
	C:N	[illegible].34 (±0.33)		32.99 (±1.85)**		N deficient
	C:P	1126.05 (±309.66)**		1701.11 (±590.60)**		P deficient
Sediment (periphyton)	N:P	24.24 (±4.67)	35.57 (±8.40)	23.99 (±20.24)	11.07 (±6.11)++	P deficient
	C:N	**30.12 (±4.51)****	**26.42 (±2.50)****	**21.55 (±7.18)++**	**15.96 (±1.77)****	N deficient; High growth
	C:P	**718.81 (±88.72)****	**941.44 (±259.70)****	**431.92 (±195.26)****	**182.62 (±118.68)****	P deficient

[1]While algae ratios are not directly comparable to SAV, they are applied here as a point of reference.
Red text signifies P deficiency, whereas blue text signifies N deficiency. **Indicates strong, as opposed to moderate deficiency.
++Indicates high growth rate.

- Nutrients, both N and P, are generally more limiting later than earlier in the season
- The exception is periphyton (sediment), which seems to indicate severe N and P limitation throughout the growing season

Scaling: Key Assumptions

Uptake Rate Constants

To address spatial variability:

- +SAV uptake rate if water >20 cm deep, otherwise –SAV otherwise

And spatial variability:

- Clear water rates from June1 through July 15th
  - For both daytime and nighttime
- Green water rates from July 15th through September
  - Nighttime = 12 hours, Daytime = 12 hours

Scaling: Key Assumptions

Background Conditions

- Used T0 (background at start of experiment) as estimate of background conditions
- To address total vs. dissolved disconnect we used the 90th percentile from open water measurements (conservative assumption):
  - TP = TDP
  - NO3 = TN * 0.08

Scaling: Context Matters

Trip	TRT	T0-N	T0-P	NO3-UP	NO3-UP (1/day)	MRT - NO3-N	Depth (cm)	MESO-Vol	NO3-U
1	+SAV	0.075	0.010	-0.72	-17.18	0.968	43.5	1.24	0.562
1	-SAV	0.057	0.016	-0.21	-4.95	3.358	43.5	1.24	0.122
2	+SAV	0.004	0.021	-0.77	-18.43	0.903	4.8	0.14	0.004
2	-SAV	0.005	0.069	-1.00	-23.98	0.694	4.8	0.14	0.005
3	+SAV	0.019	0.057	-0.98	-23.47	0.709	3.2	0.09	0.014
3	-SAV	0.006	0.072	**-2.25**	**-54.04**	**0.308**	**3.2**	**0.09**	**0.011**
4	-SAV	6.677	0.050	**-0.11**	**-2.55**	**6.529**	**60.8**	**1.74**	**10.336**

- The volume makes a difference: in mesocosms and the Spur
- Background concentrations make a difference

As they should!

Stepping it up…

- Compared daily uptake vs. daily input (loads)

- How often did daily load exceed assimilative capacity?
  - Nitrate
    - 7.3% (26/352) – All at end of growing season
  - Phosphate
    - 10.7% (38/352) – All early in 2011
- What is the average assimilative capacity?
  - Nitrate: 25,888 lbs.
    - Among days with deficit? **-119 lbs.**
  - Phosphate: 1,791 lbs.
    - Among days with deficit? **-546 lbs.**

What about the future?

- Added the load from plant at design capacity and without nutrient treatment (see load report):
  - High: N = 30 mg/L, P = 5 mg/L (500#/day & 83 #/day)
  - Moderate: N = 20 mg/L, P = 4 mg/L (334#/day & 67 #/day)
- On days where uptake < loads, allow nutrients to start accumulating from background conditions
- Would the concentrations ever exceed thresholds of concern?
  - *Hoven et al.* experiments:
    - N = 1-1.1 mg/L, P = 0.05 mg/L

What about the future?

High (Worse Case) Scenario

- P from this scenario never causes an exceedance, but
  - Background, late season values are already close!

- N was exceeded in the late season of 2012 & 2013, but
  - This only occurred once the tailrace was isolated from the open waters of the Spur

What does this mean?

- Current conditions **do not** suggest that the discharge poses a problem
  - **Plenty of assimilative capacity** for most of the growing season, but
  - This is **less true at the end, during dry years**

- Future conditions that might be a concern?
  - **Loss of SAV**
    - Would cause a reduction in assimilative capacity
    - We do not know the cumulative effects of stressors
  - **Loss of hydrologic connection to GSL**
    - Potential for year-to-year increases
  - **Plant at capacity and not addressing nutrients**
    - We did not see a problem, but it was close!

Questions?

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