Diurnal vertical Migration of Cyanobacteria and Chlorophyta in eutrophied shallow freshwater lakes

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Motivation

Harmful algae blooms (HAB) can affect health:

- Skin rash, nausea, vomiting, Liver damage, paralysis

HAB typically occur during summer, varying toxicity

- Weather, Fertilizer (PO_4)
- Lake characteristics

Lake Erie

- US Summer 2014
- Drinking water ban
  for 500,000 people

Prediction: Smartphone App Model (Verhulst, ΔT, PO_4)
[Android, iOS]

Smartphone prediction of HAB

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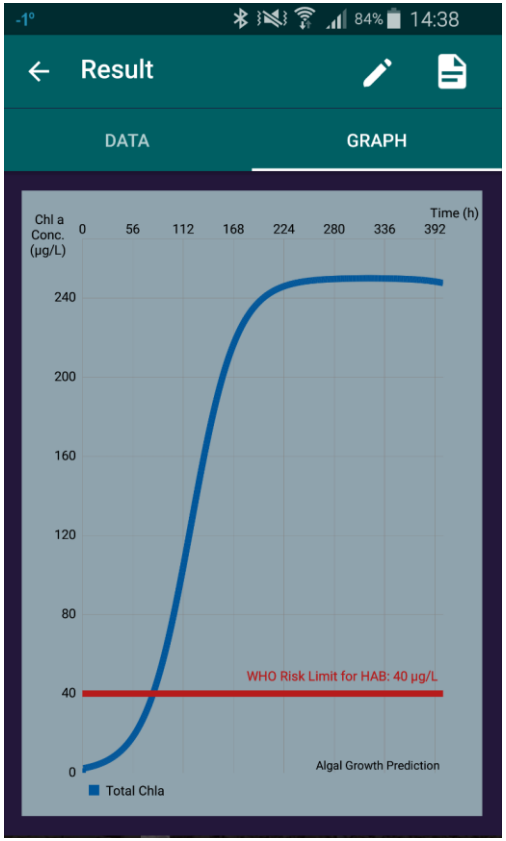
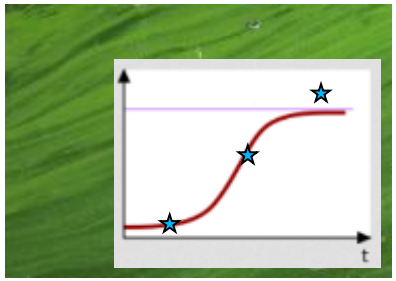
Easy to access input values:

- Surroundings
- Temperature
- Lake Depth
- Secci Depth
- Test strips
  - PO_4
  - DO



Validation
Refinement
Data Mining

Prediction output



Prediction model for HABs: Flow Chart

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Input

Cy Chl a (µg/L) | Tot Chl a (µg/L) | Surf. Temp | SD (m) | DO (%)

$$Tot = -6.4775 + 21.6396/SD + 0.0006*DO^2$$

$$Cy = 0.409 + 17.6979/SD - 0.7486*T_S$$

Input conversion

direct: Chl a (µg/L)

estimated: Chl a (µg/L)

Verhulst Parameter

N_{CUR} (µg/L)

Carrying capacity
K [K_{max}=250µg/L and 200µg/L]
(depending on PO_4)

Growth rate
r_0 [µ]
(depending on
ΔT and PO_4, T and
Light availability)

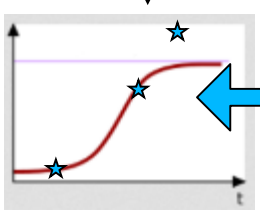
Verhulst

$$N_t=(N_0*k)/(N_0+(k-N_0)*\exp(-r_0*t))$$

with t = 0,24,48, …,192

Starting value
N_0 = 5µg/L

output



$$t = -\frac{1}{r_0}\log\left(\left(\frac{1}{K-N_0}\right)\left(\frac{N_0 * k}{N_{IN}} - N_0\right)\right)$$

Lake Monitoring Scedule

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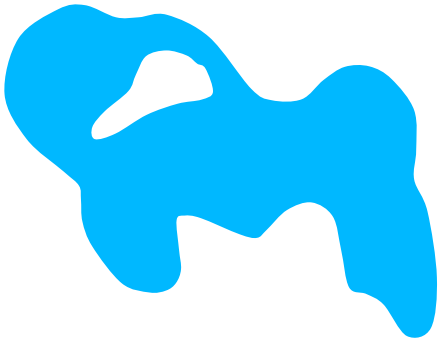
Shortterm Study

- 24 hr depth profiling 0 - 0.1 - 0.5 -1- 2 m (n=4) in 2 hr increments
  - Chl a (*Chlorophyta, Cyanobacteria*)
  - 0.1 and 2 m: Light + Temp. (n=1), PO_4-P (n=4)

Lake Stadtgraben, Germany
Spring (May 11th)
Fall (Aug 11th)

Area 24.941 m^2
L: 55 m
W: 25–70 m
mesotrophic

Lake Russo, WI, USA
Fall (Aug 11th)



Area 89.031 m^2
L: 592 m
W: 238 m
oligotrophic

Longterm Study

Lake Stadtgraben

- weekly depth profiling 0,1,2,3 m (n=4) (a.m.)
  - Chl a, Nutrients, Temperature, Light

Longterm Sampling Strategy: Eutrophied shallow lake (Germany)

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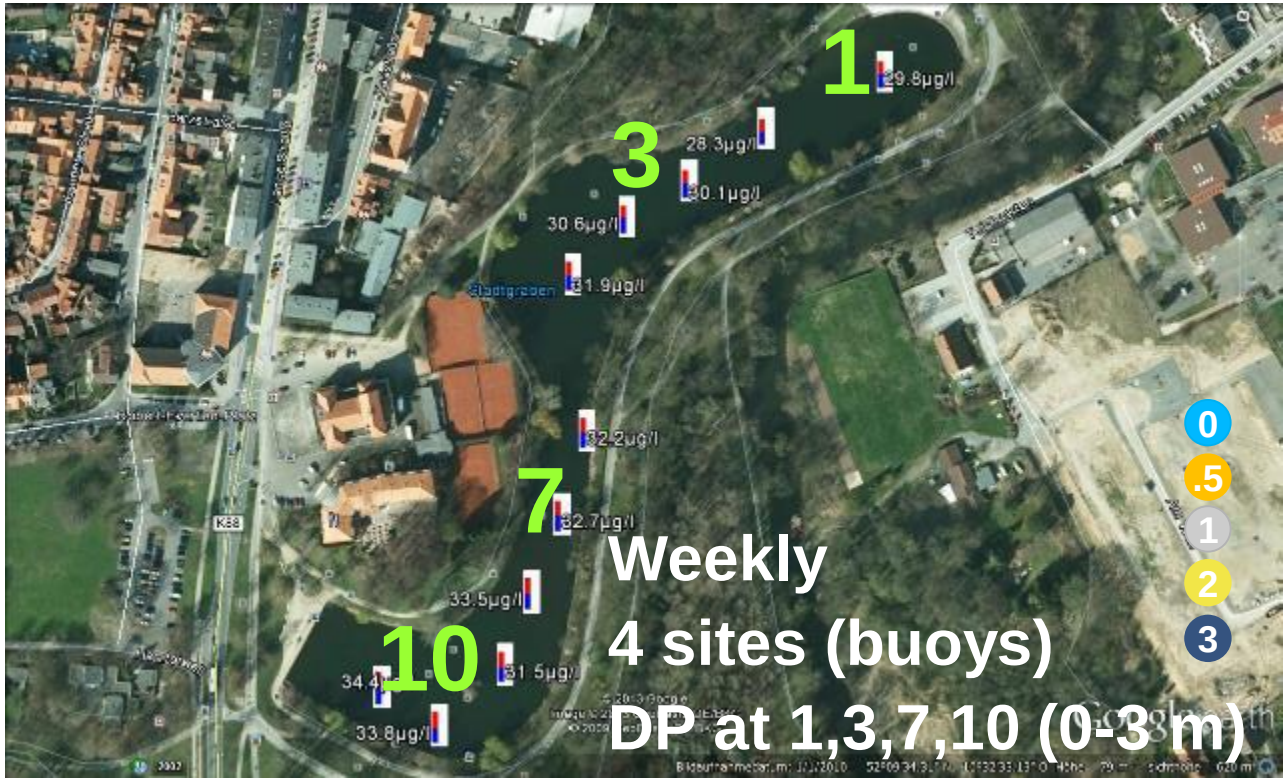

Lake Stadtgraben, Wolfenbüttel, City Park

Lat: 52.164
Long: 10.5408
51.546 Citizens

mesotrophic
Study period: May–Nov. 2016

General *(on site)*: Temp, pH, DO, SD, depth
Microalgal population: Chl a Cyanobacteria and Chlorophyta
Nutrients: NH_4-N, NO_3-N, NO_2-N, PO_4-P

Shortterm Study Results: Temperature and Light

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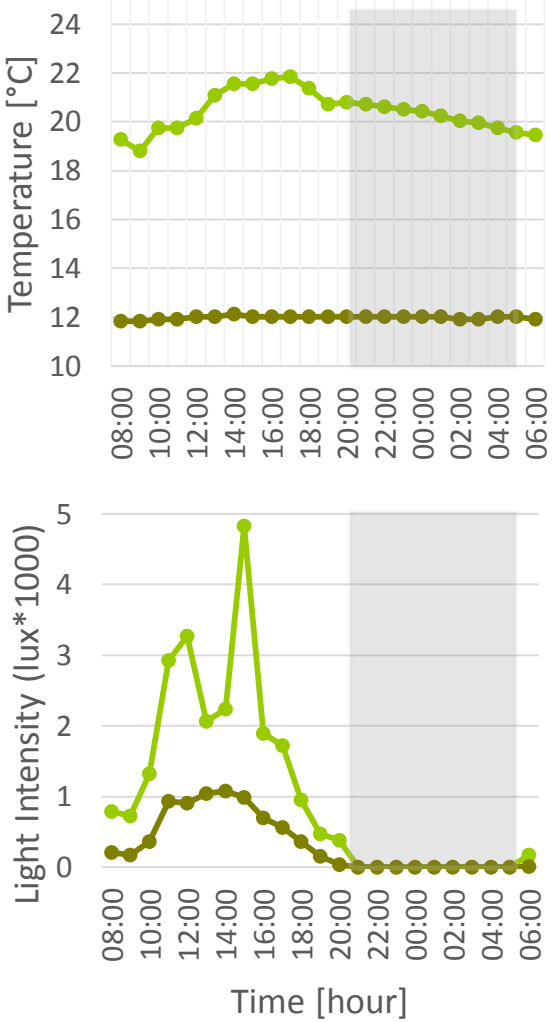
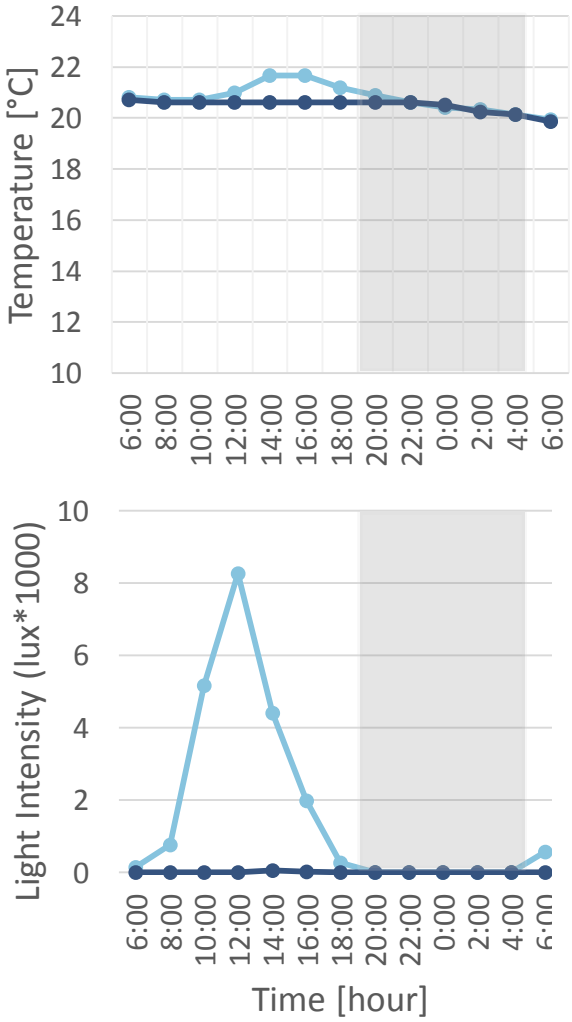
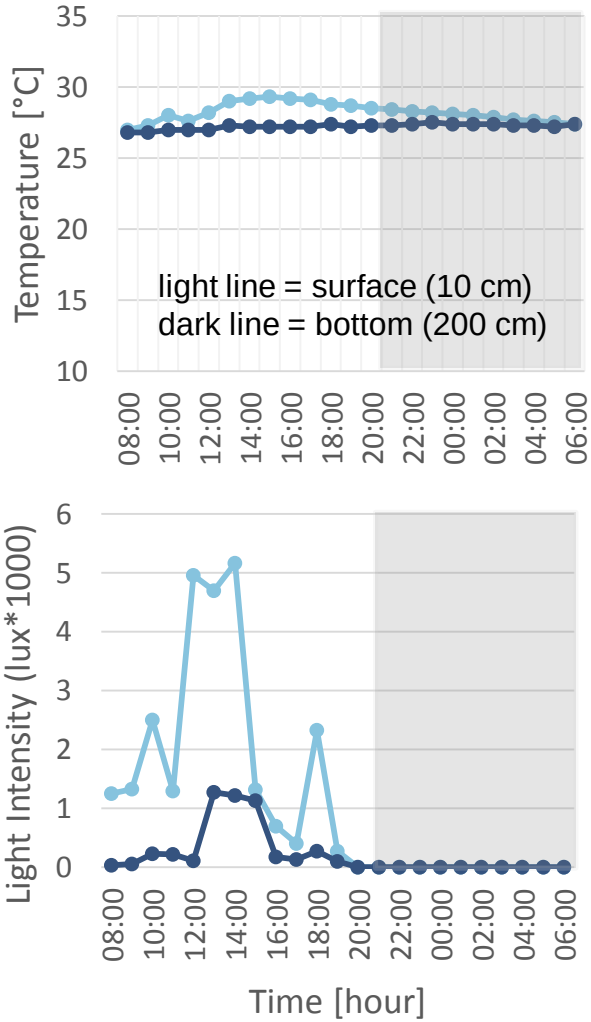
Stadtgraben Spring



Stadtgraben Fall



Russo Fall



Shortterm Study Results: PO_4-P

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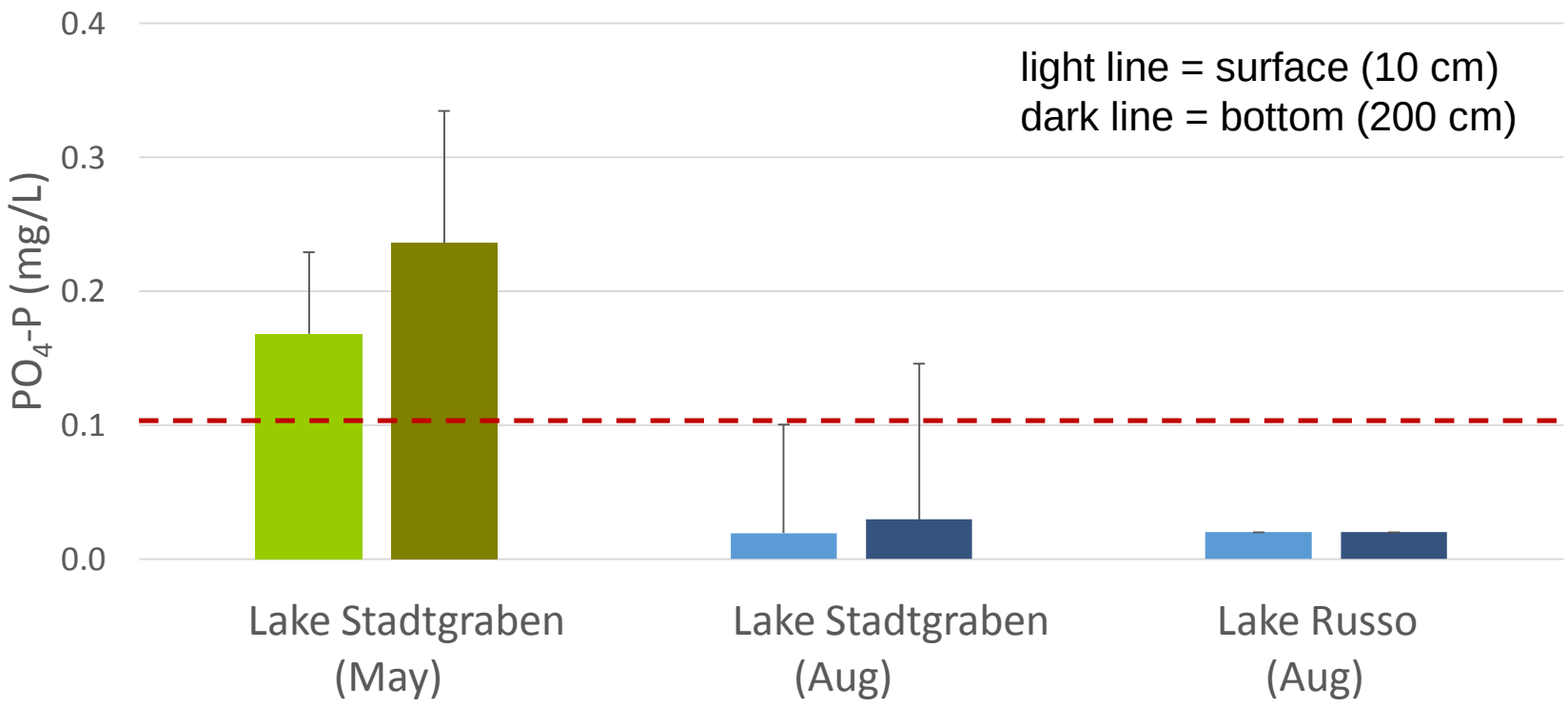

mesotroph | oligotroph | oligotroph

Shortterm Study Results: Chlorophyta

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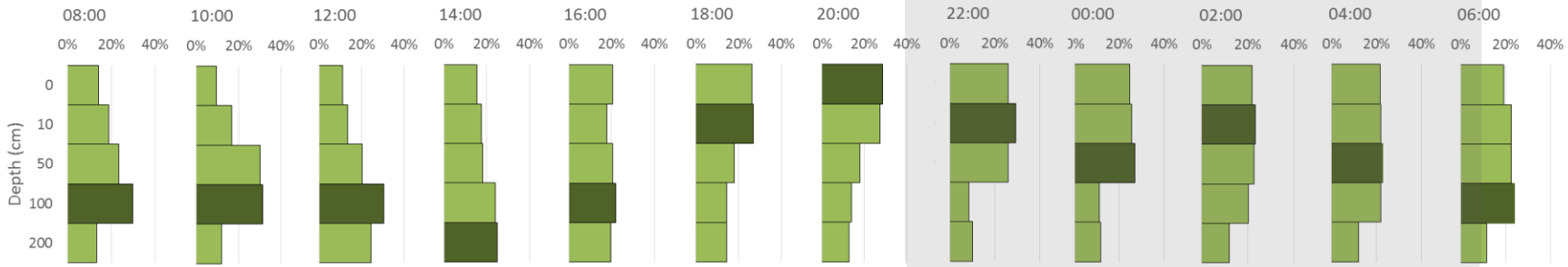
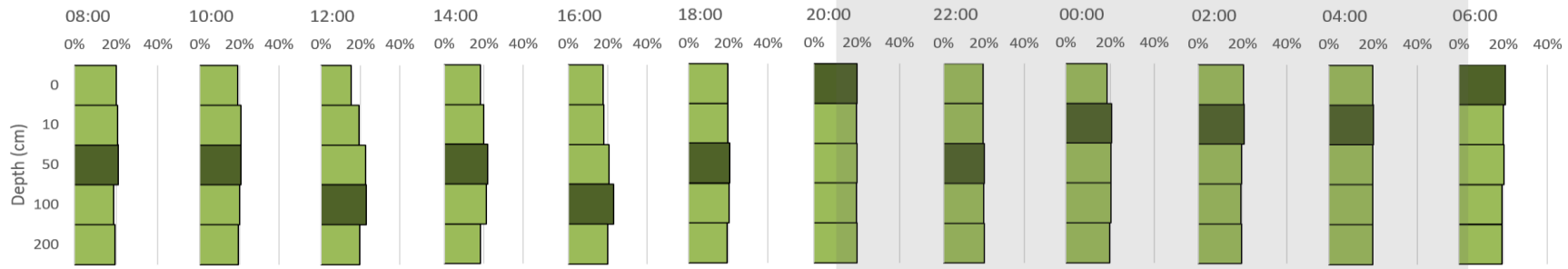
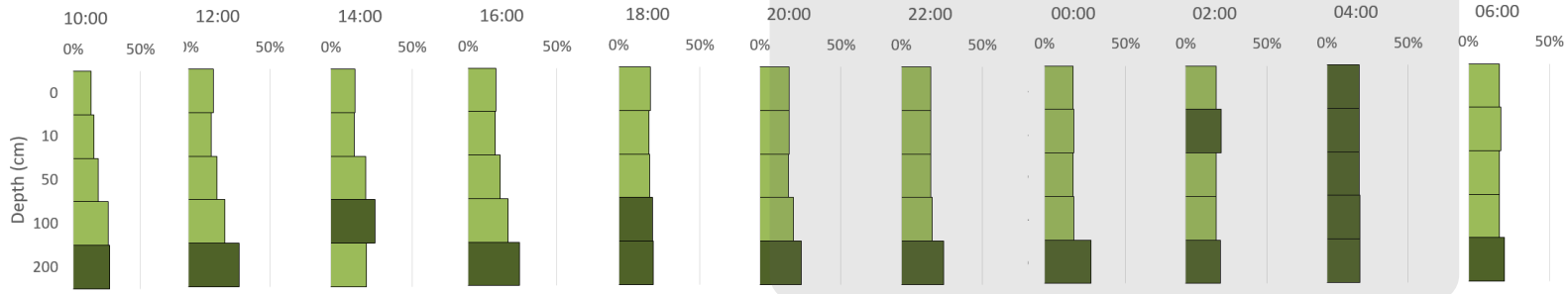
Lake Stadtgraben – Spring (10-60 µg/L Chl a)



Lake Stadtgraben – Fall (10-17 µg/L Chl a)



Lake Russo – Fall (0-15 µg/L Chl a)



Shortterm Study Results: Cyanobacteria

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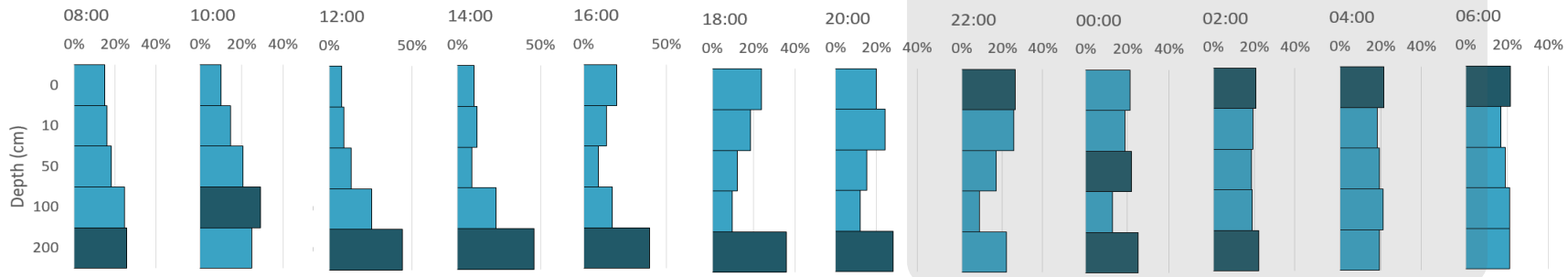
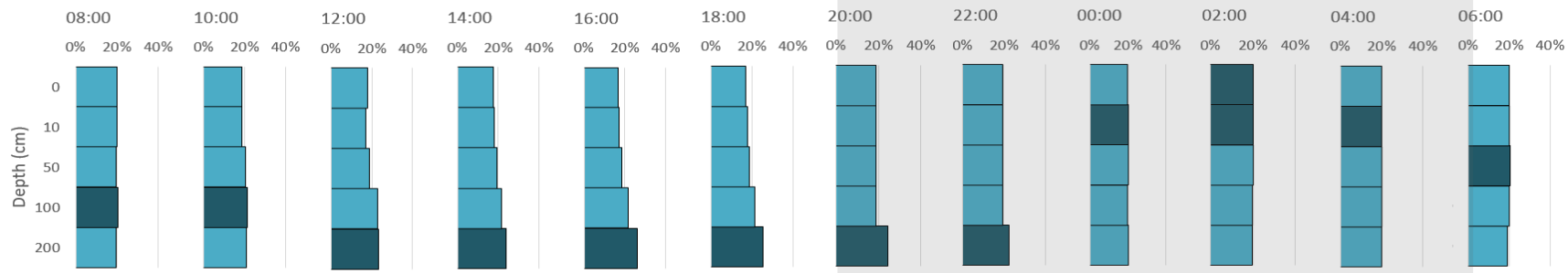
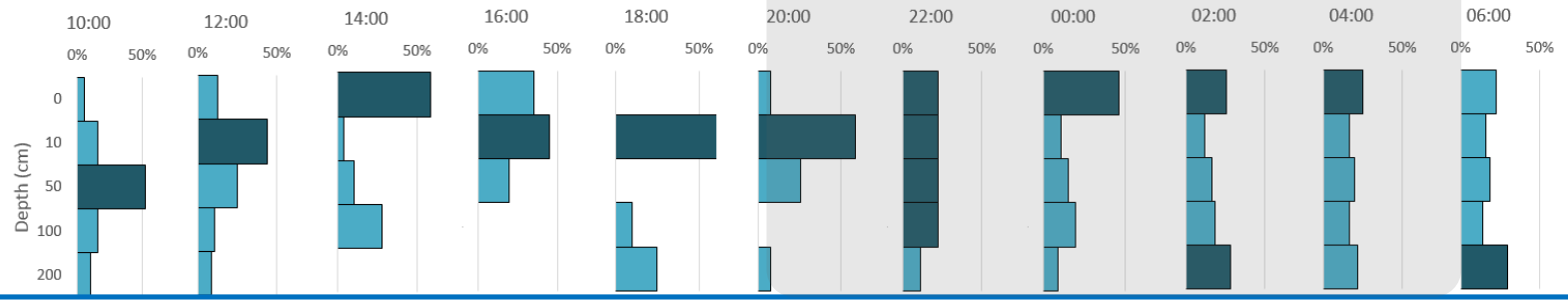
Lake Stadtgraben – Spring (0-5 µg/L Chl a)



Lake Stadtgraben – Fall (10-25 µg/L Chl a)



Lake Russo – Fall (0-1.5 µg/L Chl a)



Longterm Study Results: Air Temperature

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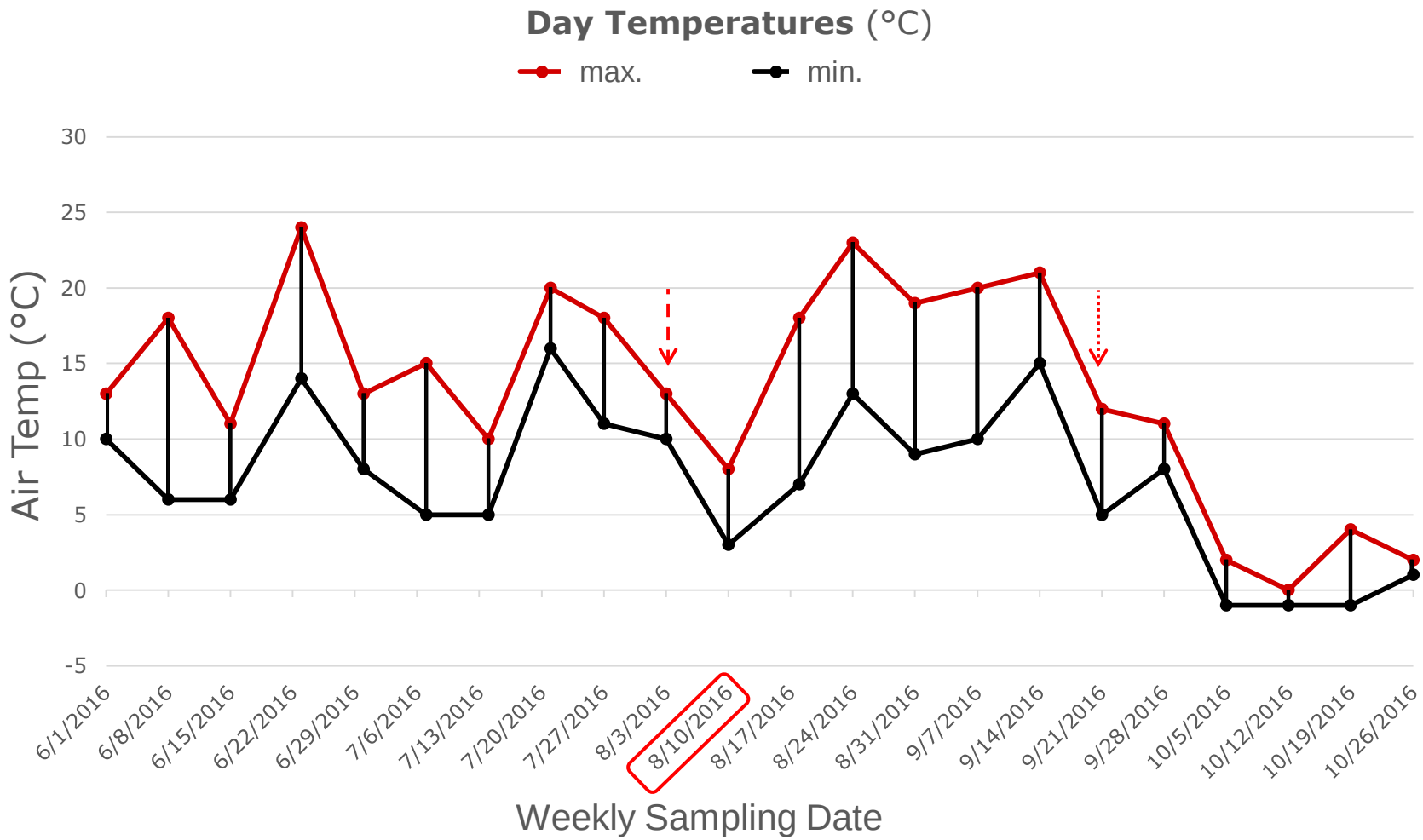

Longterm Study Results: Temperature and DO

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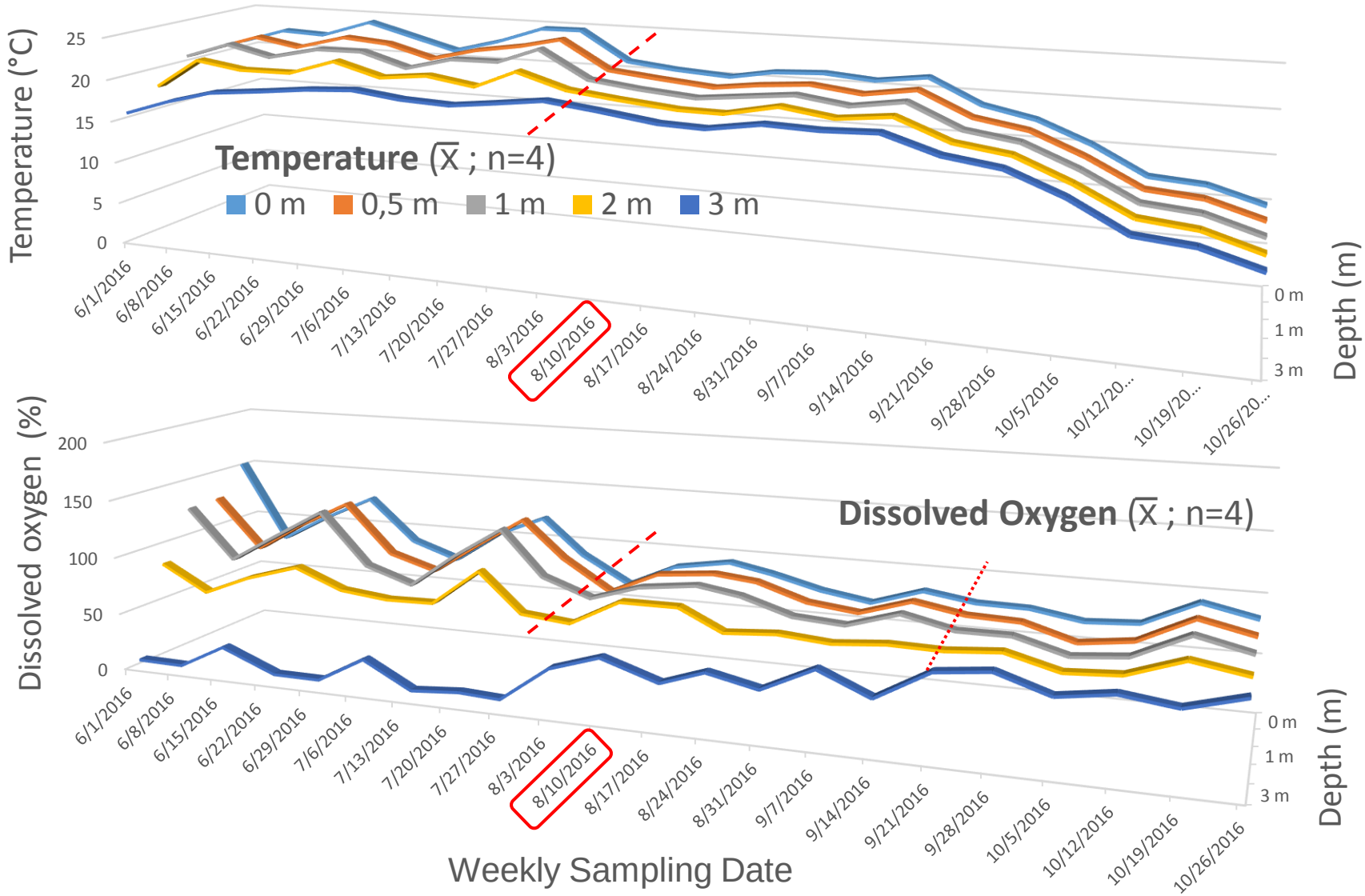

Longterm Study Results: Nutrients 1

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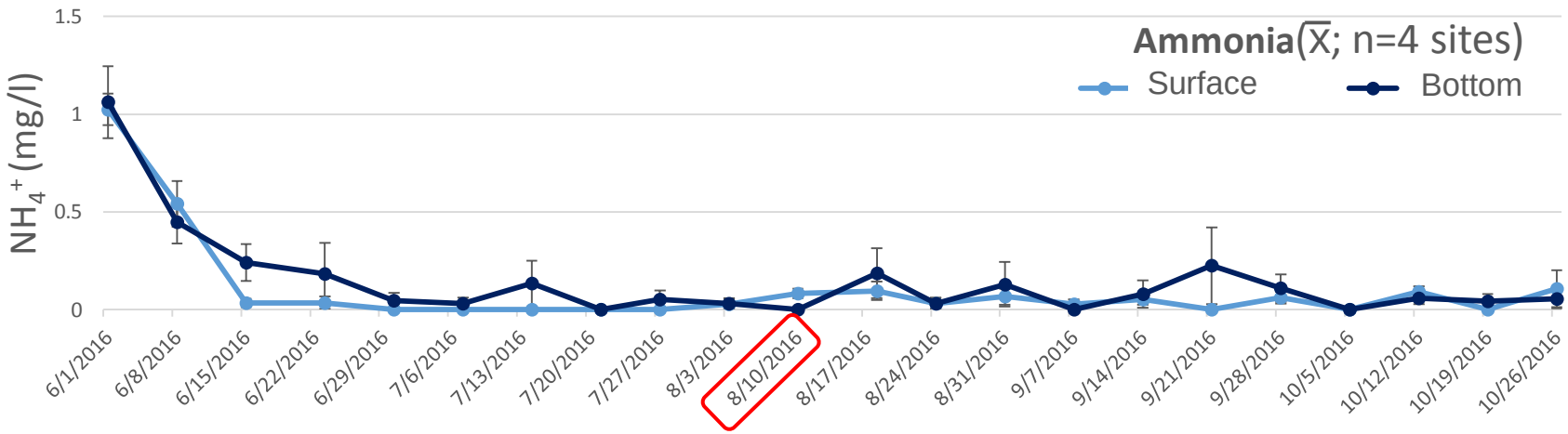

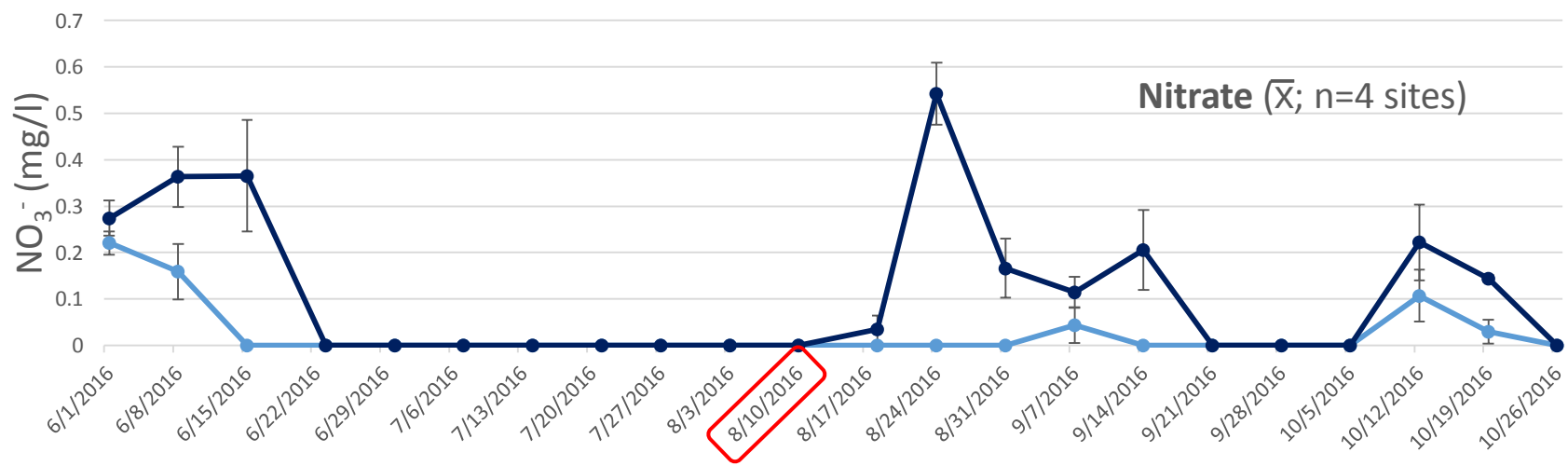

Longterm Study Results: Nutrients 2

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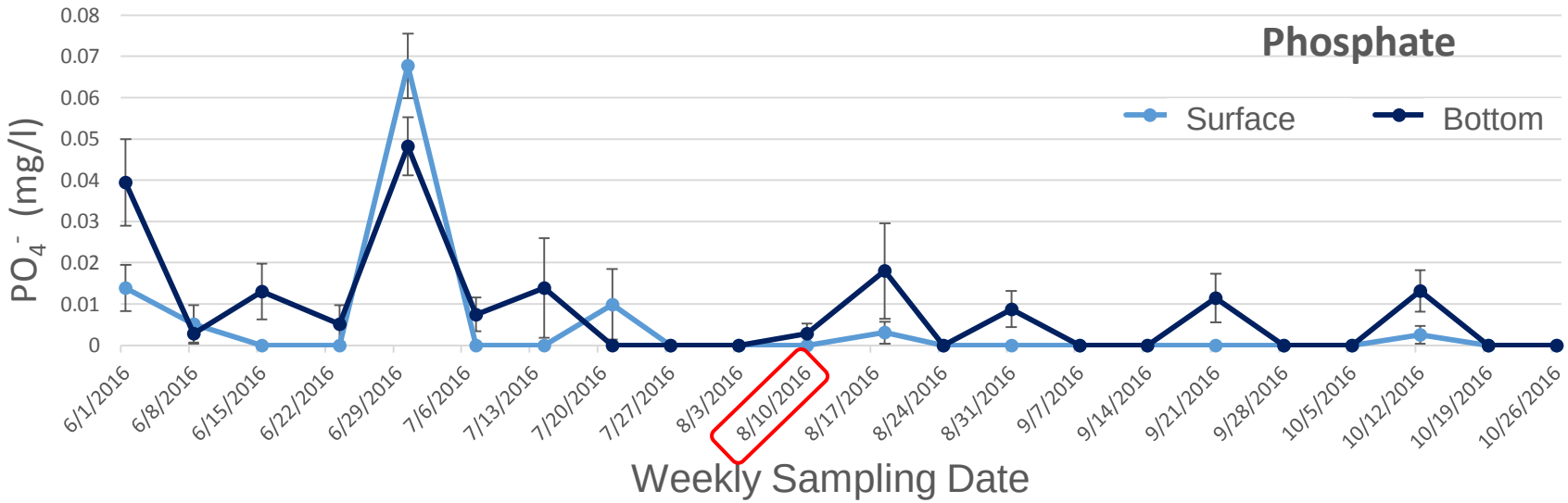

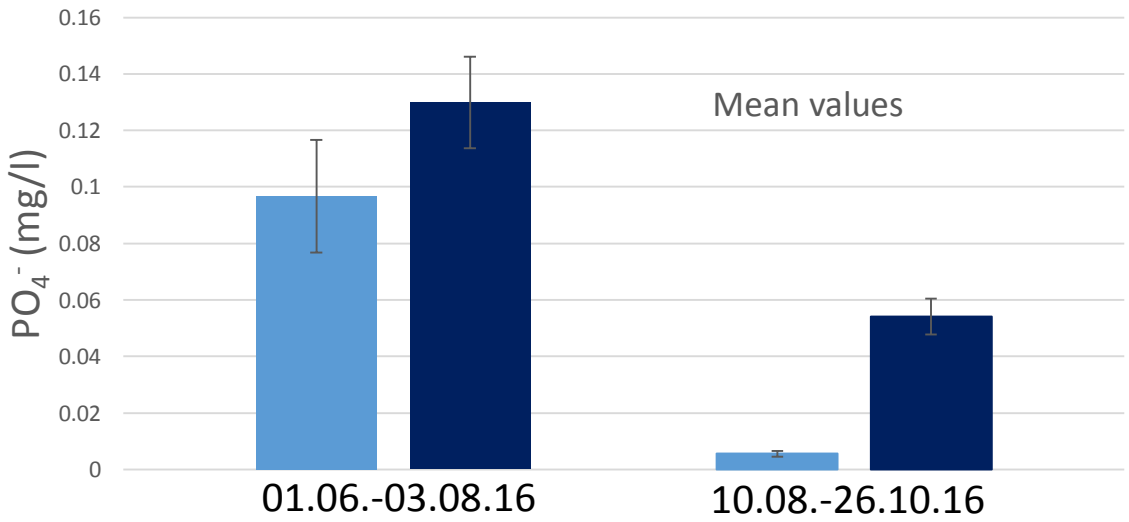

Longterm Study Results: Chl a

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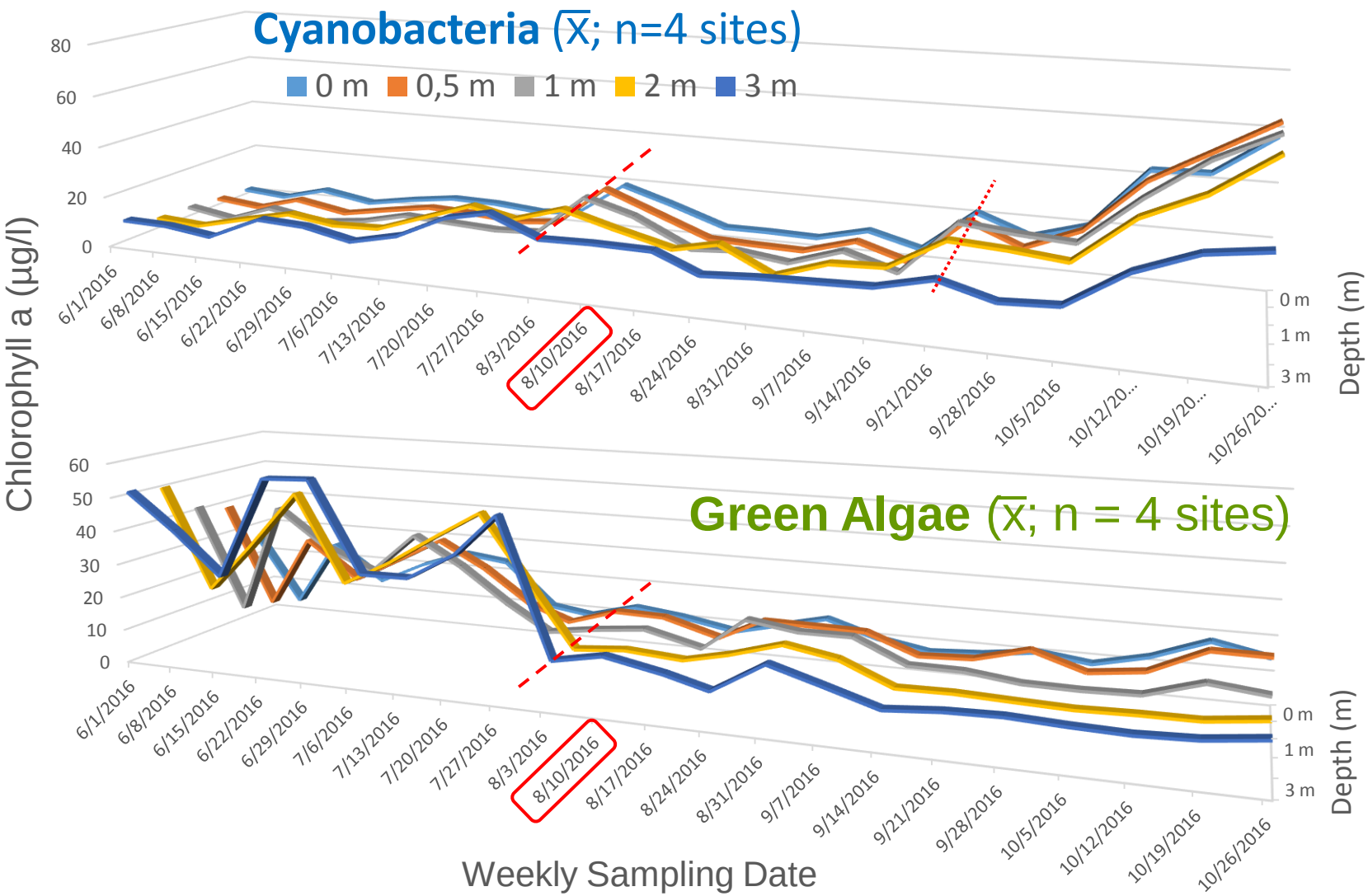

Outcome

- **Shortterm Study**:
  - Different migrational pattern for Cyanobacteria and Chlorophyta
  - Diurnal migrational pattern seems to be seasonally dependent
  - Light and Phosphate availability may drive the rhythm
- **Longterm Study:**
  - Chlorophyta populations reach peak values prior to Cyanobacteria
  - Different migrational pattern
  - Temperature stratification influences migrational patterns
    - Turnover situations reduce anoxic zone areas
      - Anoxic zones decrease Phosphate availability

- Chl a distribution within the water body may be time dependent
- Changes in distribution may account for different levels of toxicity in algal blooms, models would have to account for that

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Thank you for listening!

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Add on Information:

Shortterm Study Results: PO_4-P

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		Sampling Site	Lake Surface PO_4-P (mg/L)	Lake bottom PO_4-P (mg/L)
Spring	**Lake Stadtgraben May 2016** mesotroph	1	0.123	0.406
		2	0.208	0.198
		3	0.246	0.170
		4	0.095	0.170
		$\bar{x} \pm$ **SD**	**0.168 ± 0.061**	**0.236 ± 0.099**
Fall	**Lake Stadtgraben August 2016** oligotroph	1	0.017	0.026
		2	0.018	0.024
		3	0.019	0.030
		4	0.023	0.038
		$\bar{x} \pm$ **SD**	**0.019 ± 0.081**	**0.030 ± 0.117**
	Lake Russo August 2016 oligotroph	1	> 0.020	> 0.020
		2	> 0.020	> 0.020
		3	> 0.020	> 0.020
		4	> 0.020	> 0.020
		$\bar{x} \pm$ **SD**	**0,020 ± 0.000**	**0.020 ± 0.000**

Results

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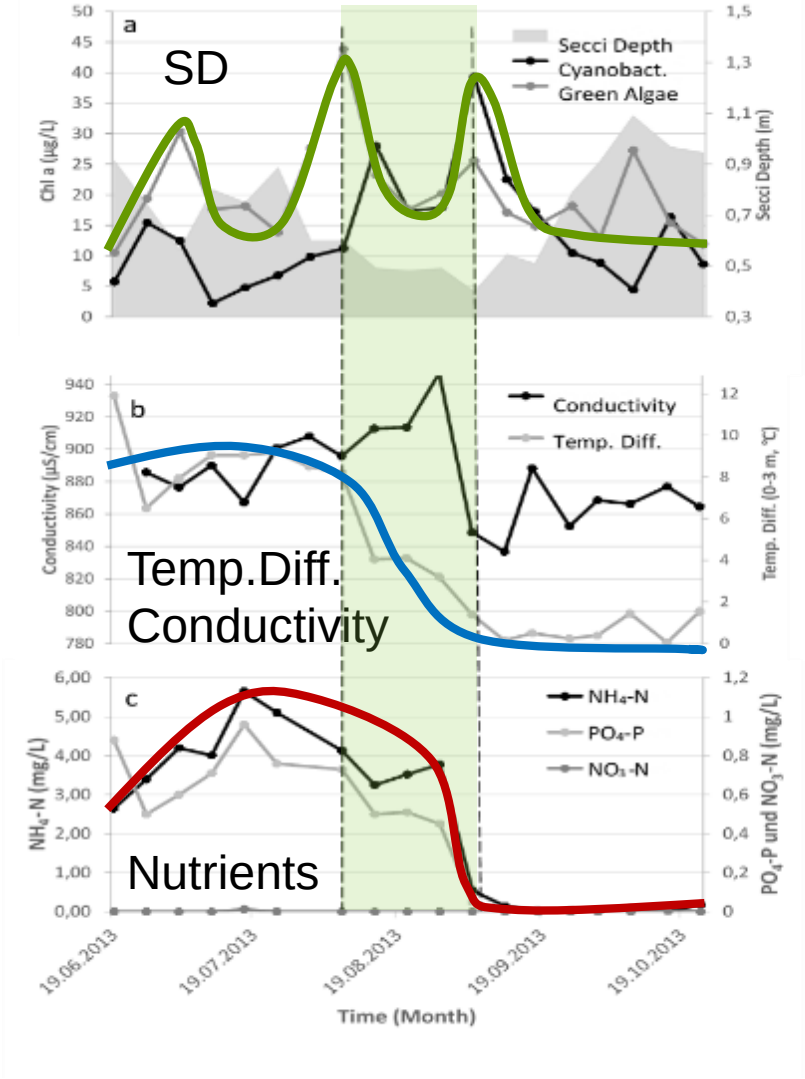

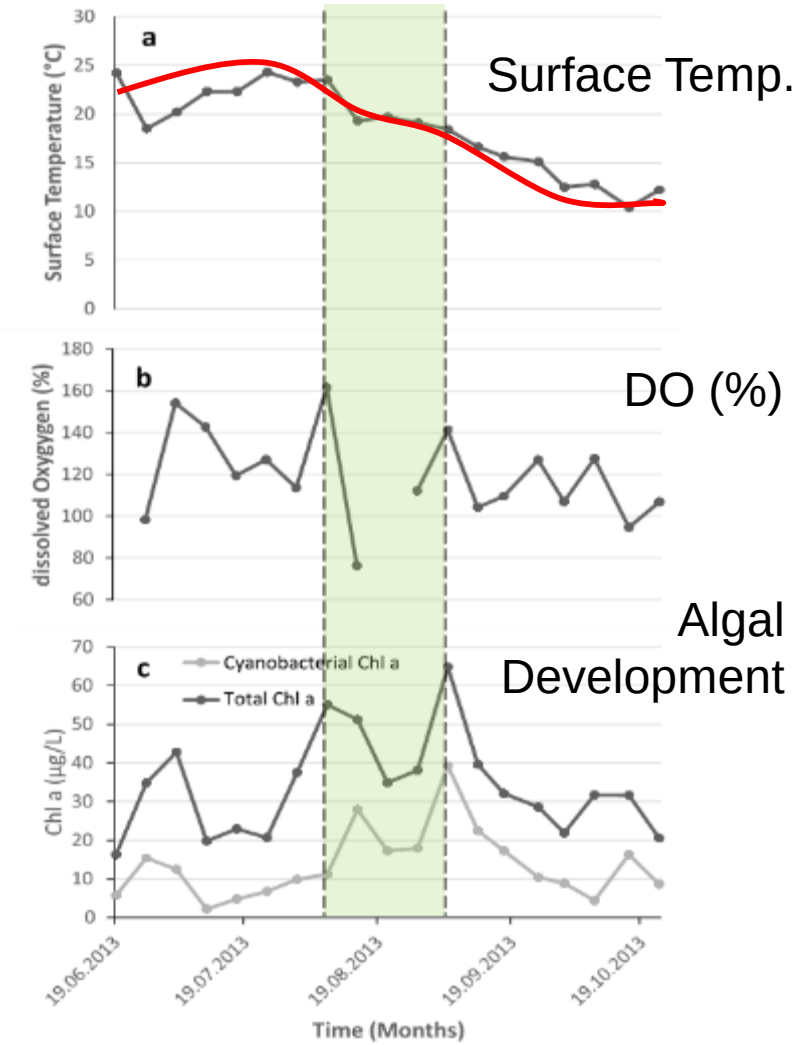

Chlorophyll

09/04/13

Chlorophyll [µg/l]:

Cyanobacteria: 39,3

Total: 64,8

10/02/13

Chlorophyll [µg/l]:

Cyanobacteria: 8,9

Total: 21,9

Chlorophyll

09/04/13 (bank)

Chlorophyll [µg/l]:

Cyanobacteria: 117,3

Total: 146,2

Turbidity [FTU]: 56,5

Chl a Estimate

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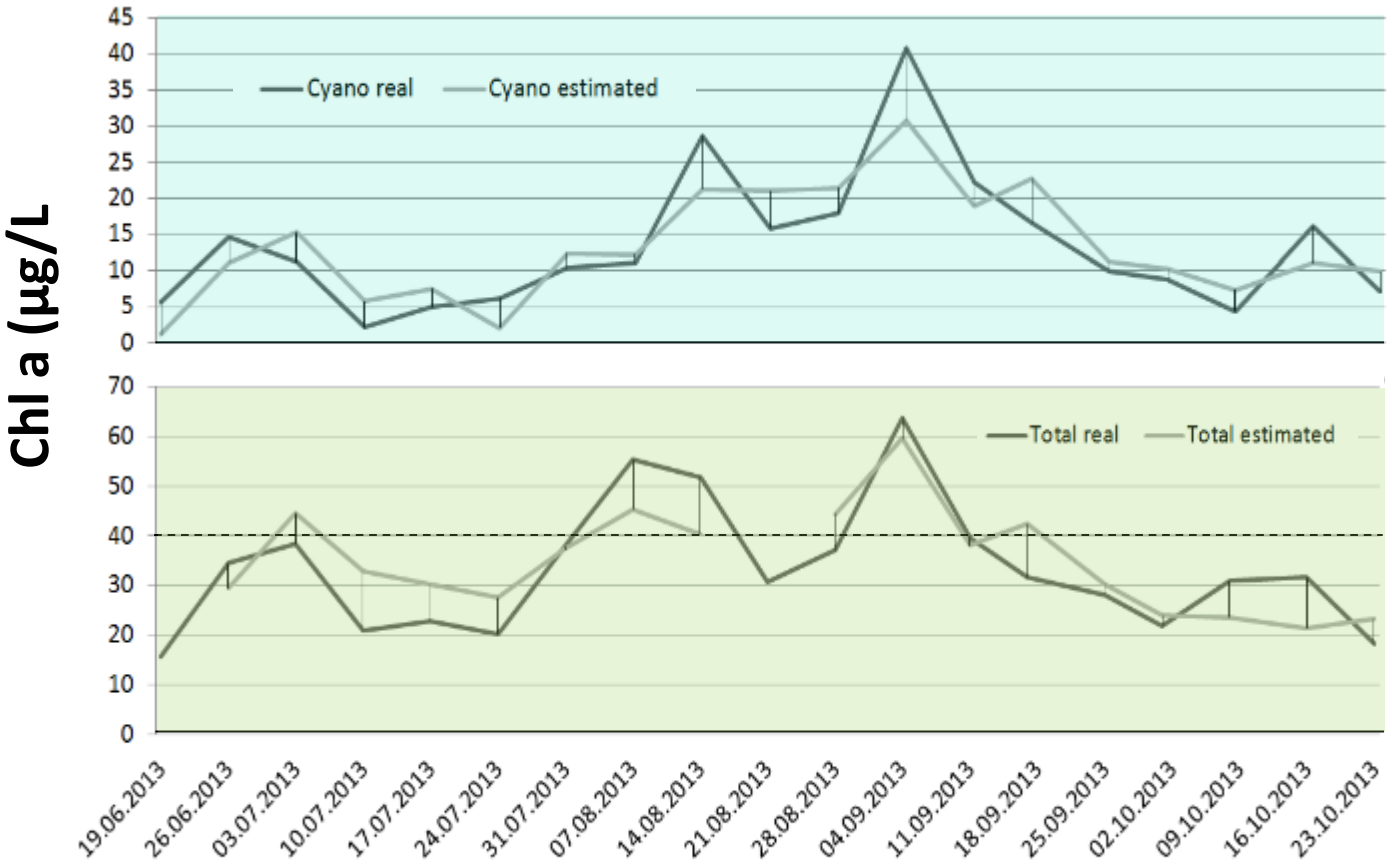
$$C_2 = 0.409 + 17.6979\,S - 0.7486\,T$$



$$C_1 = -6.4775 + 21.6396\,S + 0.0006\,D^2$$

Experimental Run: Bioreactor

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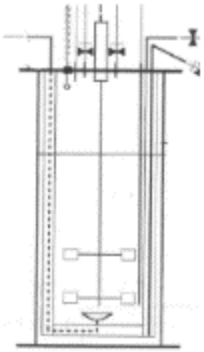
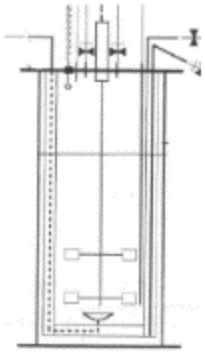
Chlorella vulgaris

2x ES medium: PO_4 free

2x ES medium





Culture Conditions:

Media: 2xES (EPSAG)

and 2x ES Phosphate free

C-Source: CO_2

pH 7 (adjusted via CO_2)

D/L 10/14

8000 lux

28°C

Stirrer 150 rpm

Inocculation 1 Mio Cells/ml

Bioreactor Volume 3,5 l

cont.: pH

10 days daily: OD, CC, Chl a

start / end: PO_4

Chlorella vulgaris culture development in phosphate free and full ES media

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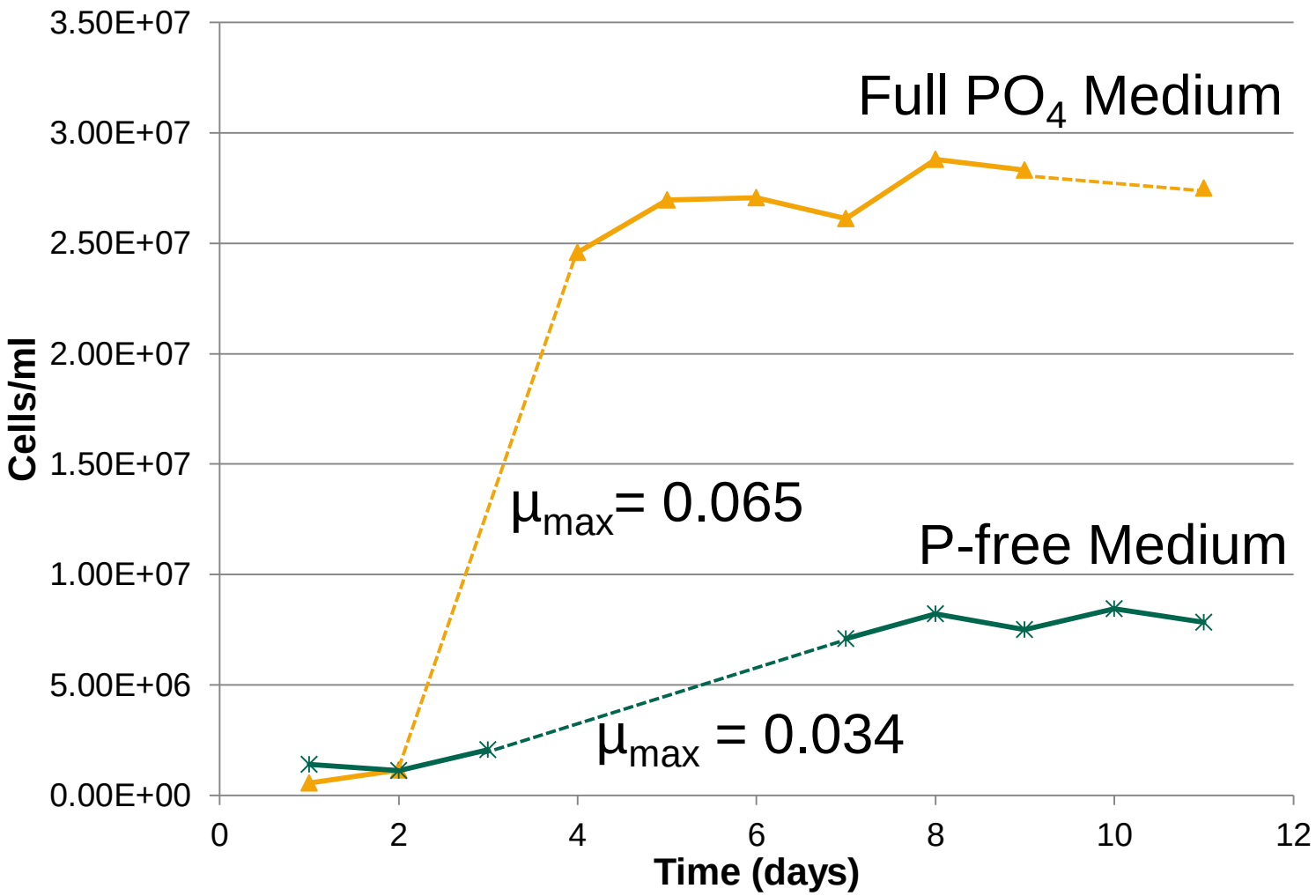

Simulation runs: Output

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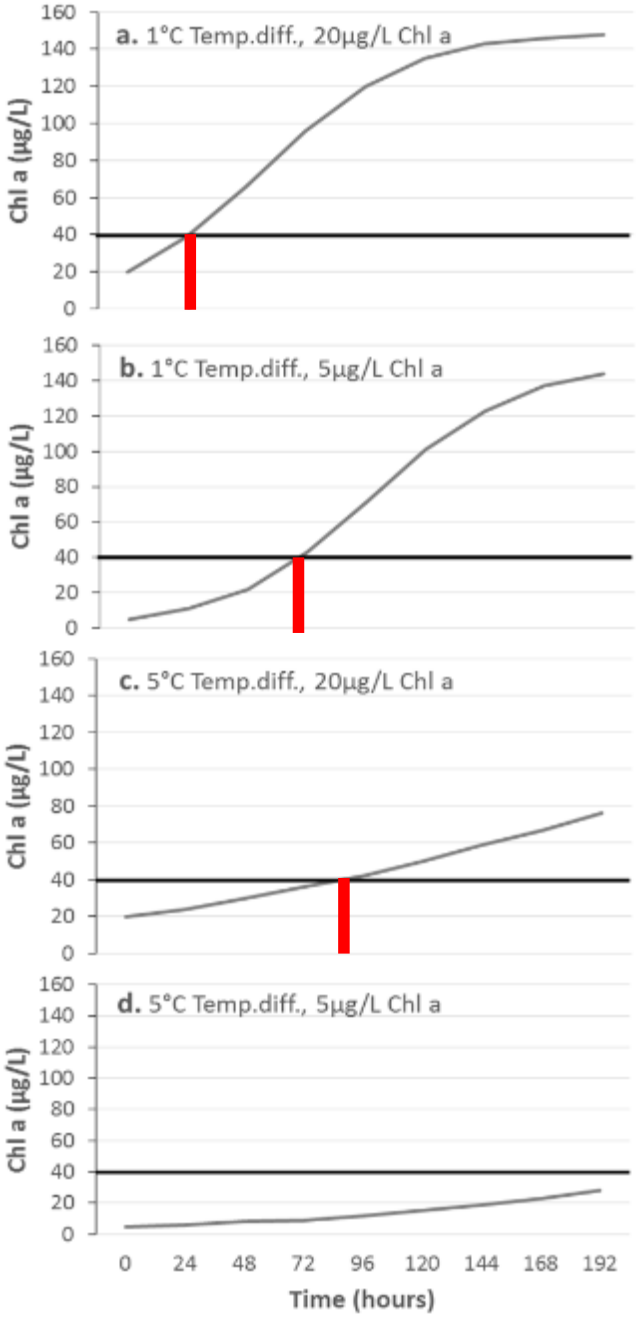
- Lake conditions: Lake depth 4 m, PO_4-P lake bottom 7 mg/L)
- Initial Chl a conditions: 5 or 20 µg/L
- Initial temperature difference between lake surface and bottom: 1 or 5 °C
- Black line: WHO Threshold value of 40µg/L Cyanobacterial Chl a
- Red line: Time when WHO threshold value is being reached



Bioreactor study (CV): Real vs estimated Chl a

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3.5 L Infors Bioreactor,
pH 7 adjusted via CO_2,
28°C, 8000 lux,
stirrer 150 rpm,
inoculation 1Mill. cells/ml,
10 days

$N_t=N_0+(k-N_0)*\exp(-r_0*t)$

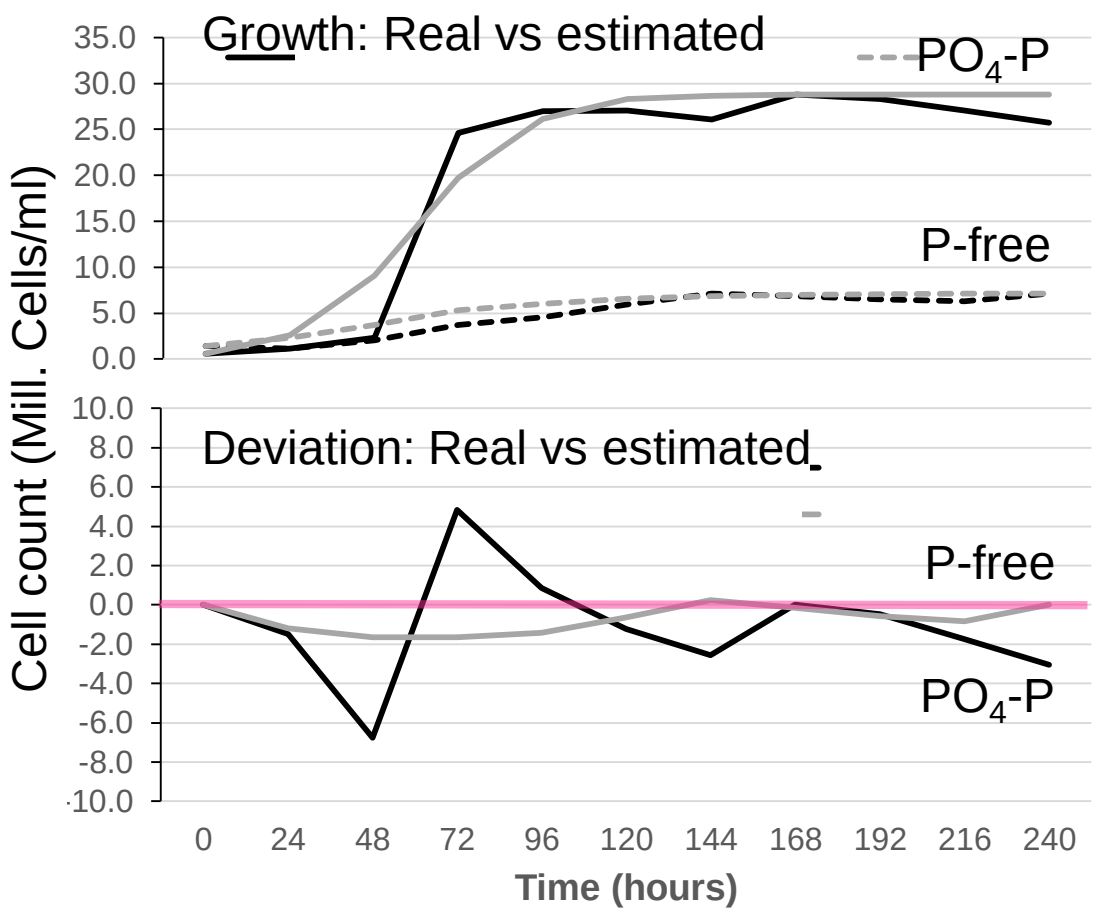
Assumptions:

P-Free:

r_0: $\mu=0.034$

K = 7.10 Mill. cells/ml

PO_4-P:

r_0: $\mu=0.065$,

K = 28.8 Mill. cells/ml