Metropolitan Water Reclamation District of Greater Chicago

WELCOME

TO THE SEPTEMBER EDITION

OF THE 2018

M&R SEMINAR SERIES

BEFORE WE BEGIN

- **SAFETY PRECAUTIONS**
  - **PLEASE FOLLOW EXIT SIGNS IN CASE OF EMERGENCY**
  - **AUTOMATED EXTERNAL DEFIBRILLATOR (AED) LOCATED OUTSIDE**
- **PLEASE SILENCE CELL PHONES OR SMART PHONES**
- **A QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION**
- **PLEASE FILL OUT THE EVALUATION FORM**
- **SEMINAR SLIDES WILL BE POSTED ON THE MWRD WEBSITE (www. MWRD.org: Home Page ⇒ Reports ⇒ M&R Data and Reports ⇒ M&R Seminar Series ⇒ 2018 Seminar Series)**
- **VIDEO STREAM OF THE PRESENTATION WILL BE AVAILABLE ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)**

Jeremy S. Guest, Ph.D.

Dr. Guest is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign (UIUC). His research focuses on resource recovery from wastewater and the development of intensive algal treatment processes.

Dr. Guest is the recipient of an NSF CAREER Award, the Paul L. Busch Award from The Water Research Foundation, and a Beckman Fellow of the Center for Advanced Study at UIUC.

Dr. Guest's formal training includes a B.S. and M.S. in civil engineering from Bucknell University and Virginia Tech, respectively, and a Ph.D. in environmental engineering from the University of Michigan.

Microalgal Bioprocesses for Nutrient Recovery from Wastewater

Jeremy Guest

Assistant Professor
Civil & Environmental Engineering
University of Illinois at Urbana-Champaign

Metropolitan Water Reclamation District of Greater Chicago
Monitoring and Research Seminar
Cicero, IL

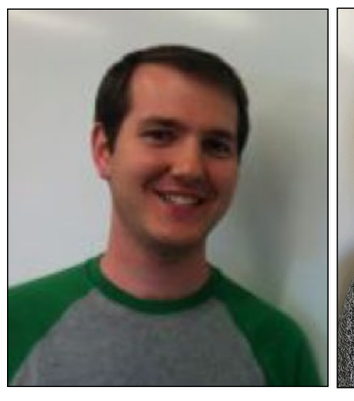
September 14, 2018

ILLINOIS

Guest Research Group
ENGINEERING FOR SUSTAINABILITY



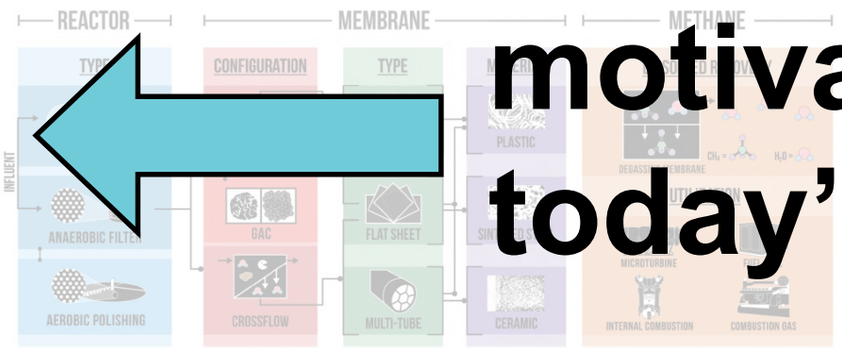




ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Guest Research Group
ENGINEERING FOR SUSTAINABILITY

algae	sustainable design	developing communities



motivation for today's discussion

Algae are often explored for their potential as a bioenergy feedstock.

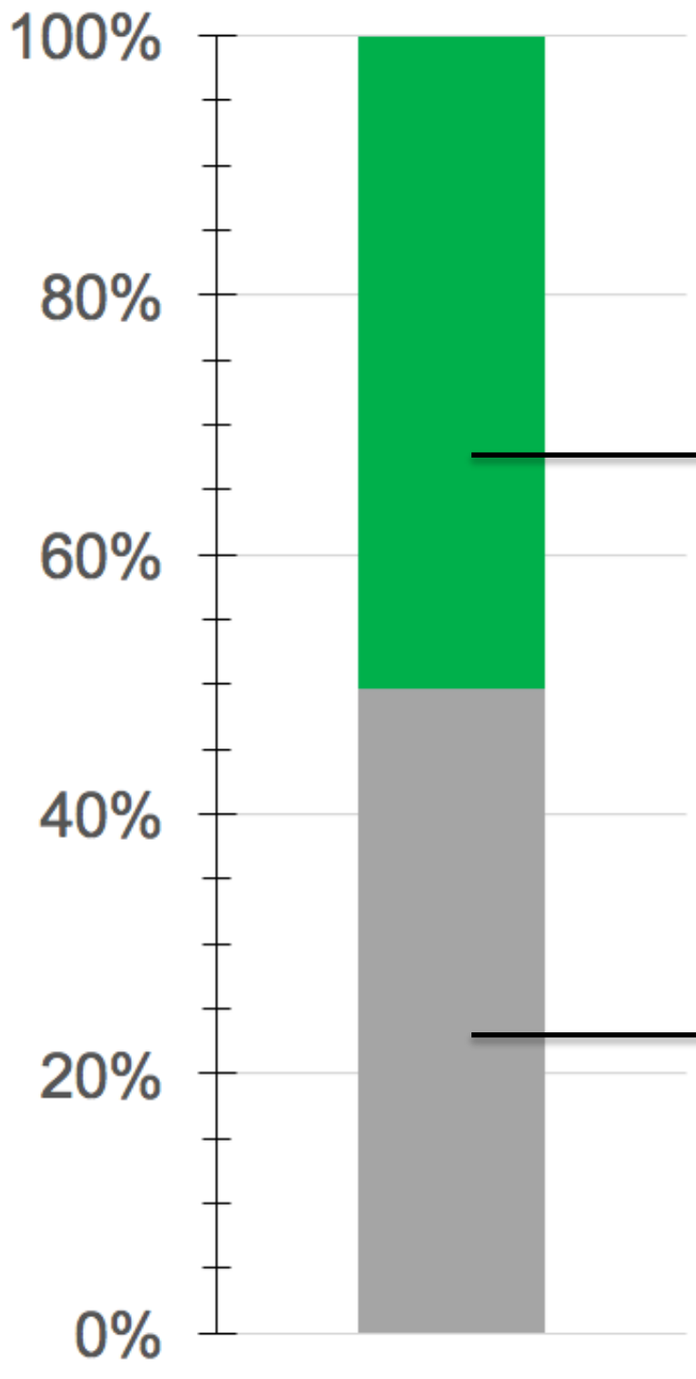
[Sh
[Le
[Li
[Leow et al. (*in preparation*)] [Li et al. (*in preparation*)]

At treatment plants, we often think of algae as a nuisance…

[Kuldip Kumar, Metropolitan Water Reclamation District of Greater Chicago]

In wastewater treatment, phototrophs have traditionally been used in low intensity systems like ponds or lagoons.

Wastewater ponds/lagoons are some of the most common technologies for small utilities.



In the U.S. in the year 2000:

~16,255 Publicly Owned Treatment Works (POTWs)

~ half (50.3%) included ponds/lagoons

~ half (49.7%) with no ponds/lagoons

[Data from Robert Bastian, US EPA; Algae Biomass Summit (ABS) Presentation, October 2016, Pheonix, AZ.]

The objective for microalgae in stabilization ponds has been to provide oxygen for BOD removal (and nitrification).

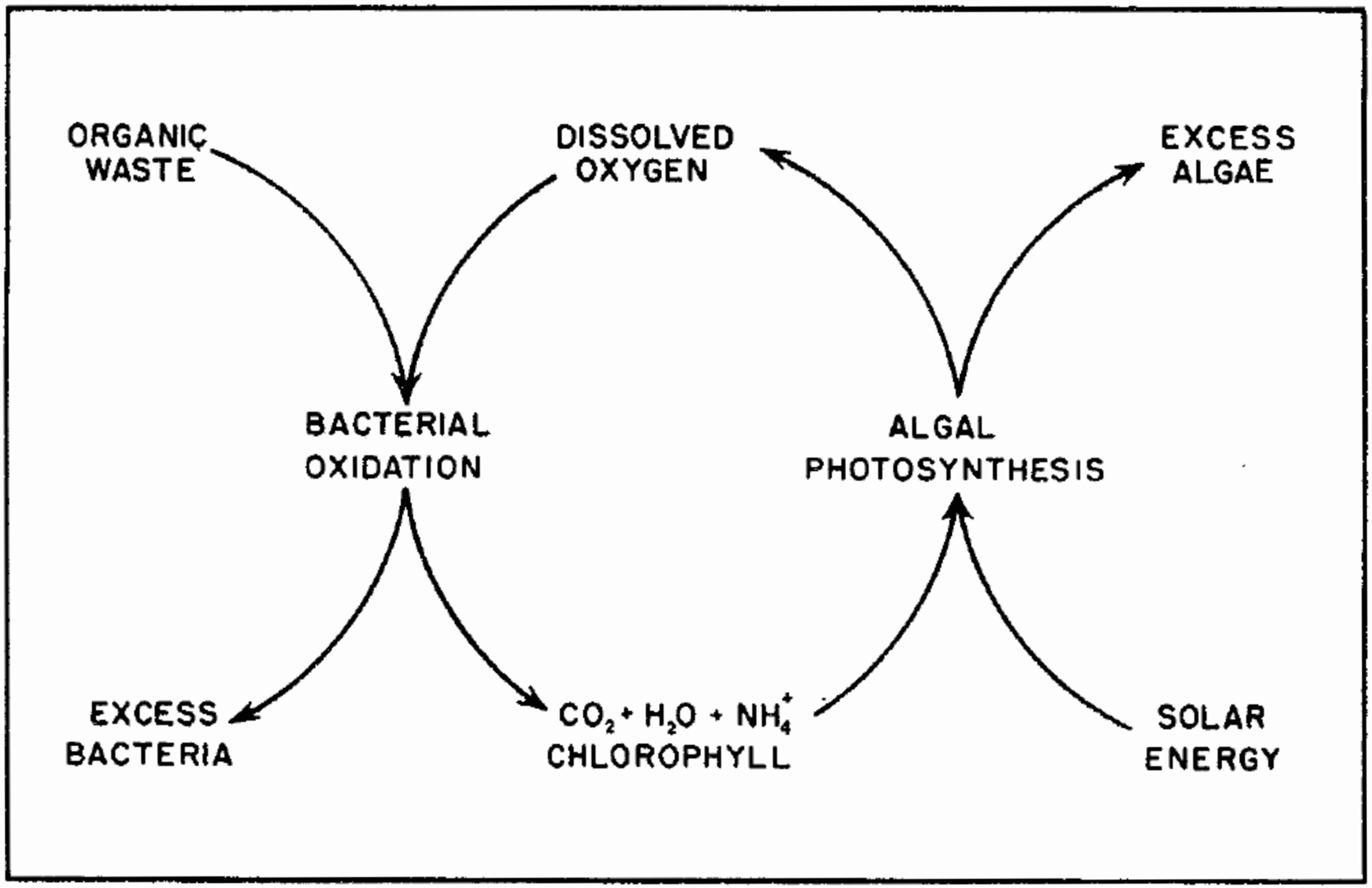


FIG. 2.—THE CYCLE OF OXYGEN AND ALGAL PRODUCTION IN SEWAGE TREATMENT BY PHOTOSYNTHESIS

[Oswald and Gotaas (1957) *Proc. Am. Soc. Civil Engrs., Separate*; 686.]

Algae growth was largely incidental. Make the pond large and shallow, and algae will come (in low concentrations).

…but conventional ponds simply haven't evolved to meet the needs of many utilities.

requirements for broader adoption of algal technologies

these objectives not met by ponds

reliable, resilient treatment

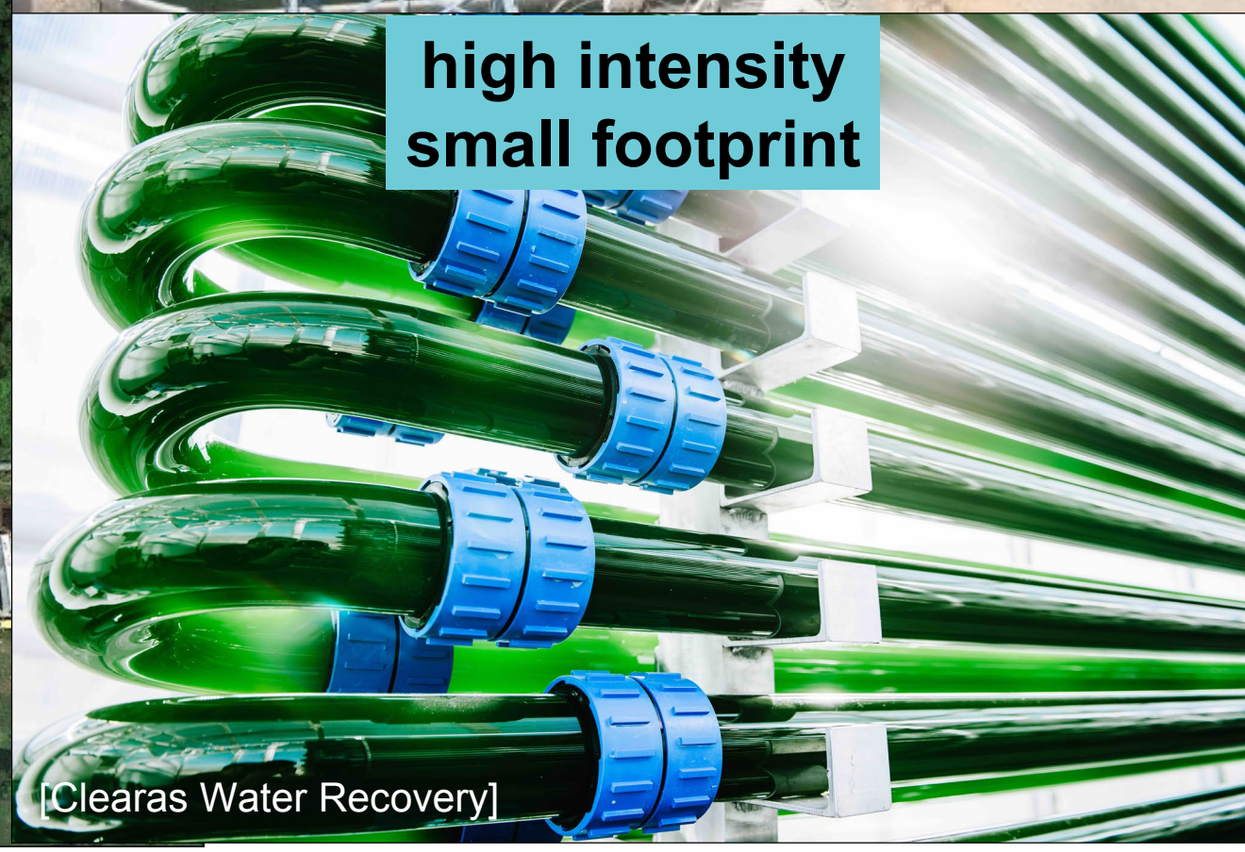
despite influent microbes and changes in weather, wastewater composition & flow, etc., MUST meet permits

small footprint

financially viable with manageable risk profile

nutrient removal or recovery

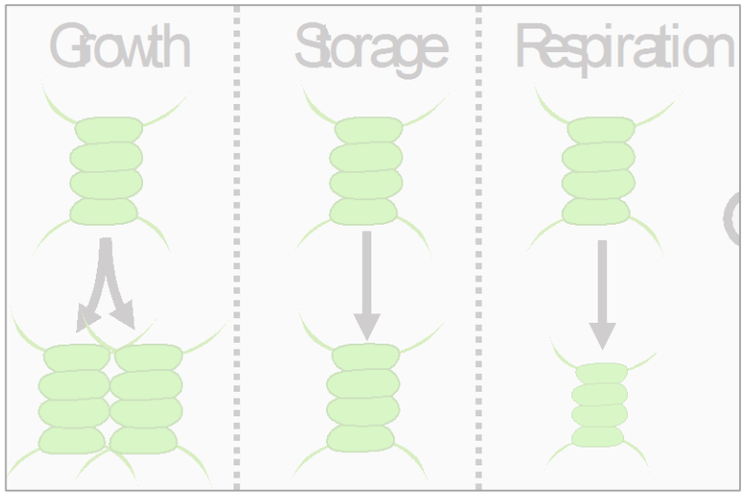
Intensification may make the technology a viable alternative for more utilities.



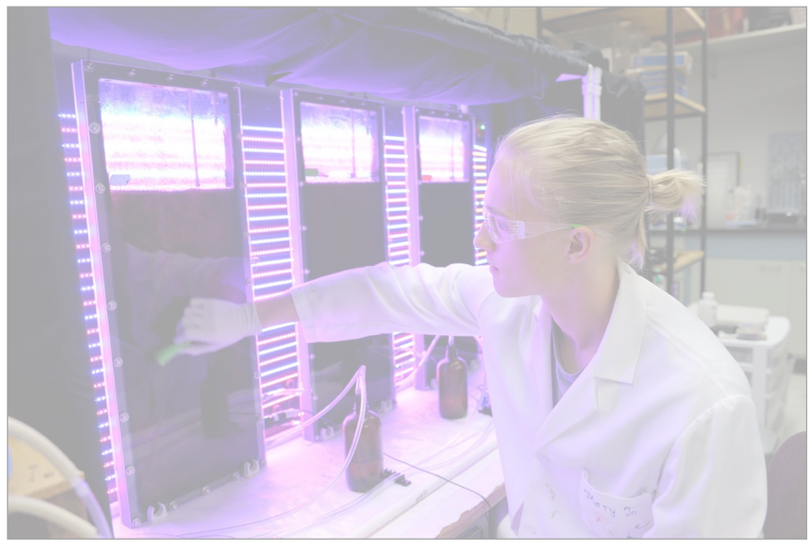
Today we'll discuss the development of suspended growth algal processes for wastewater treatment.

intensification of algal systems for nutrient recovery

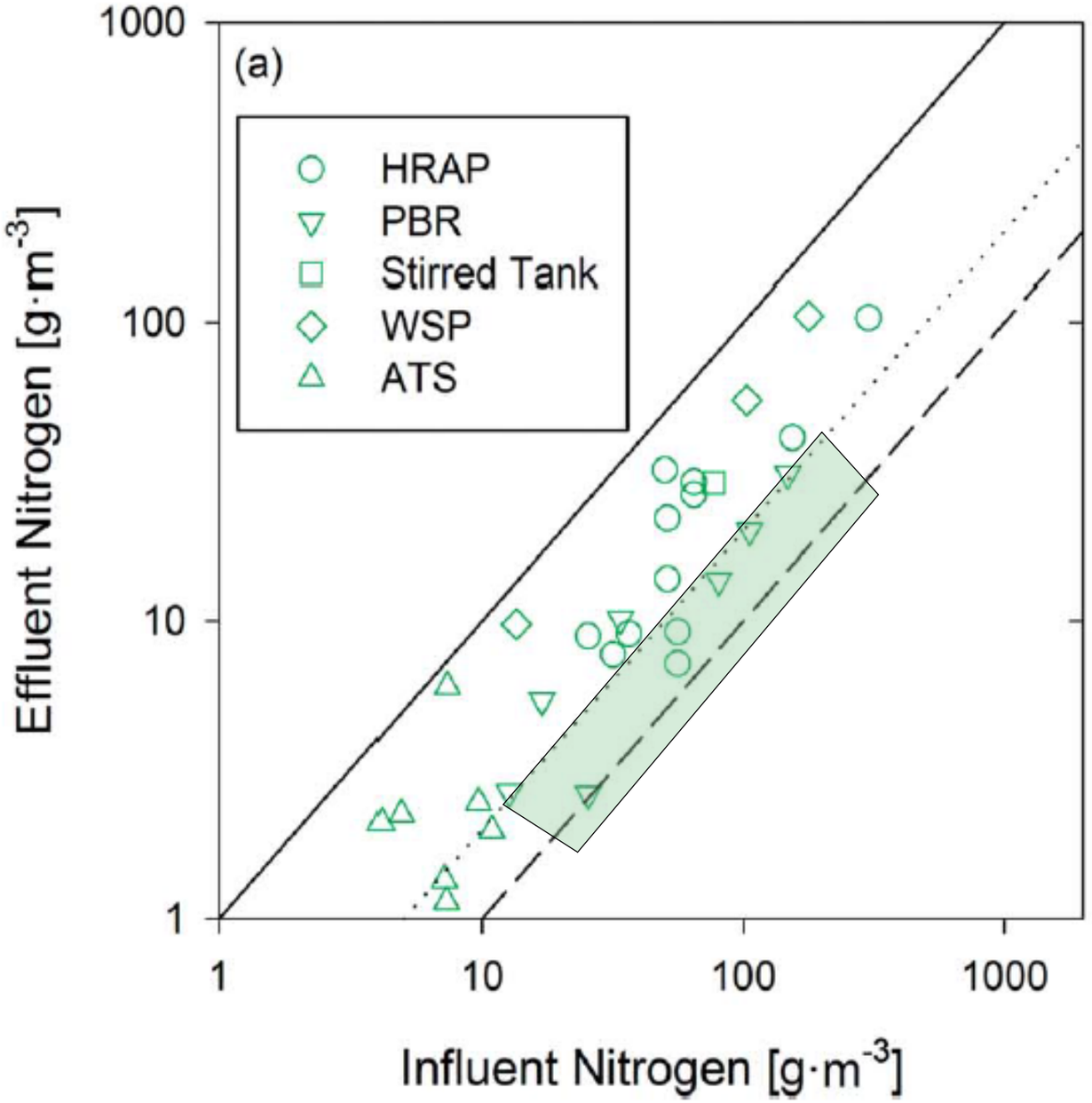
modeling & design challenges for algae

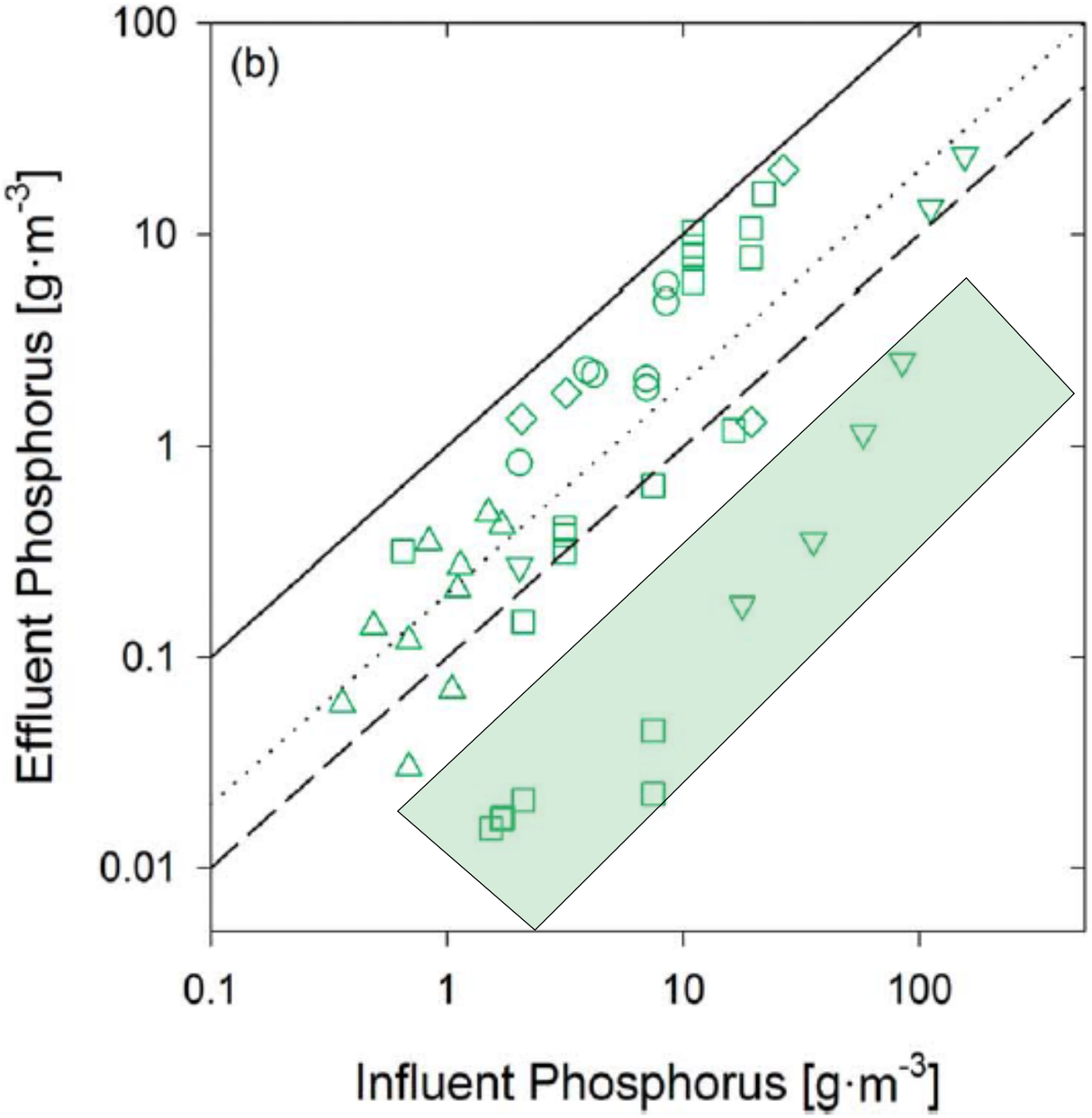


recent findings and & emerging trends in algal processes



In general, suspended growth phototrophic systems with good mixing have (in the past) achieved better effluent quality.





[Shoener et al. (2014) *Environmental Science: Processes & Impacts*; 16(6): 1204-1222]

HRAP - high rate algal pond (**suspended**)
PBR - photobioreactor (**suspended**)
Stirred Tank - stirred tank reactor (**suspended**)
WSP - waste stabilization pond (**suspended**)
ATS - algal turf scrubber (**attached**)

High rate algal ponds achieve more rapid nutrient recovery (relative to unmixed ponds).

[et.byu.edu]

High rate algal ponds are the most common approach to intensification of suspended growth processes.

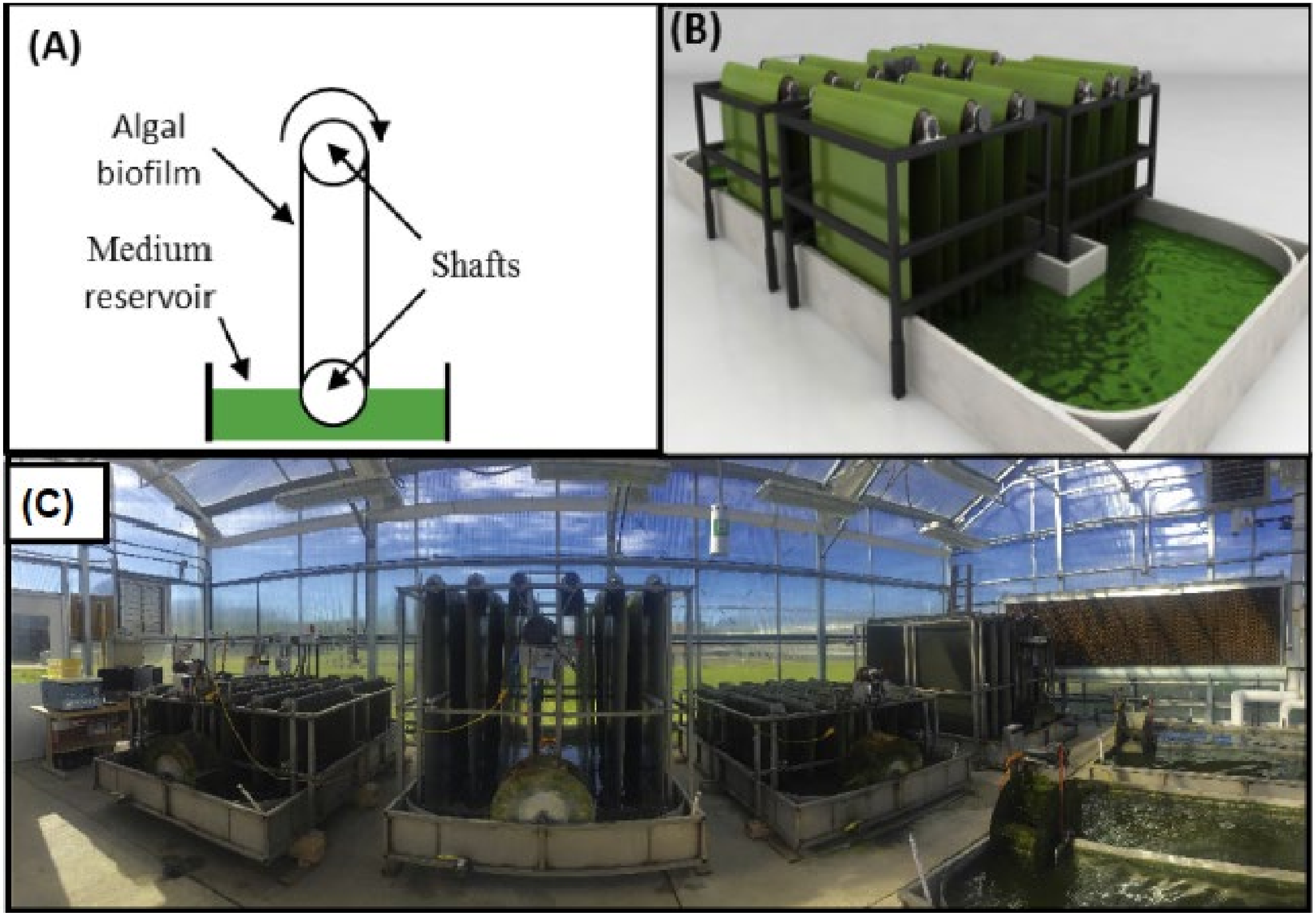
pilot-scale plant recently built in Cadiz, Spain.

[Frank Rogalla, Aqualia; ABS Presentation, October 2016]

Small-scale high rate algal ponds are also being tested at pilot-scale at treatment plants in the U.S.

[microbioengineering.com/products]

High rate ponds with the addition of attached growth are (actively) being pursued as well.



[Zhao et al., *Water Research* 143, 2018]

Photobioreactors can further intensify treatment and have been pursued at pilot-scale.

[chemicals-technology.com]

[sardi.sa.gov.au]

[Rodolfi et al., *Biotech Bioeng* 102(1), 2009]

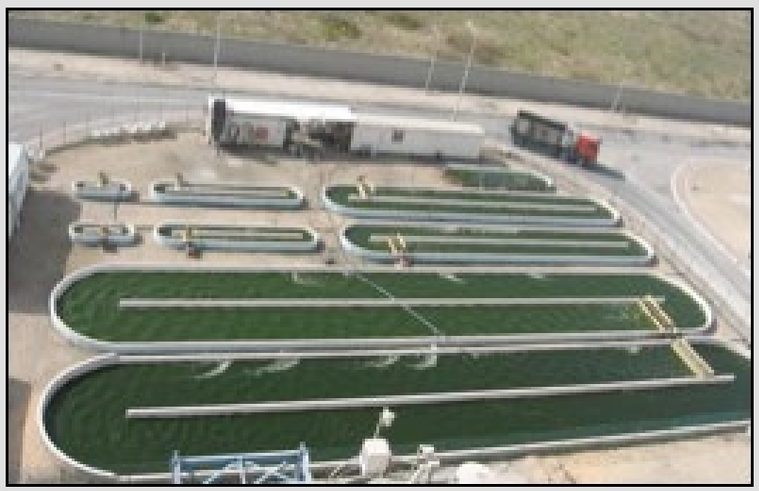
[bae.uky.edu]

At least one photobioreactor system will be operating at full-scale in the United States in 2019.

Innovation and understanding of algal systems has been constrained by a few key assumptions.

typical assumptions

HRT = SRT



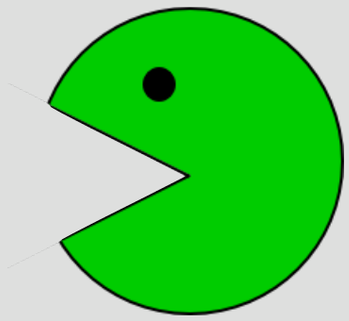
no solid-liquid separation to retain biomass in the system

fixed N:P ratios

Redfield ratio

$C_{106}N_{16}P$

N:P = 16:1



or species-specific **N:P**

we cannot control what grows

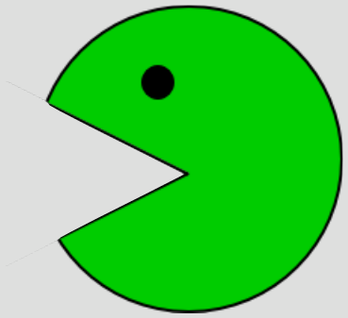
it's just a "bloom"

Intensification enables us to challenge all of these assumptions.

typical assumptions

HRT = SRT

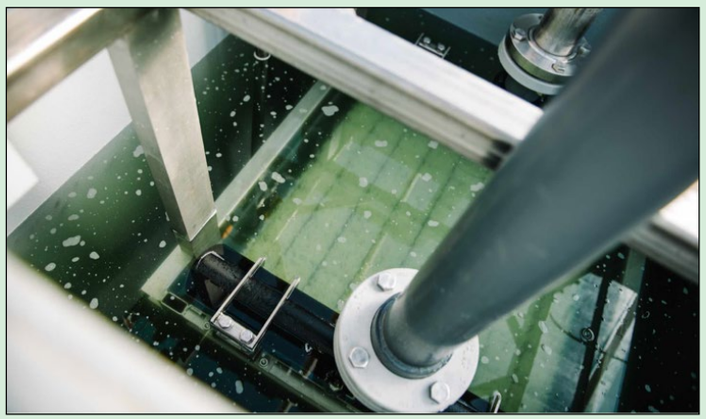
fixed N:P ratios



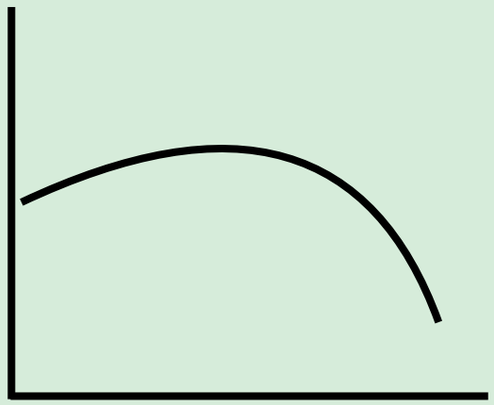
we cannot control what grows

opportunities for innovation

HRT << SRT

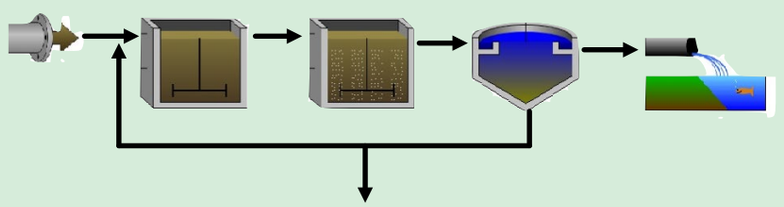


N:P is dependent on species & growth rate



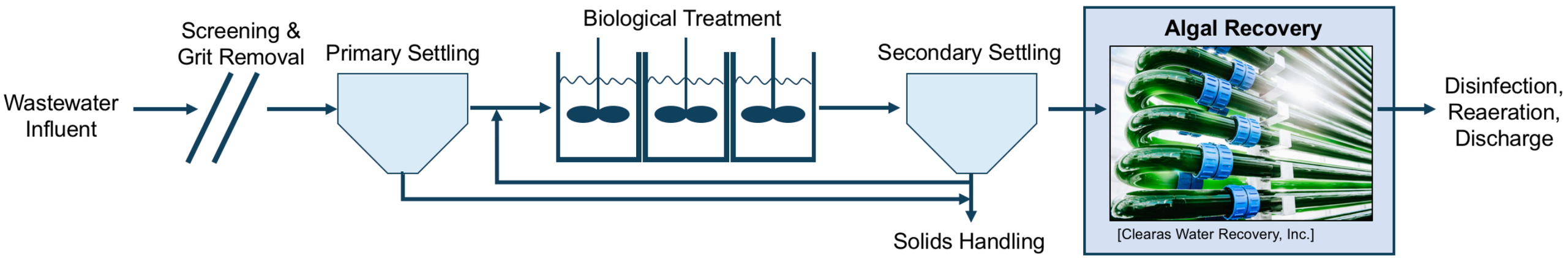
[Terry et al. (1985) *J. Phycol.* 21, 323–329.; Ågren (2004) *Ecol. Lett.* 7, 185–191.]

selective pressures can enable reliability



These processes have the potential to achieve tertiary or sidestream nutrient recovery.

Tertiary Treatment



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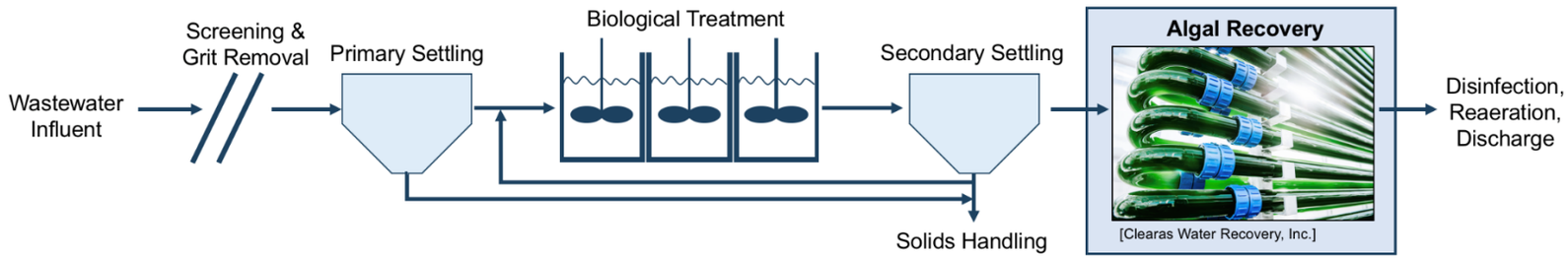
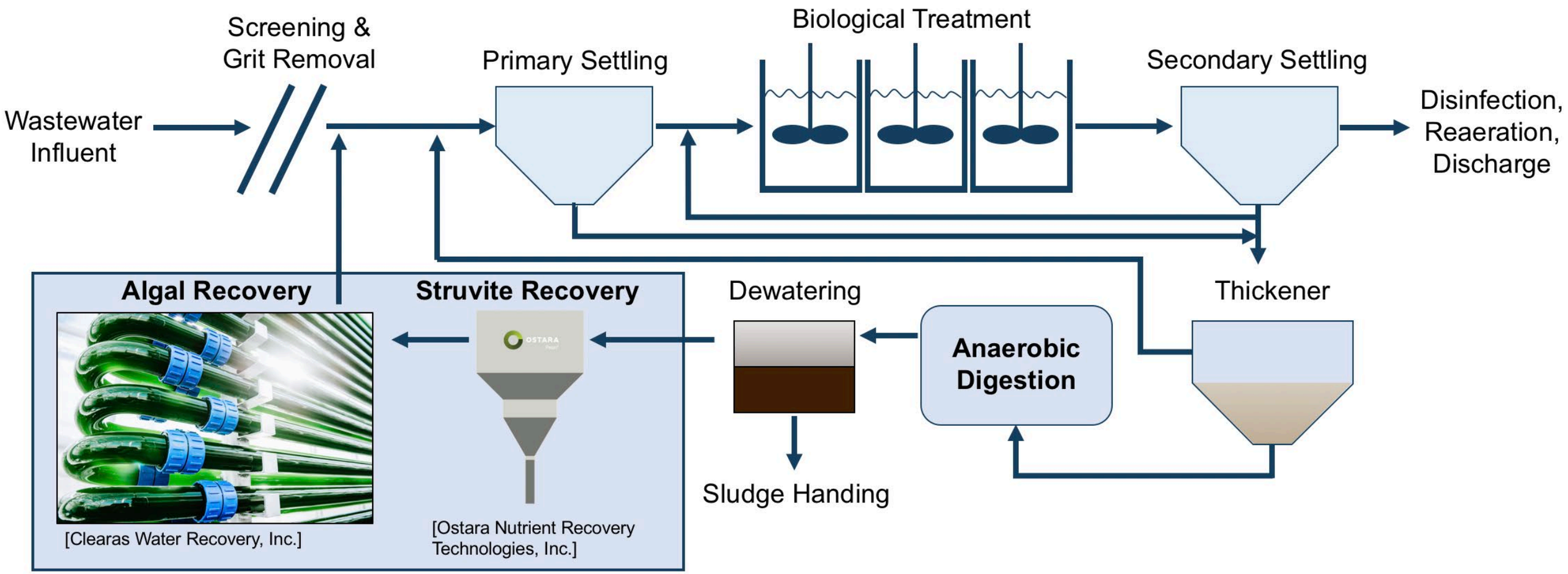


Sidestream Treatment



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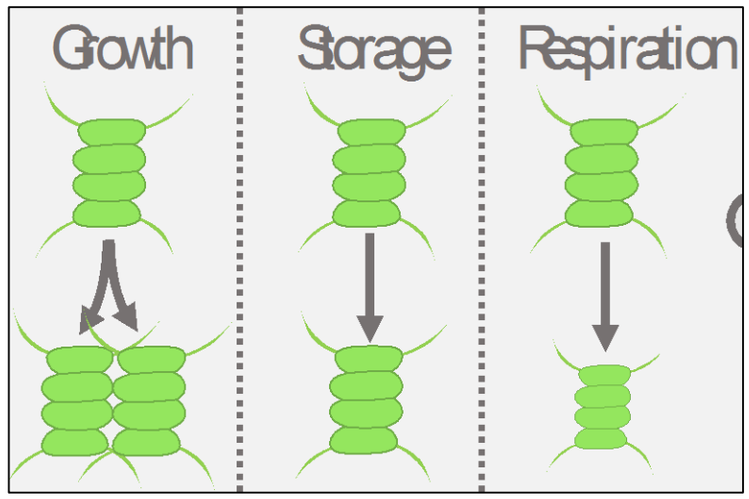

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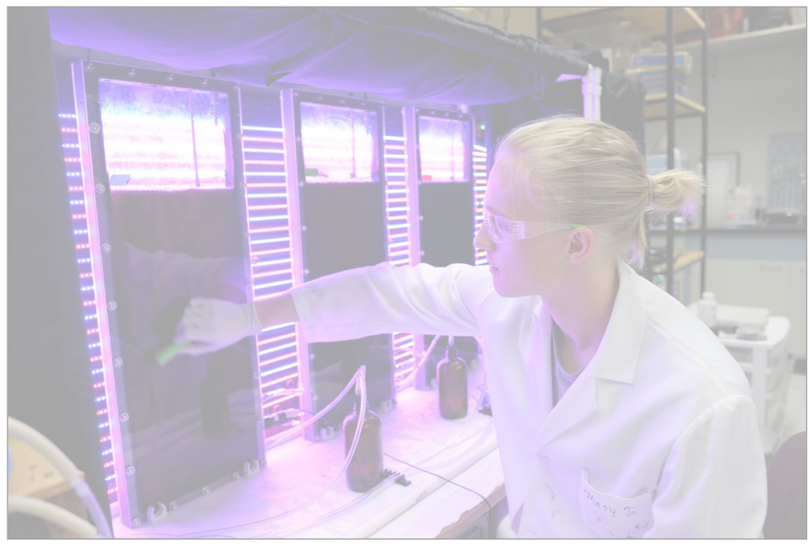
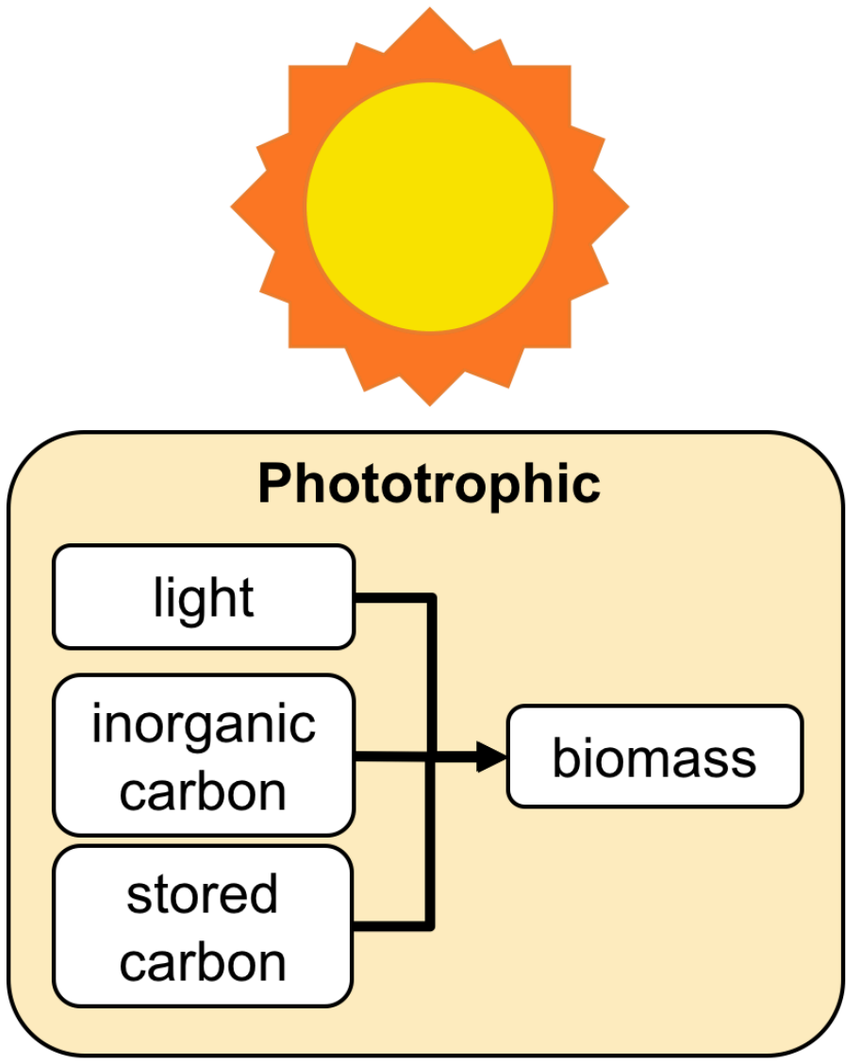


Algae possess multiple metabolisms that should be considered when formulating a model.



[Shoener *et al*., 2018 (in preparation)]

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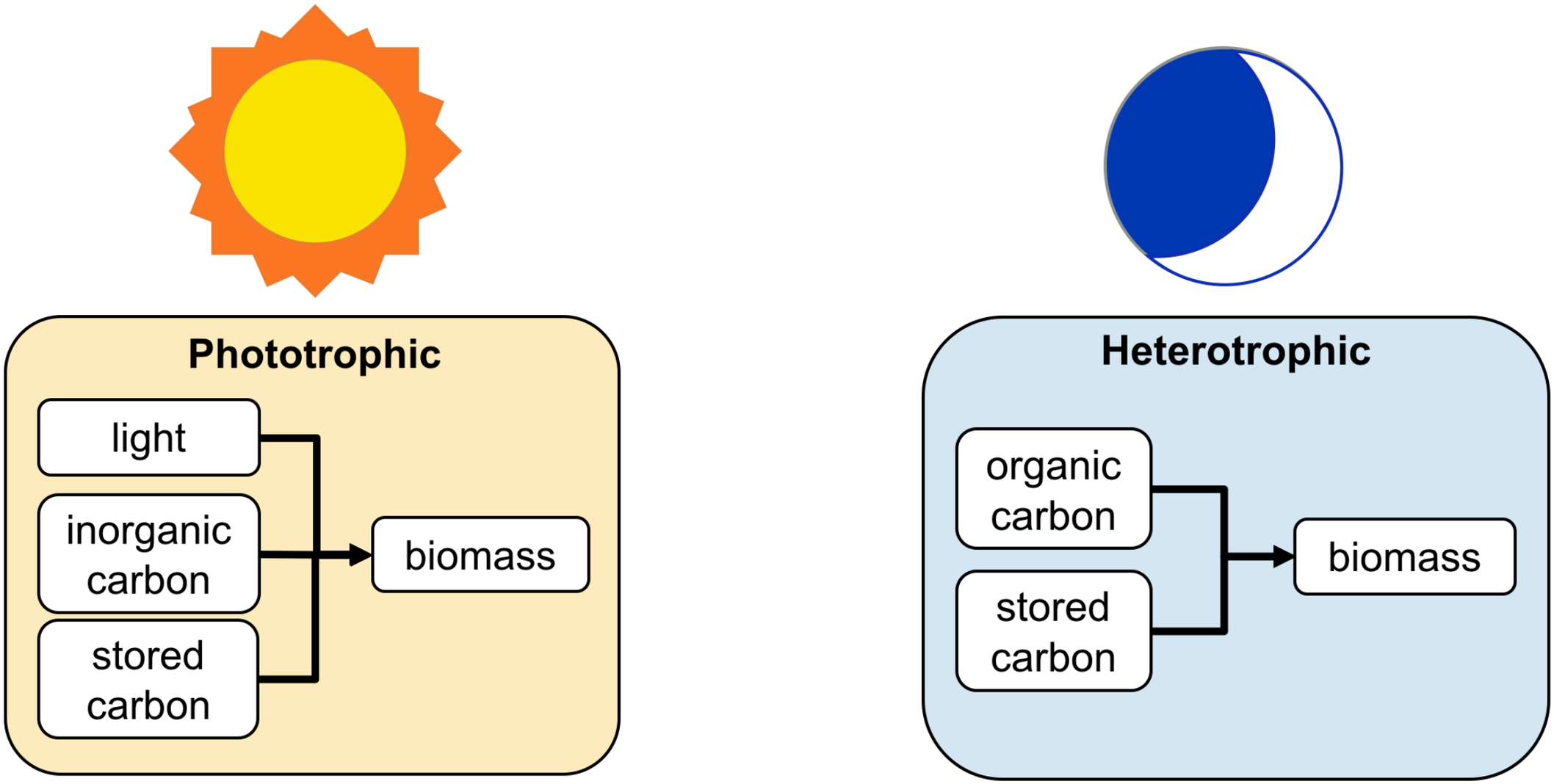

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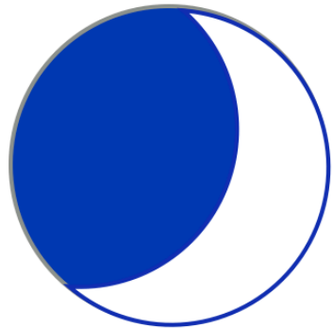

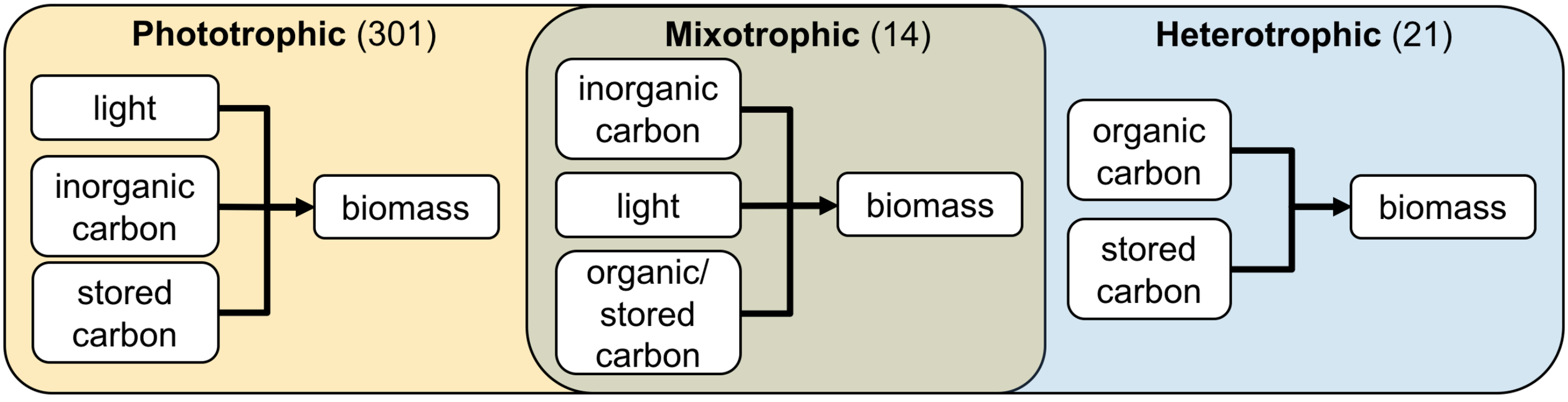

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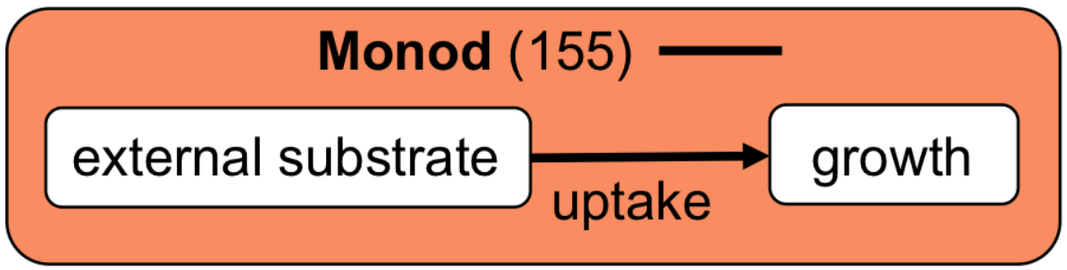
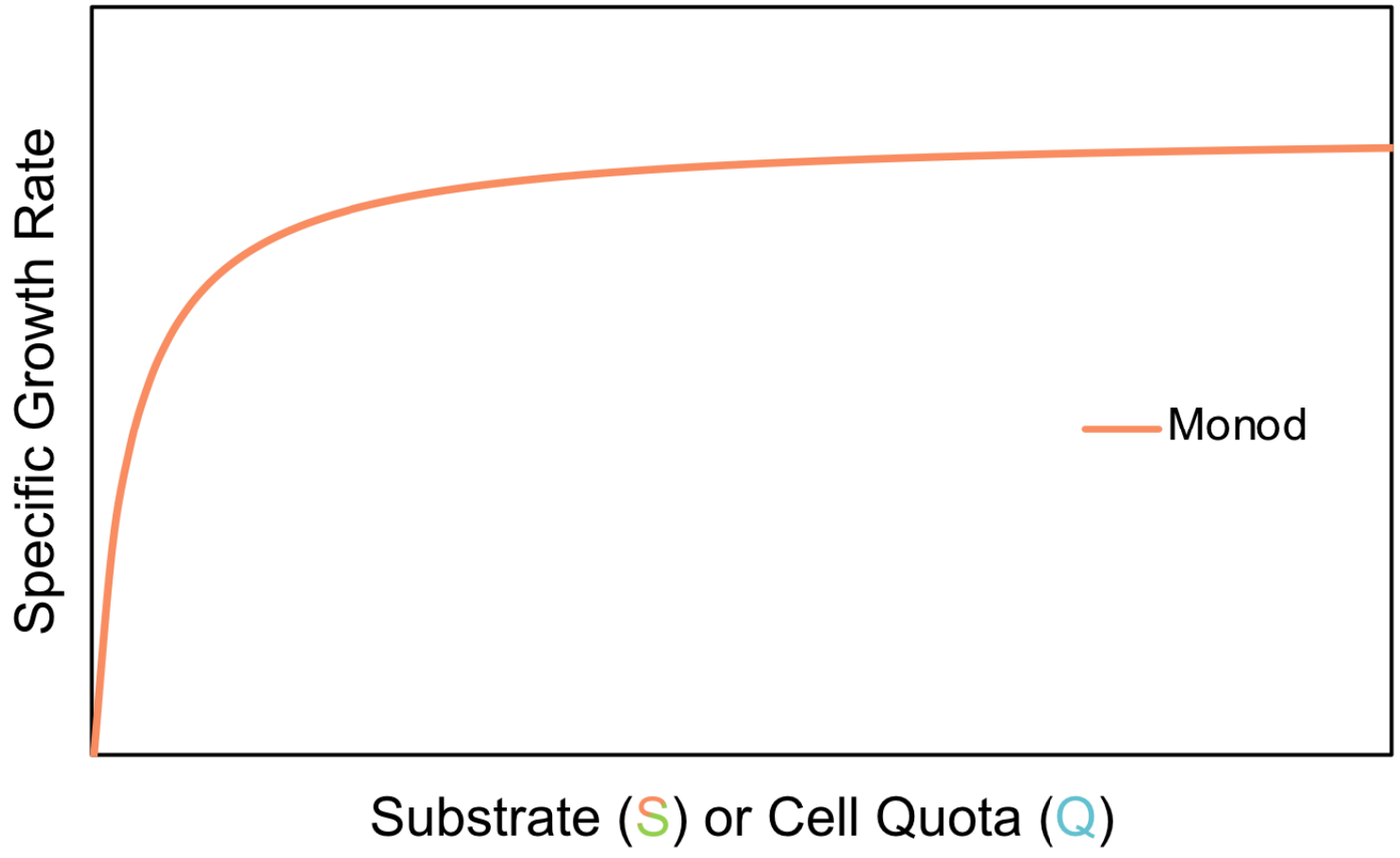
Although we typically assume Monod kinetics in wastewater treatment, Droop will often be more appropriate for algae.





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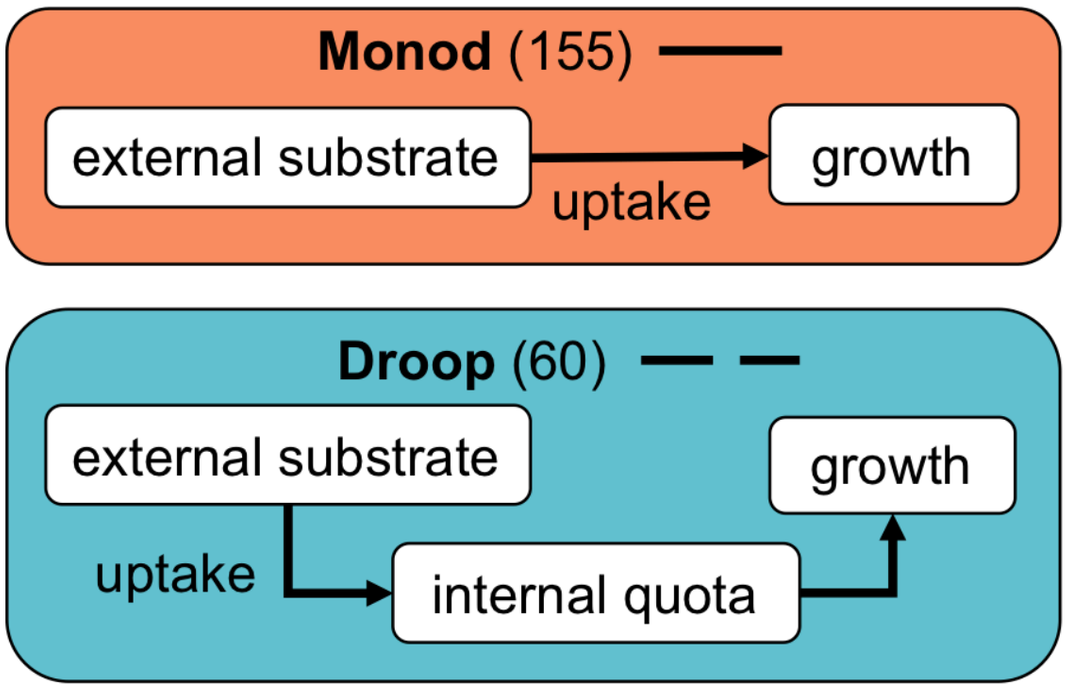

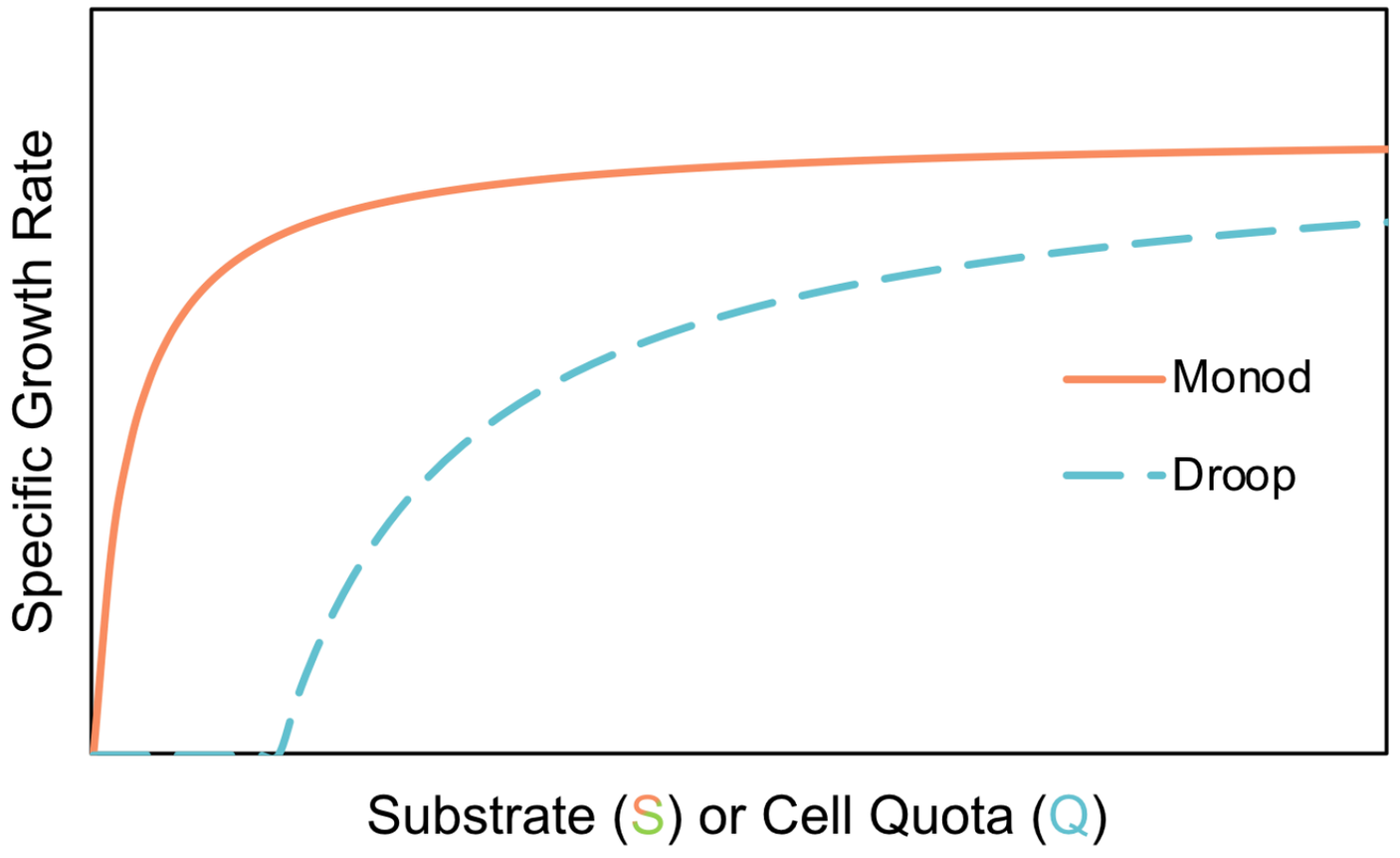

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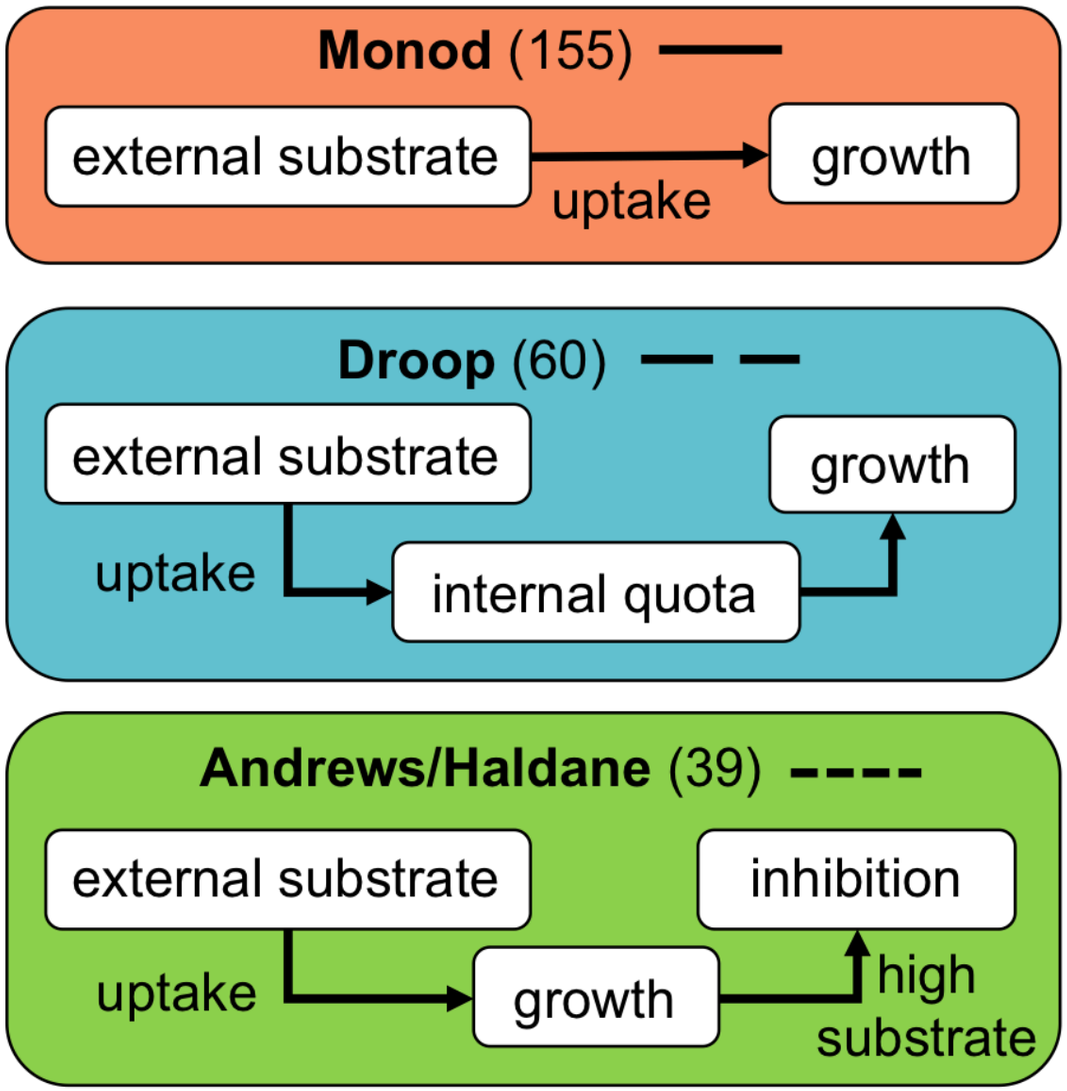
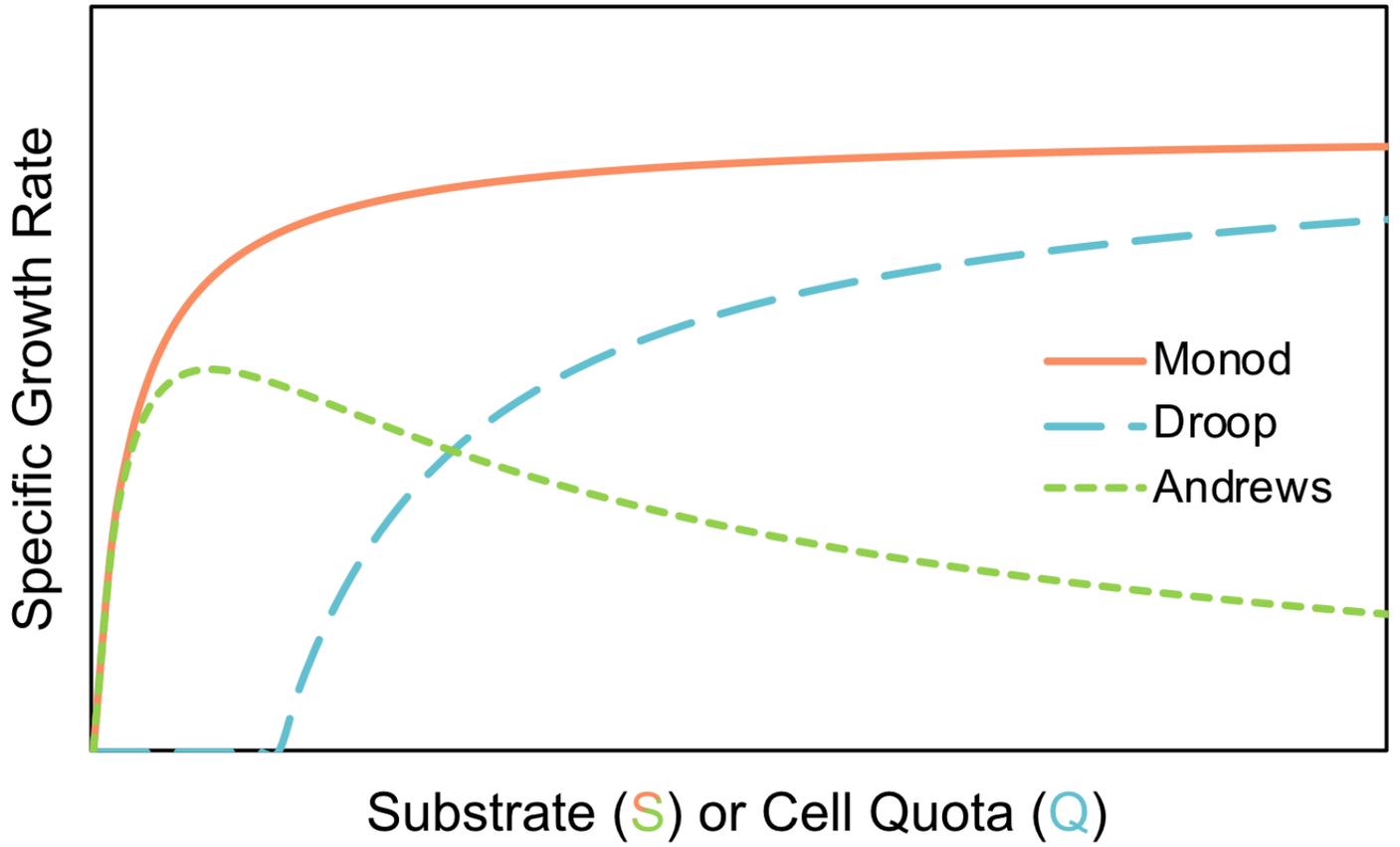
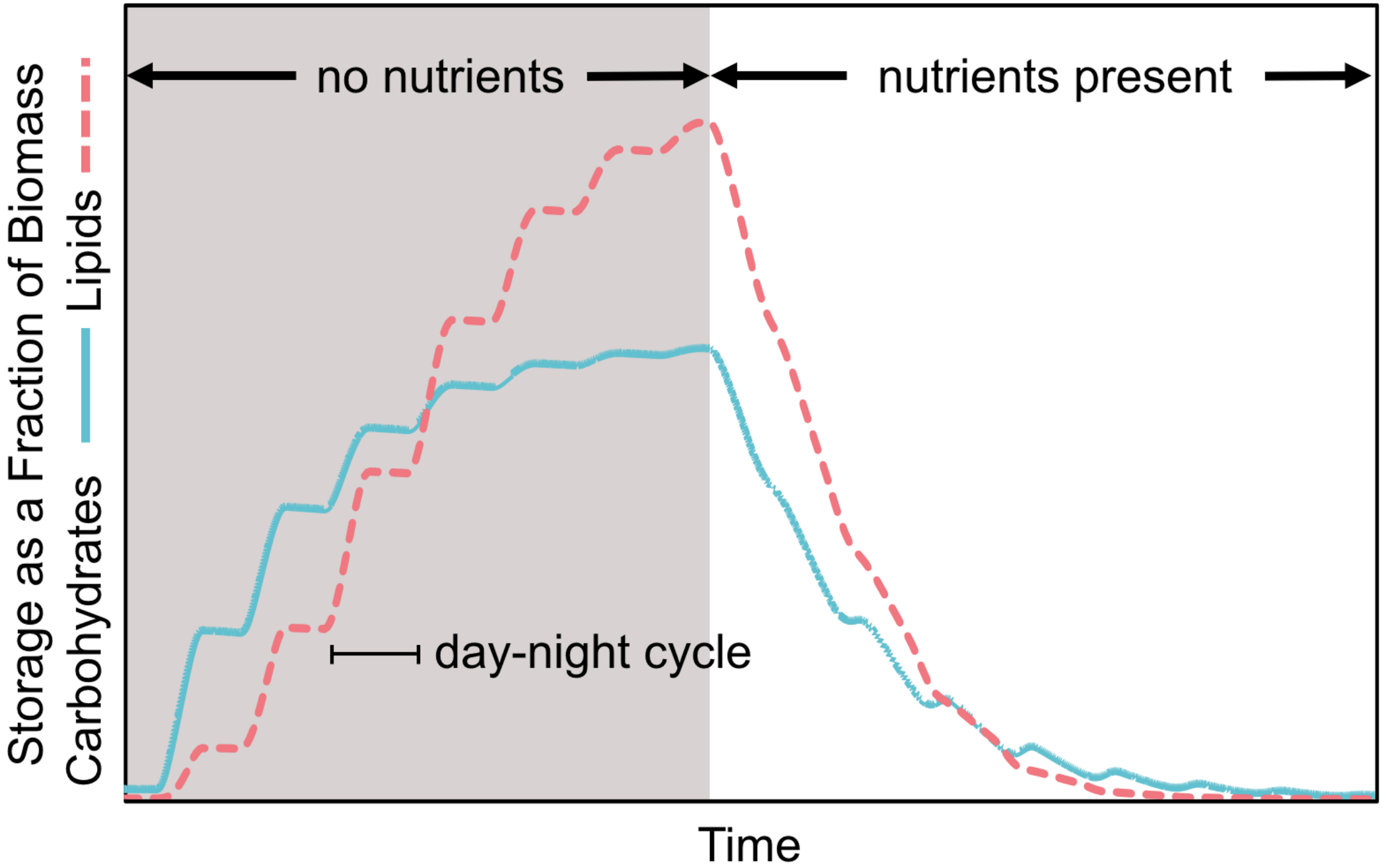




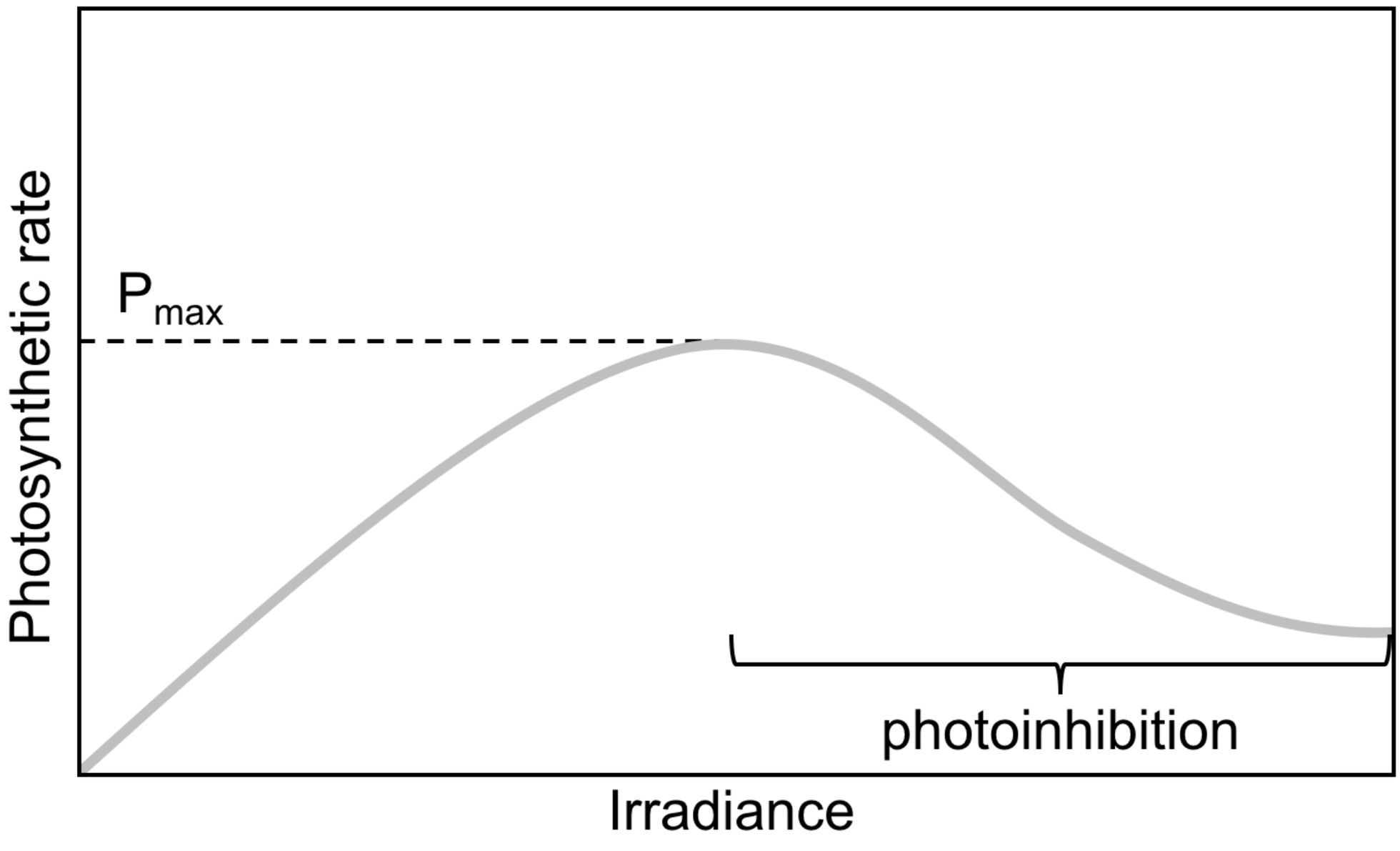
[Shoener *et al*., 2018 (in preparation)]

Carbon storage can be critical for coping with stress and for growth in dark conditions.



[Shoener *et al*., 2018 (in preparation)]

Lots of light can actually be inhibitory (too much of a good thing).



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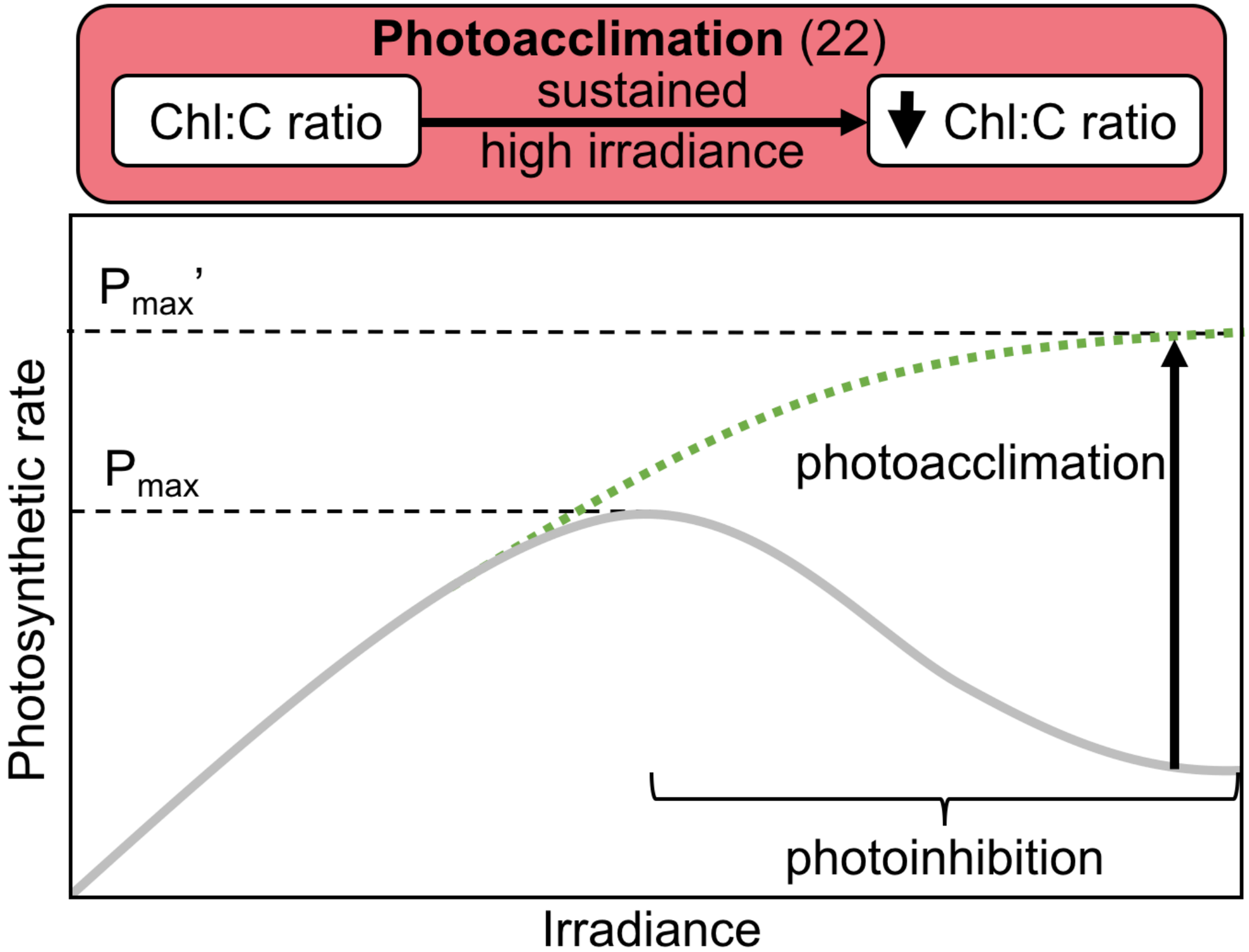
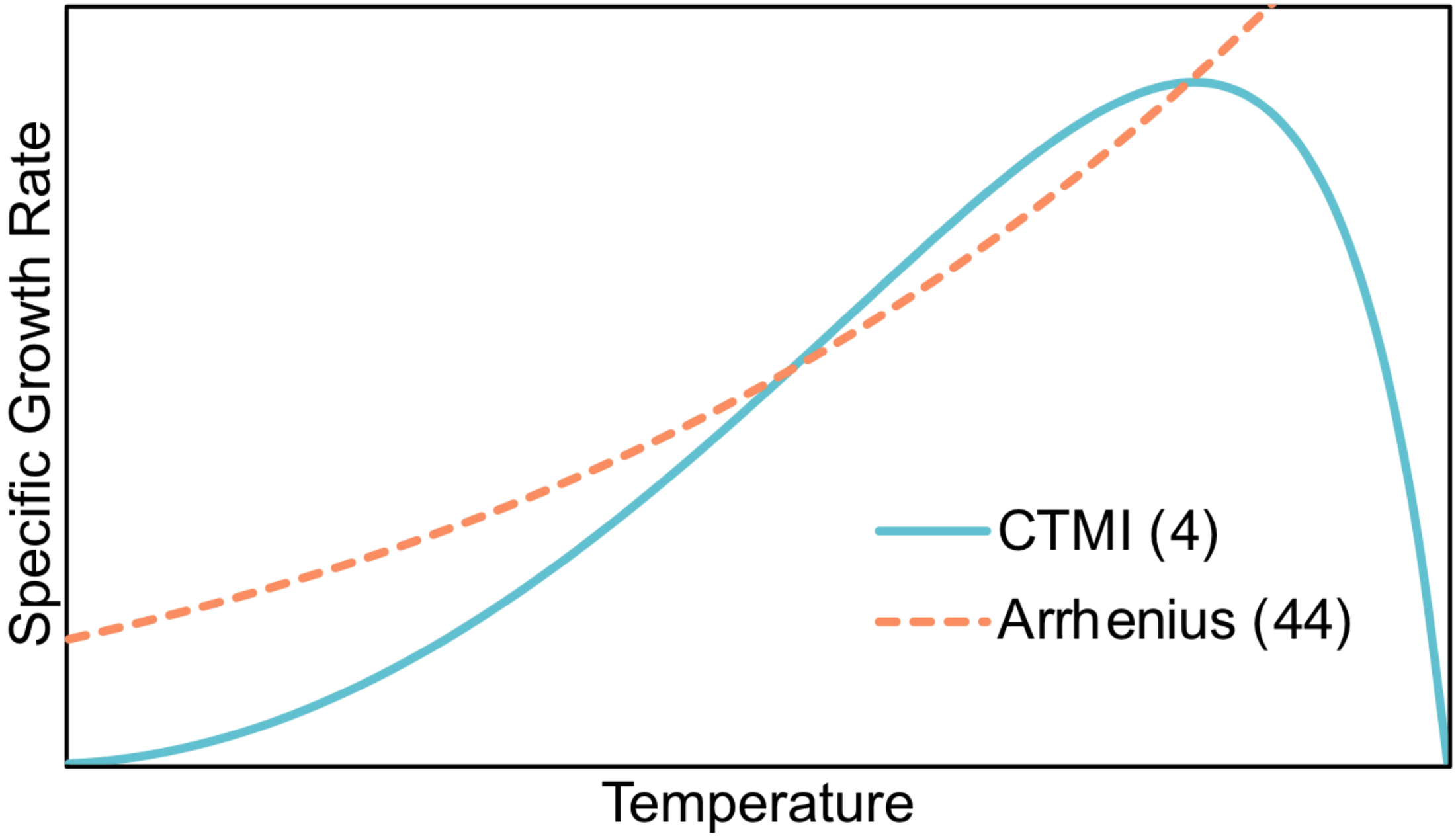


[Shoener *et al*., 2018 (in preparation)]

Algae may also be sensitive to high temperatures, which is not exactly what we would predict from most wastewater bacteria.



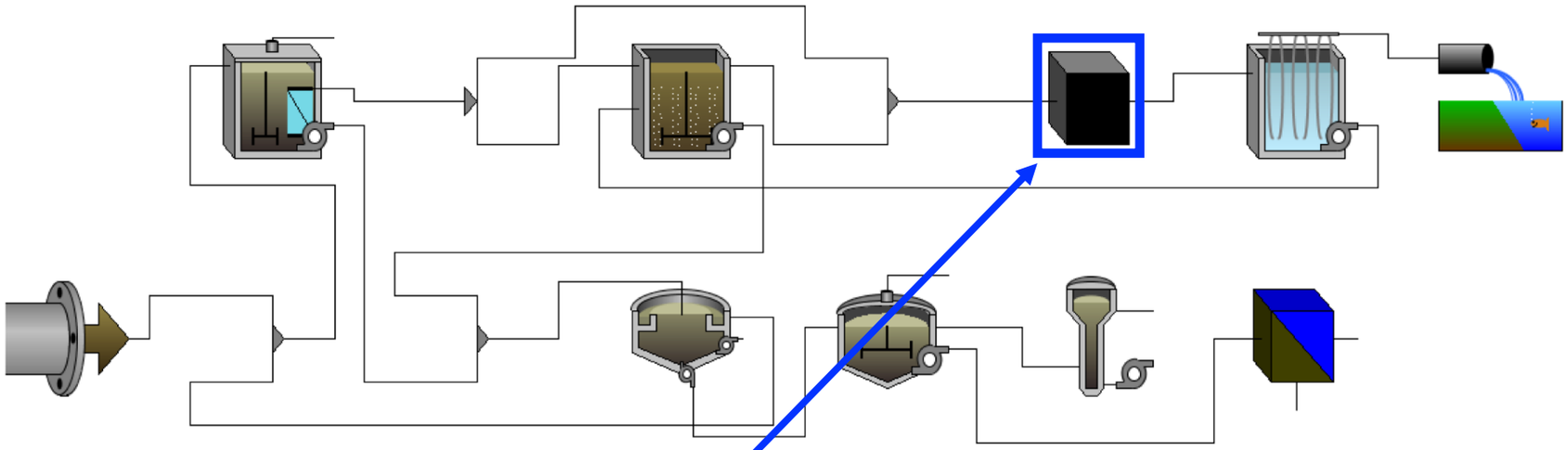
[Shoener *et al*., 2018 (in preparation)]

We are in the process of building this model structure into wastewater modeling platforms and calibrating/validating.

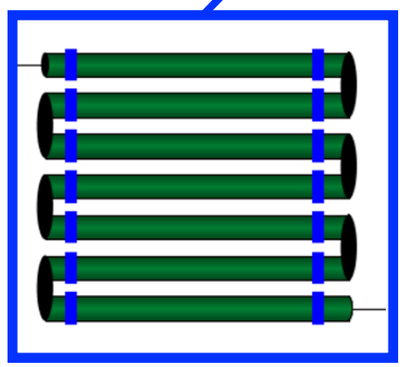
use whole-plant, dynamic models

ASMs, ADM1, Mantis, phys-chem models

GPS-X™



add in algal unit processes with the phototrophic process model (PPM)



[Guest et al., *Environmental Science & Technology*, 2013.]

[Shoener *et al*., 2018 (in preparation)]

[Shoener *et al*., (in progress)]

CLEARAS WATER RECOVERY

THE Water Research FOUNDATION

NSF

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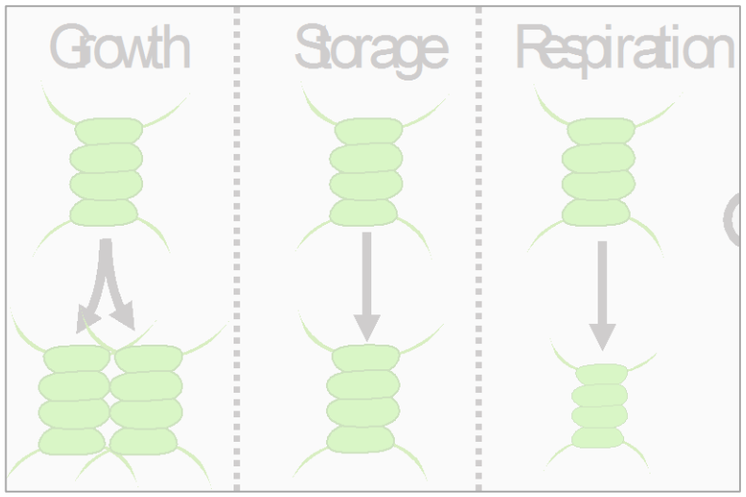
intensification of algal systems for nutrient recovery

modeling & design challenges for algae



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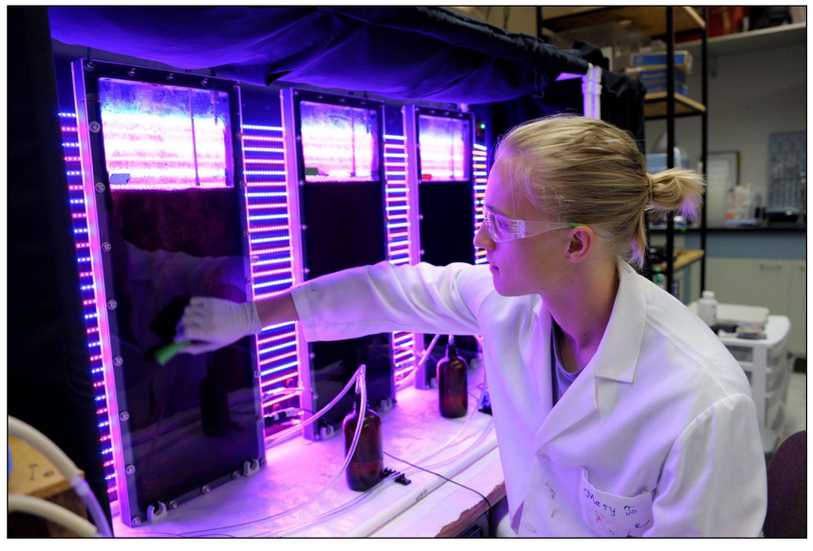
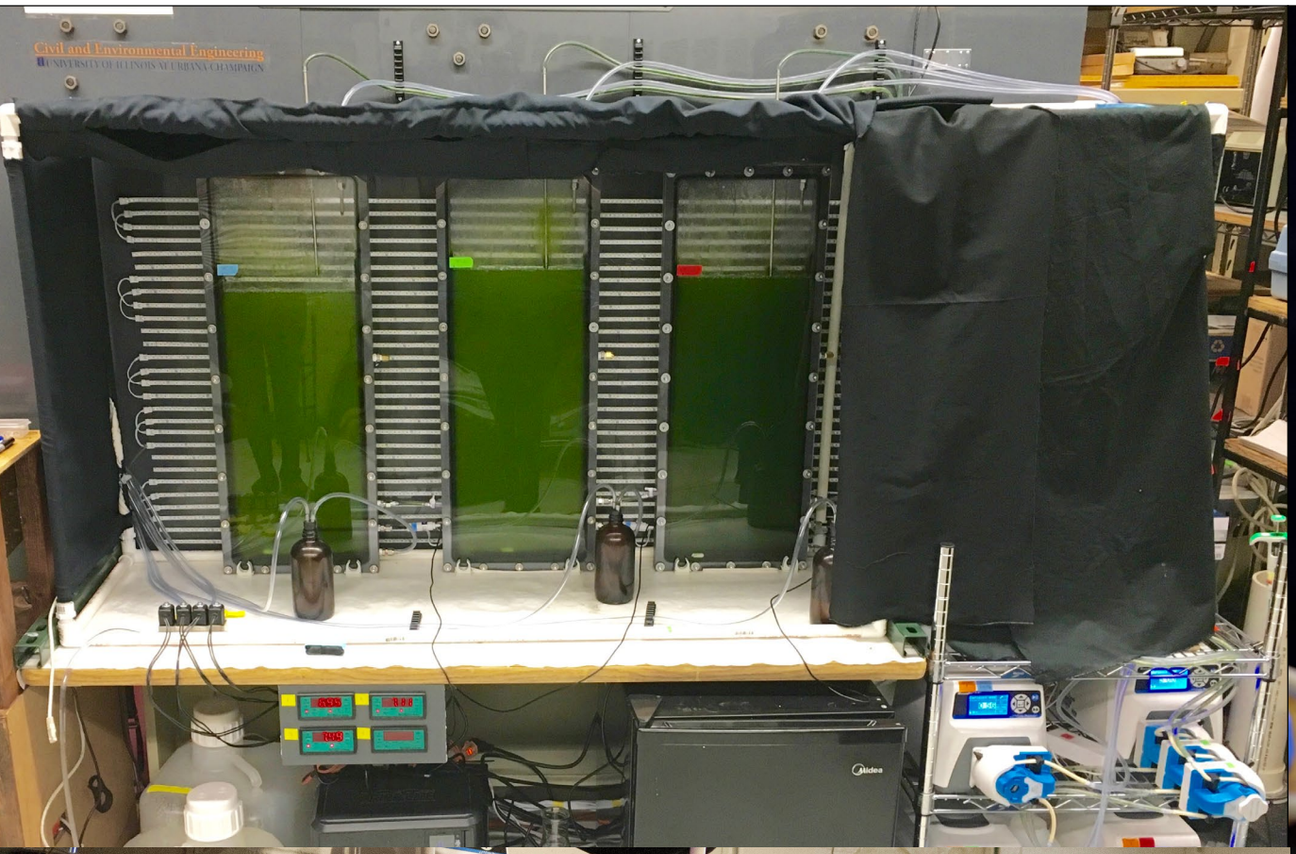
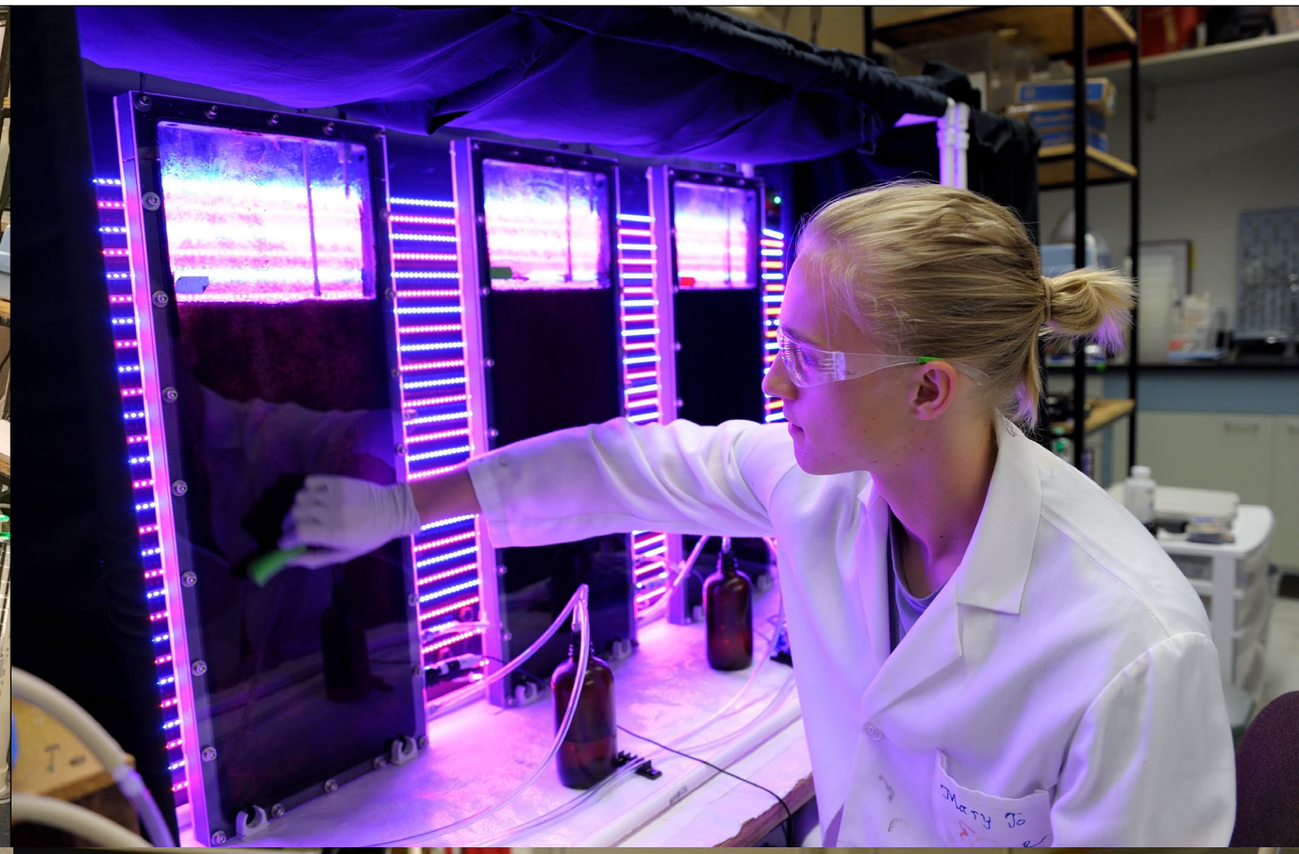
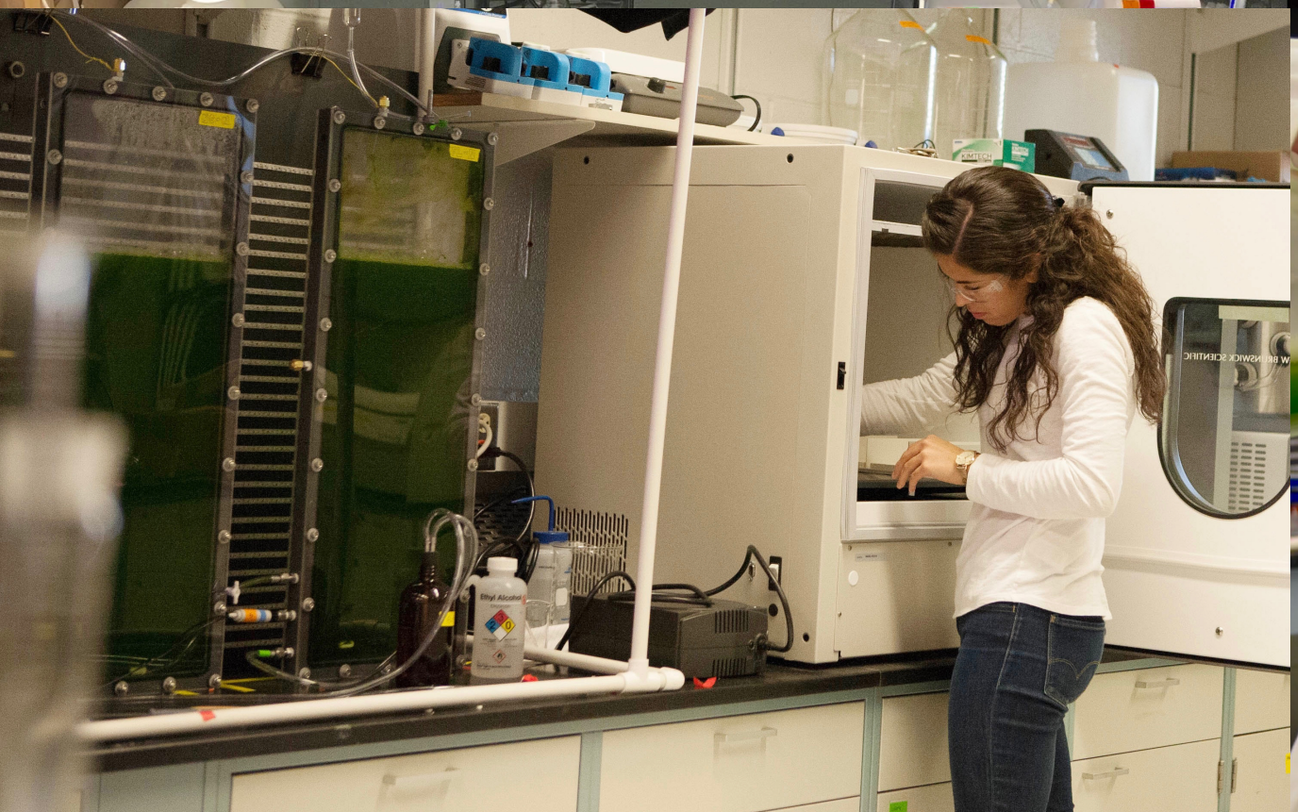


We conduct experimental studies with real and synthetic wastewater, pure and mixed cultures, etc.







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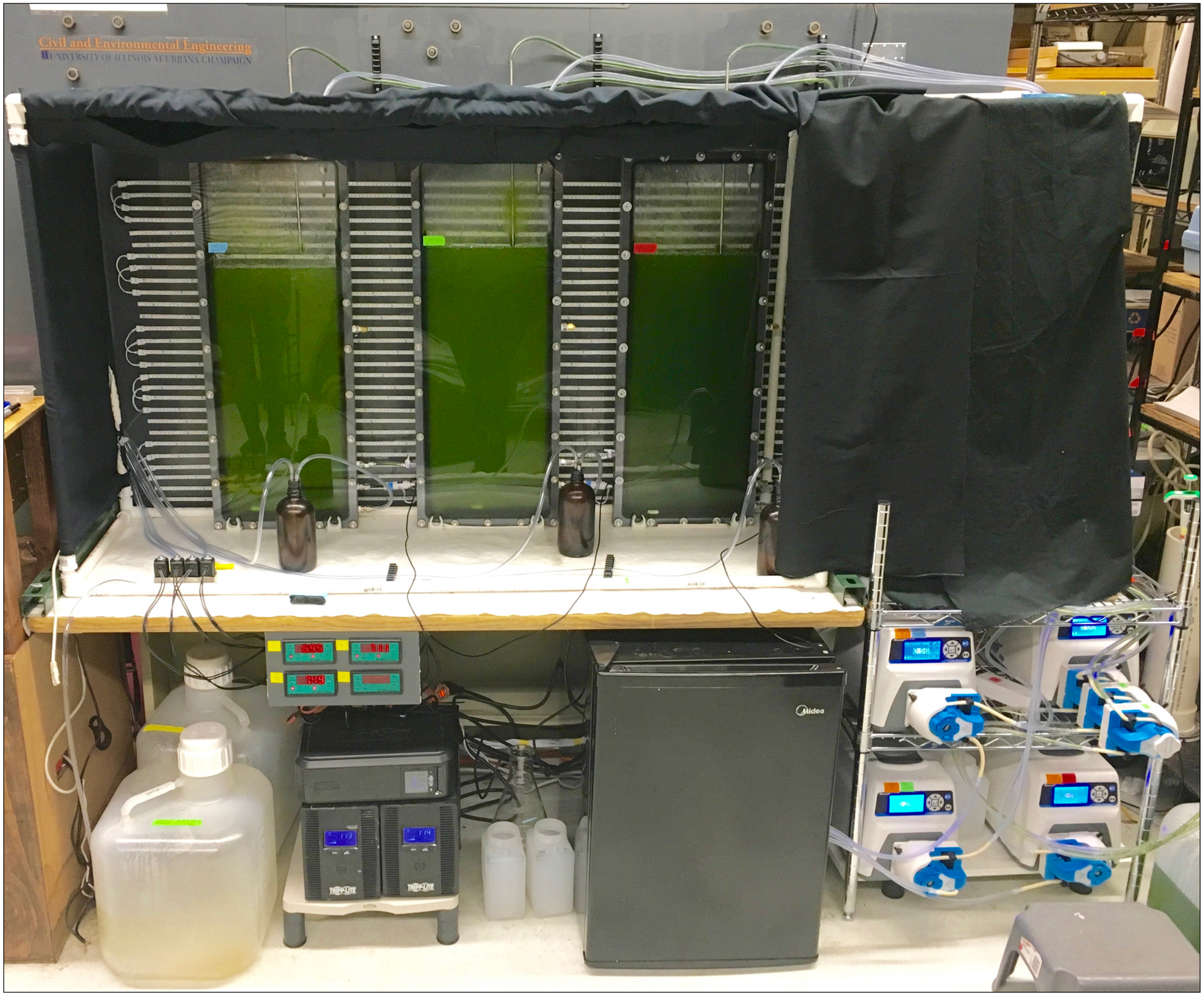
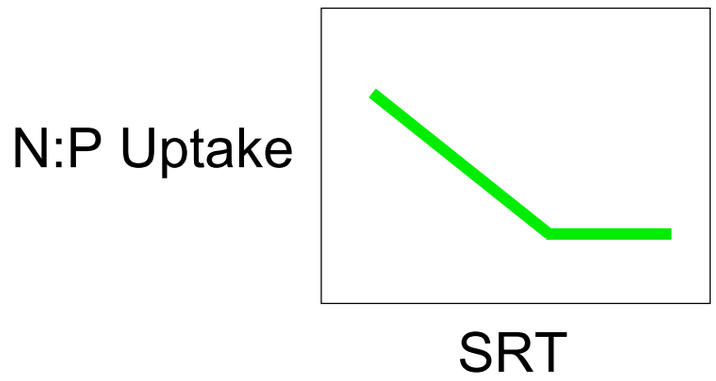


With further development, we may be able to:

1. tailor N:P recovery



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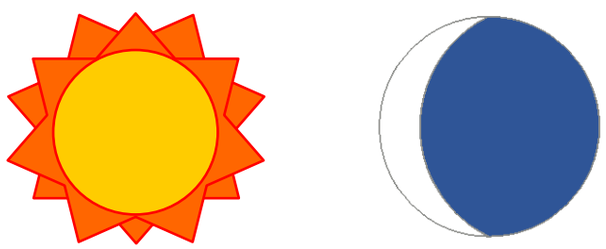
2. use only natural light



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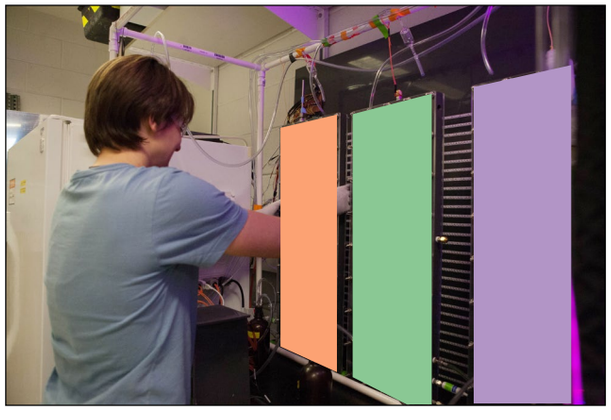
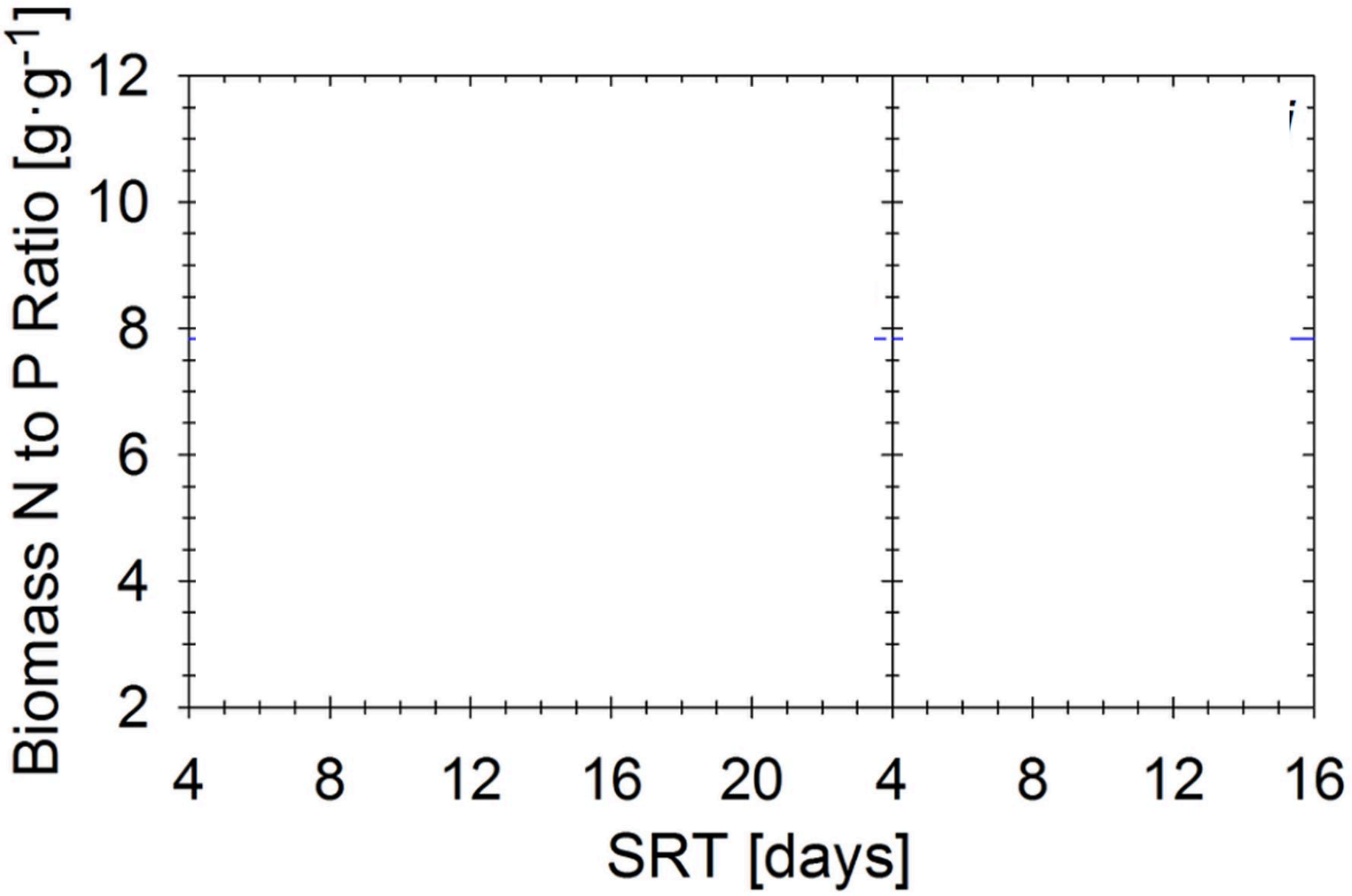
3. use local algae

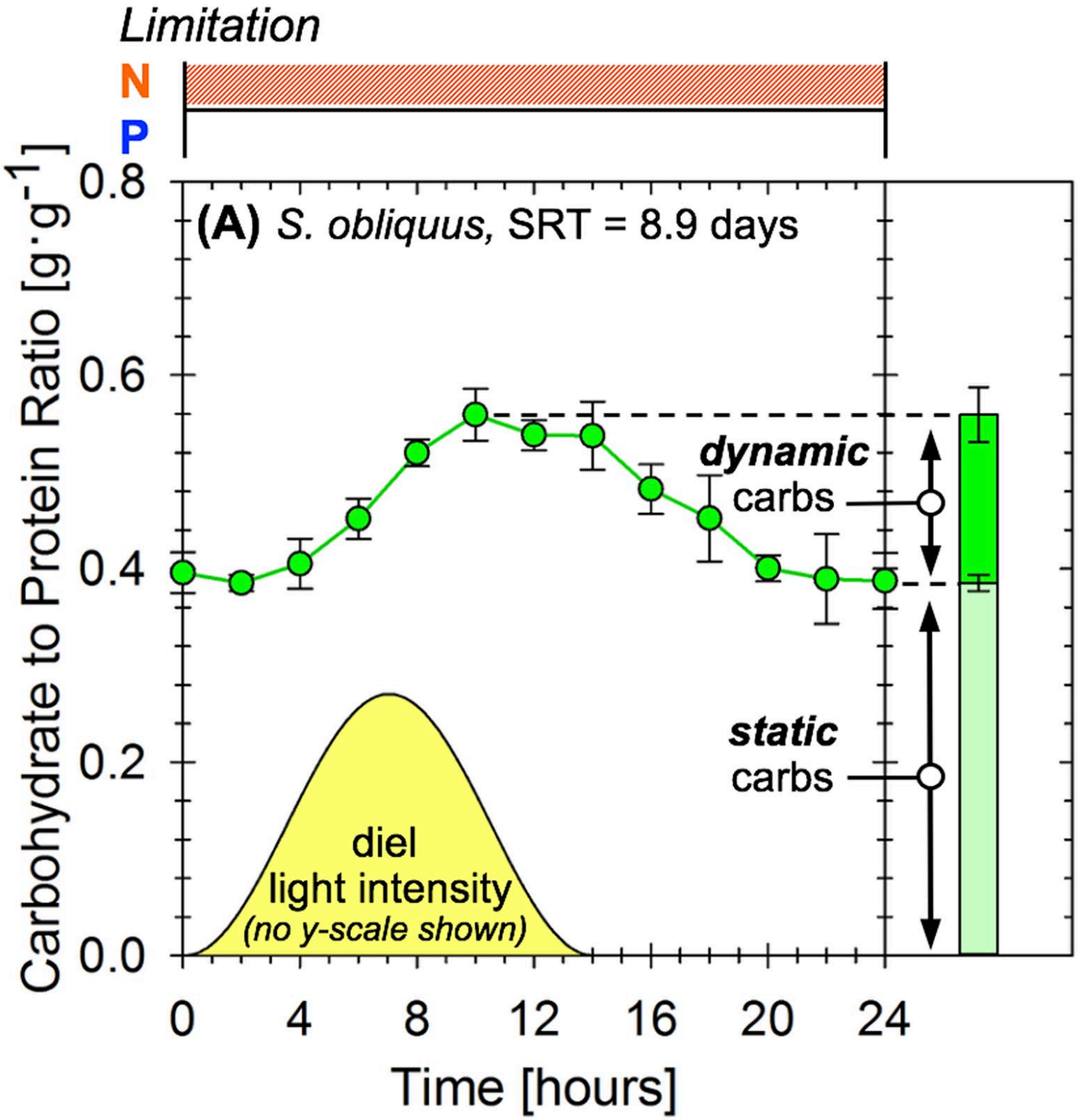


1. The N:P uptake ratio of algae can be influenced by controlling growth rate (via solids residence time, SRT).



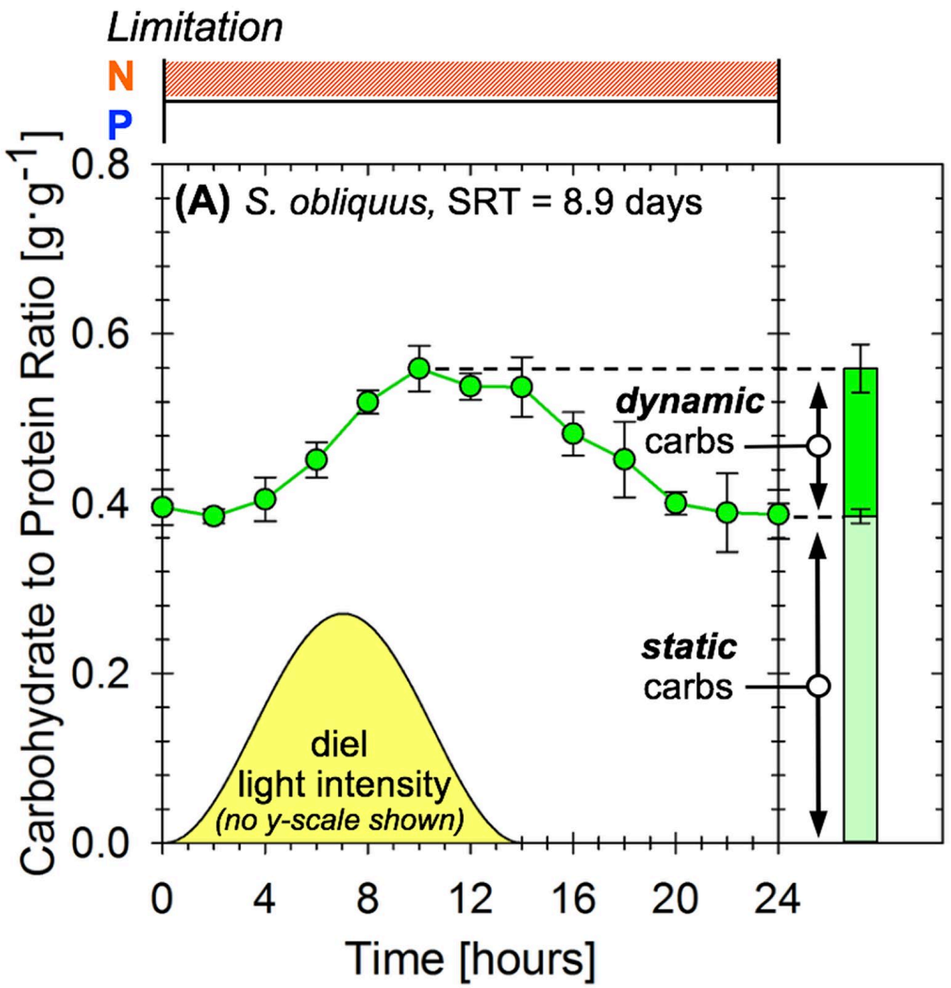
[Gardner-Dale, D.A.; Bradley, I.M.; Guest, J.S. Influence of solids residence time and carbon storage on nitrogen and phosphorus recovery by microalgae across diel cycles. *Water Research*, 2017, 121: 231-239.]

2. Algae can take up nutrients at night by using intracellular, stored organic carbon.



[Gardner-Dale, D.A.; Bradley, I.M.; Guest, J.S. Influence of solids residence time and carbon storage on nitrogen and phosphorus recovery by microalgae across diel cycles. *Water Research*, 2017, 121: 231-239.]

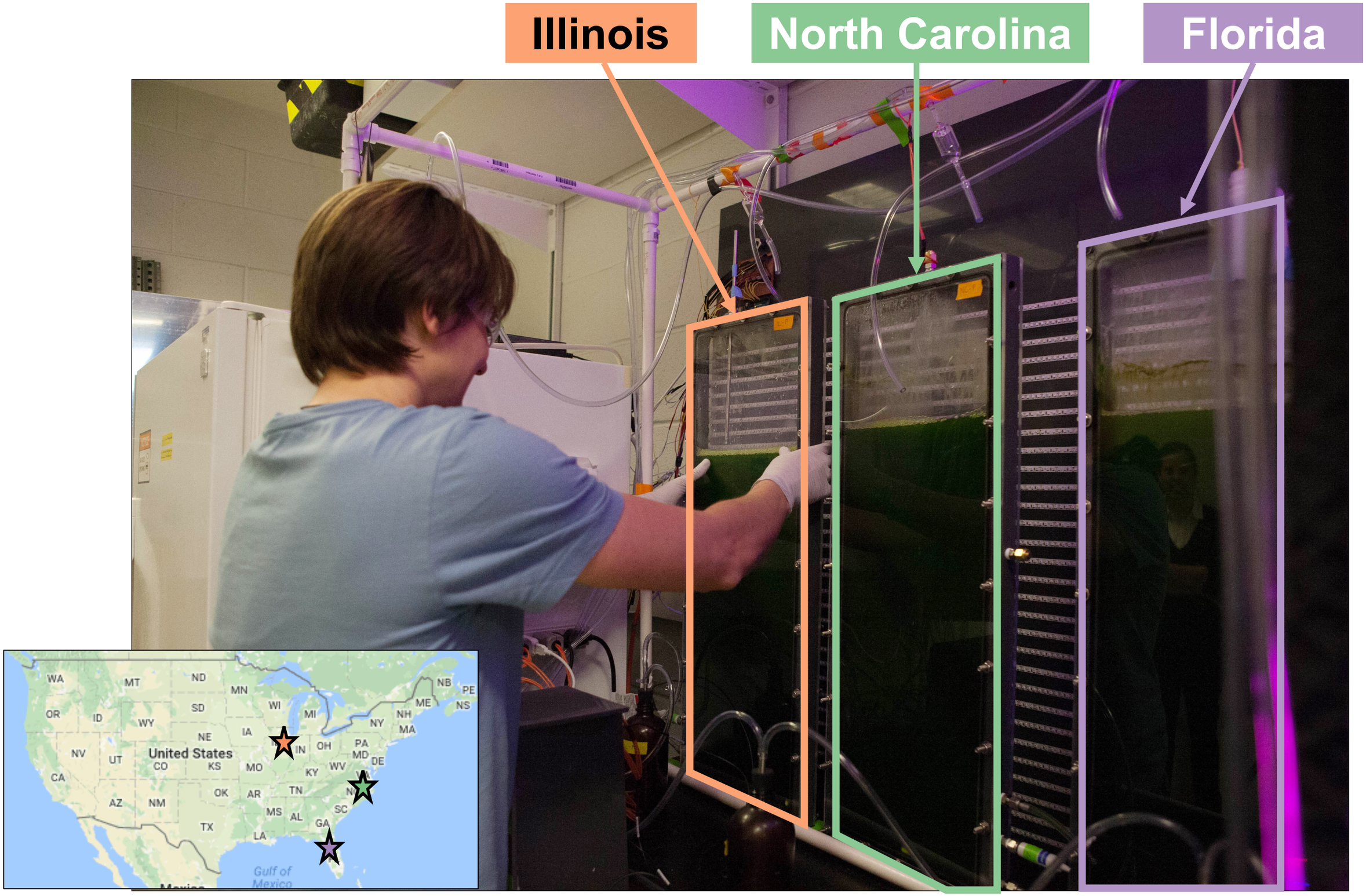
2. Across algae and across SRTs, the amount of dynamic carbohydrates relative to P uptake is relatively consistent.



	dynamic carbohydrates	dynamic carbs for P recovery
S. obliquus	56 +/- 10 mg·L^{-1}	46 +/- 9 mg-carb·mg-P^{-1} *for P-limited cultures* **nutrient uptake is decoupled from growth**
C. reinhardtii	52 +/- 4 mg·L^{-1}	

[Gardner-Dale, D.A.; Bradley, I.M.; Guest, J.S. Influence of solids residence time and carbon storage on nitrogen and phosphorus recovery by microalgae across diel cycles. *Water Research*, 2017, 121: 231-239.]

3. You may be able to achieve reliable performance with your local algae.



[Fedders, A.C.; DeBellis, J.L.; Bradley, I.M.; Sevillano-Rivera, M.C.; Pinto, A.J.; Guest, J.S. Comparable nutrient uptake across diel cycles from three distinct algal communities. *In revision.*]

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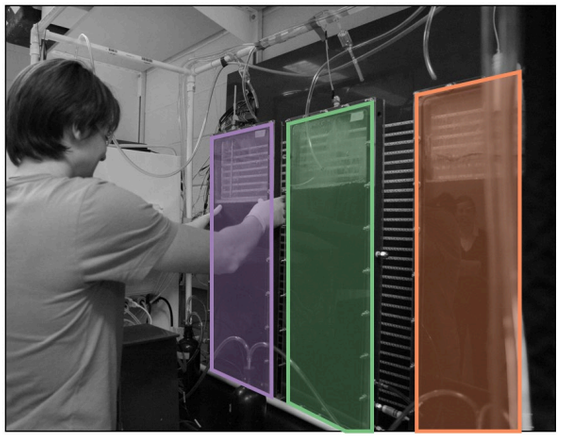
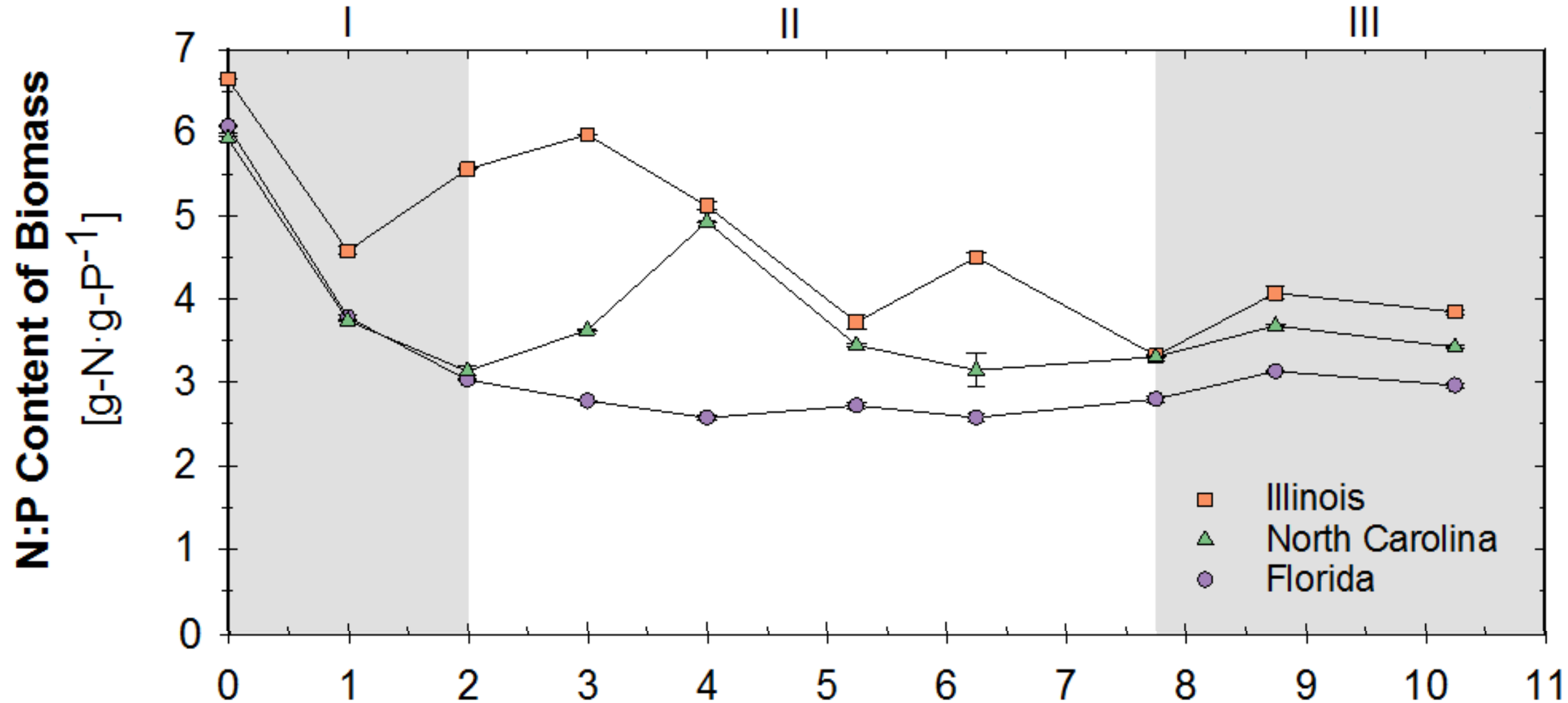


<u>across all reactors:</u>

no detect **N by end of night**

similar volatile suspended solids (VSS)

similar carbohydrate storage



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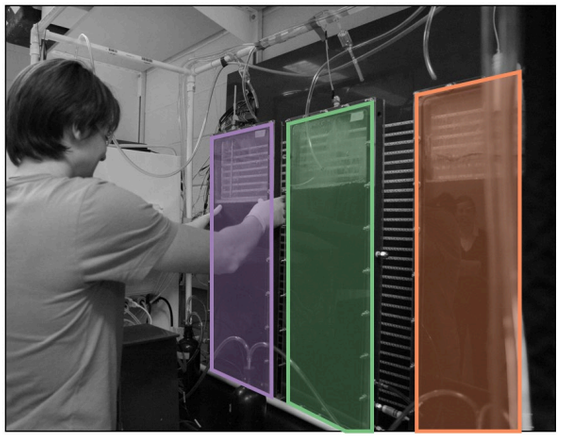
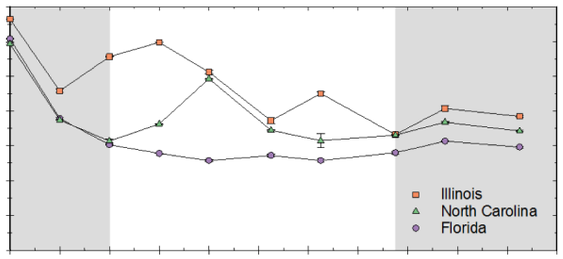
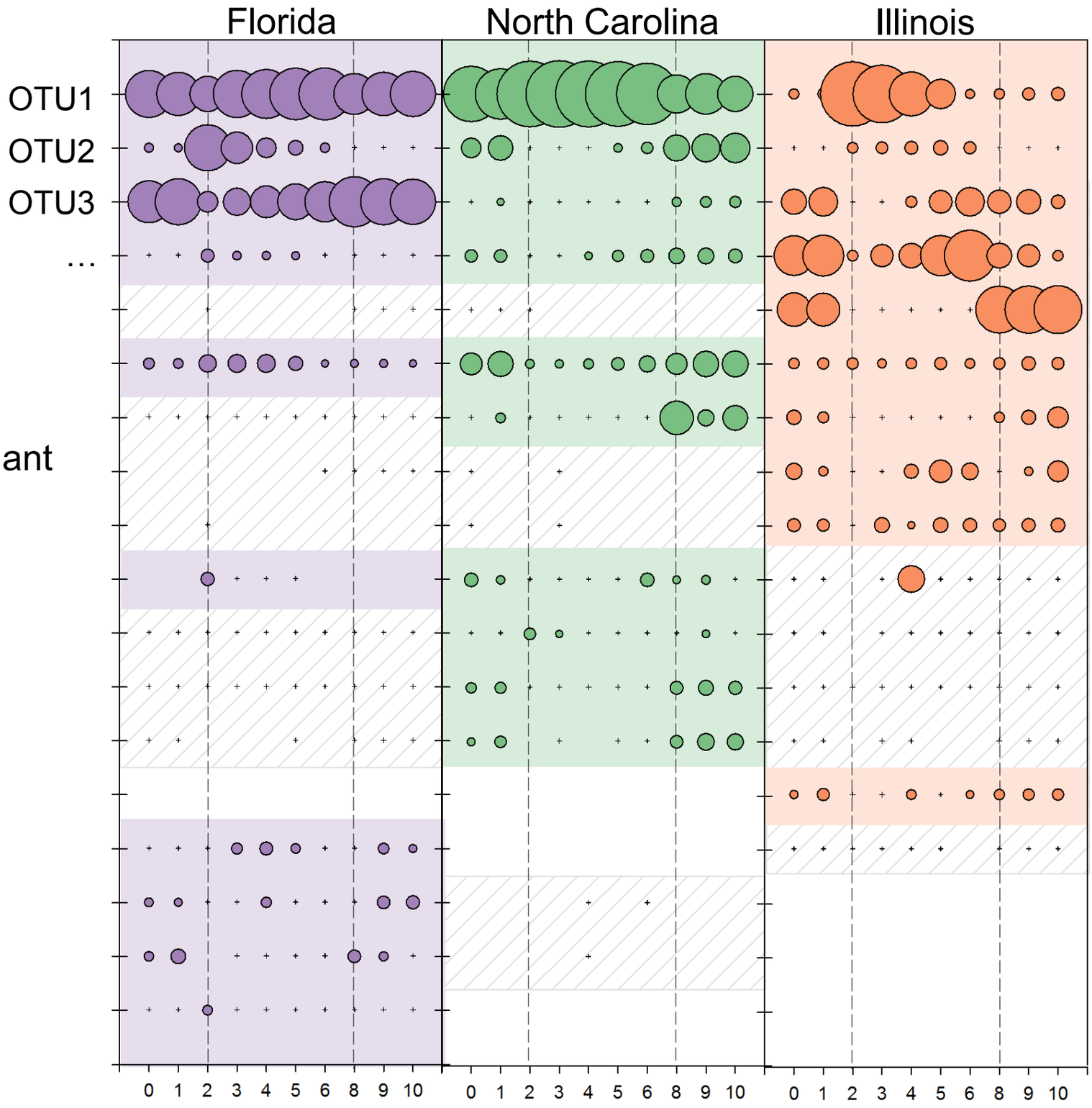




Most Abundant OTUs



< 1% 5% 25% 50% 100%

Mean Relative Read Abundance

MiSeq-compatible 18S rRNA primers

[Bradley et al. *Applied and Environmental Microbiology*, 2016, 82(19): 5878-5891]

[Fedders, A.C.; DeBellis, J.L.; Bradley, I.M.; Sevillano-Rivera, M.C.; Pinto, A.J.; Guest, J.S. Comparable nutrient uptake across diel cycles from three distinct algal communities. *In revision.*]

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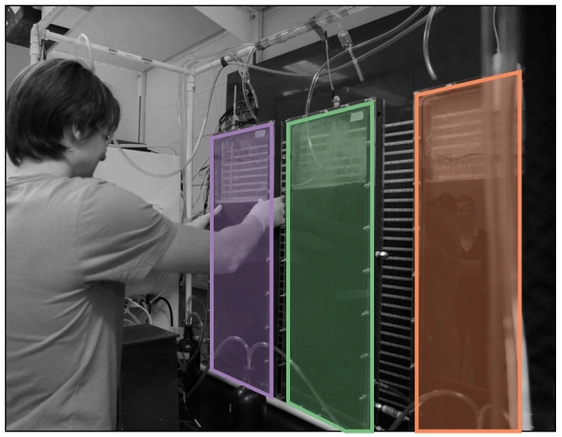
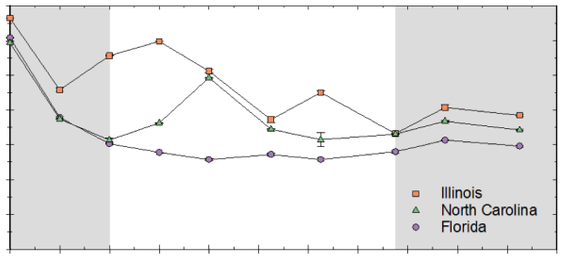
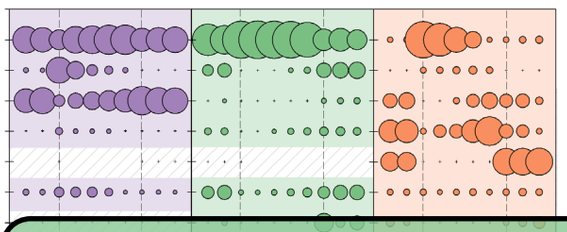
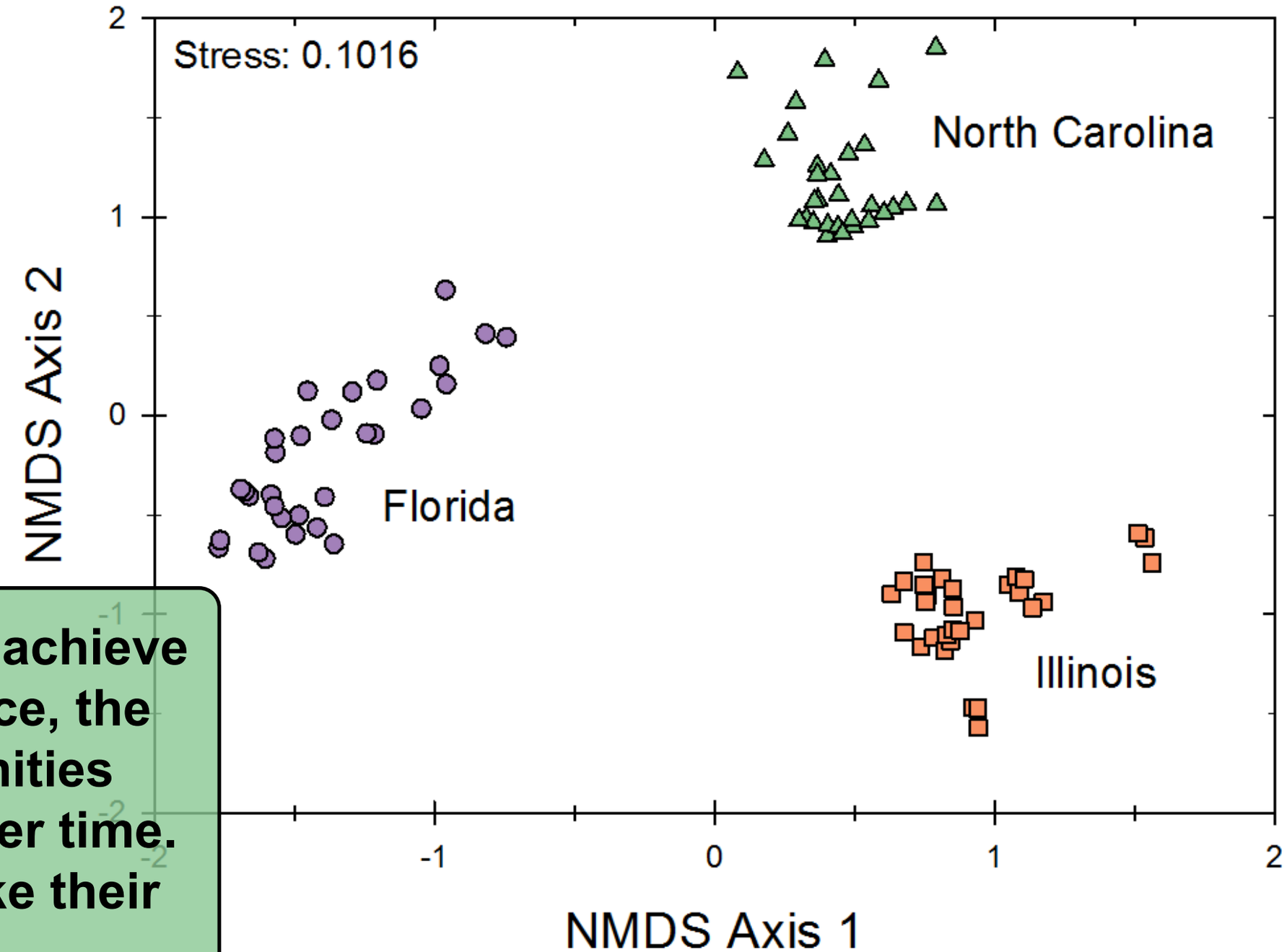






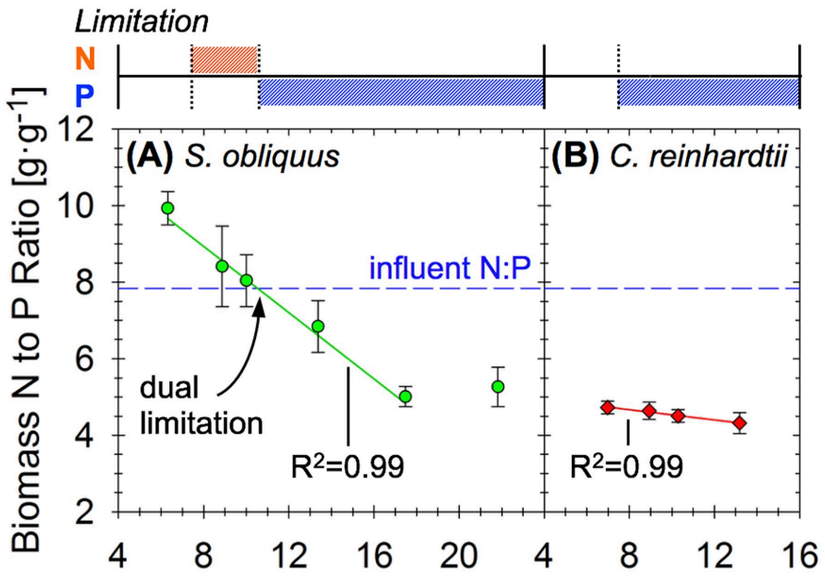


Even though they achieve similar performance, the microbial communities remain distinct over time. They look more like their own inocula.

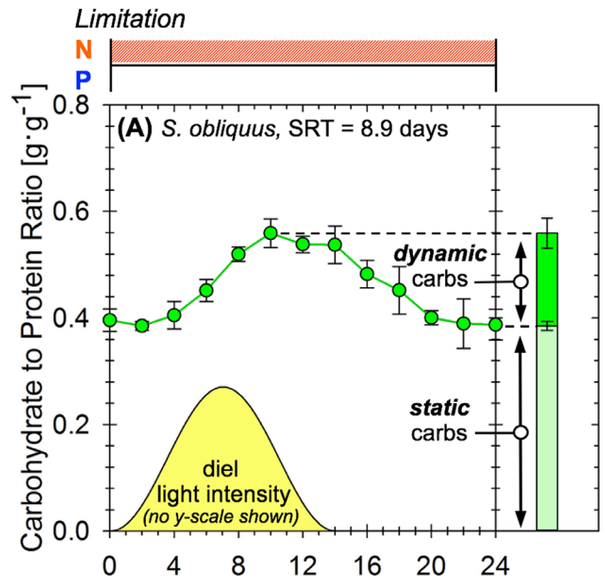
[Fedders, A.C.; DeBellis, J.L.; Bradley, I.M.; Sevillano-Rivera, M.C.; Pinto, A.J.; Guest, J.S. Comparable nutrient uptake across diel cycles from three distinct algal communities. *In revision.*]

In the near future, we'll be designing algal bioprocesses with the same rigor and reliability as activated sludge.

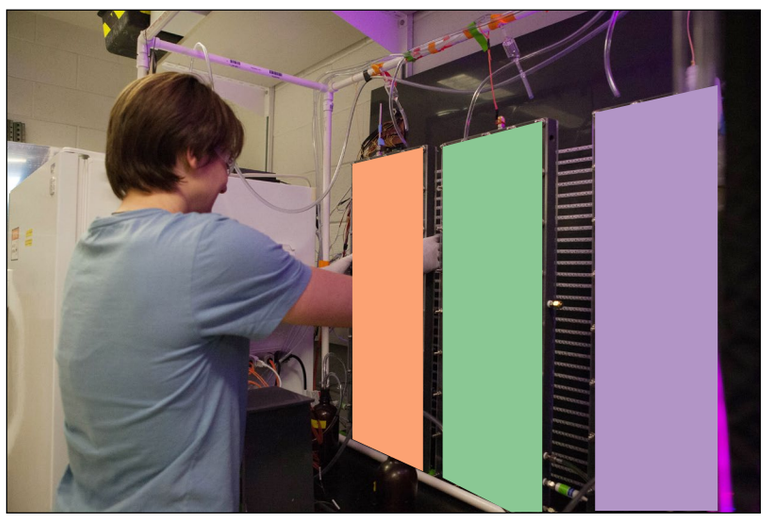
tailor N:P uptake



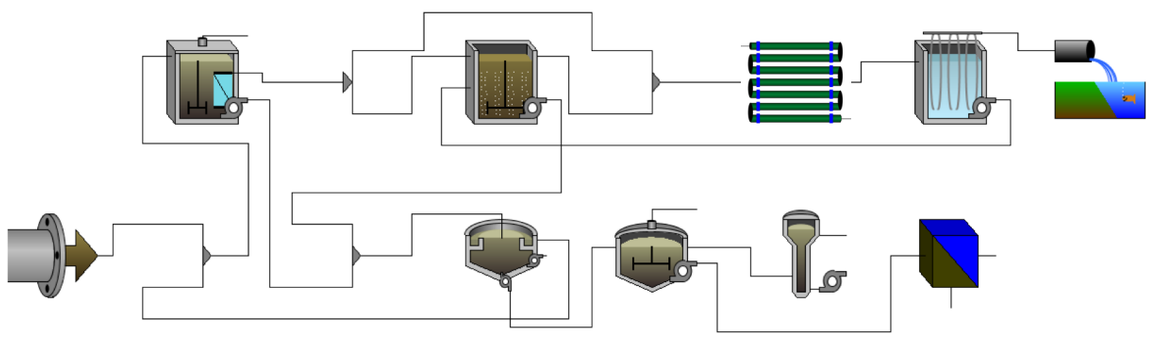
achieve 24-hr nutrient uptake



leverage local algae



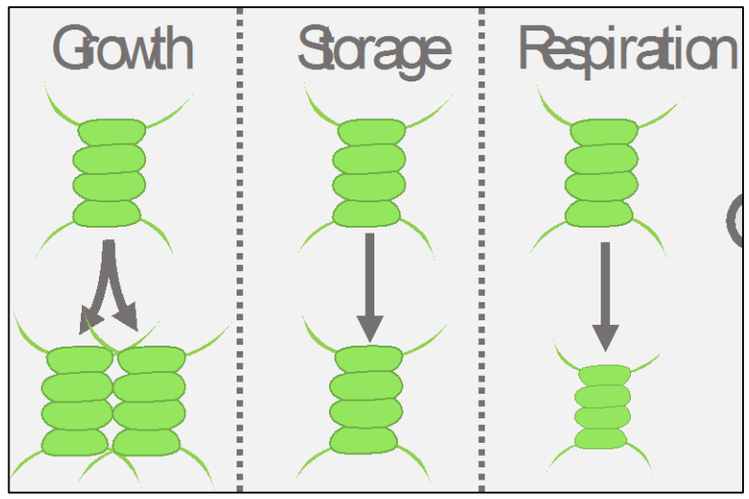
model and design these processes with rigor & reliability



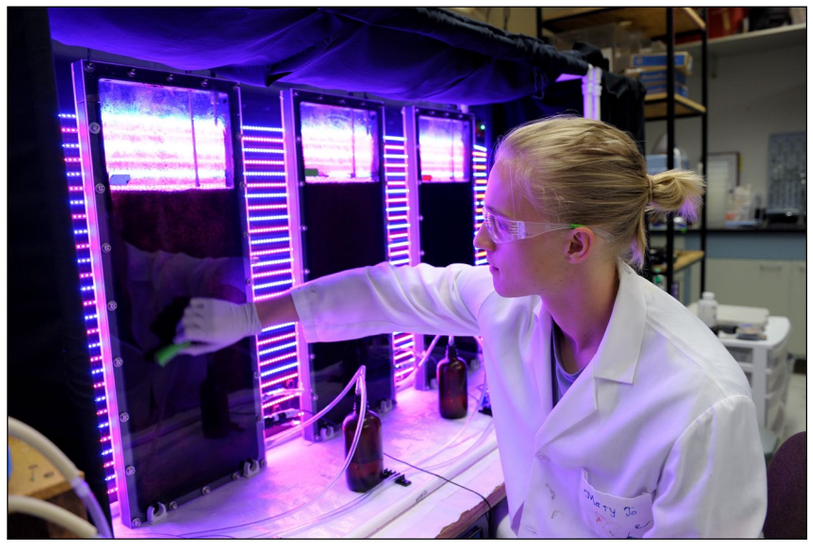
Today we've discussed the development of suspended growth algal processes for wastewater treatment.

intensification of algal systems for nutrient recovery

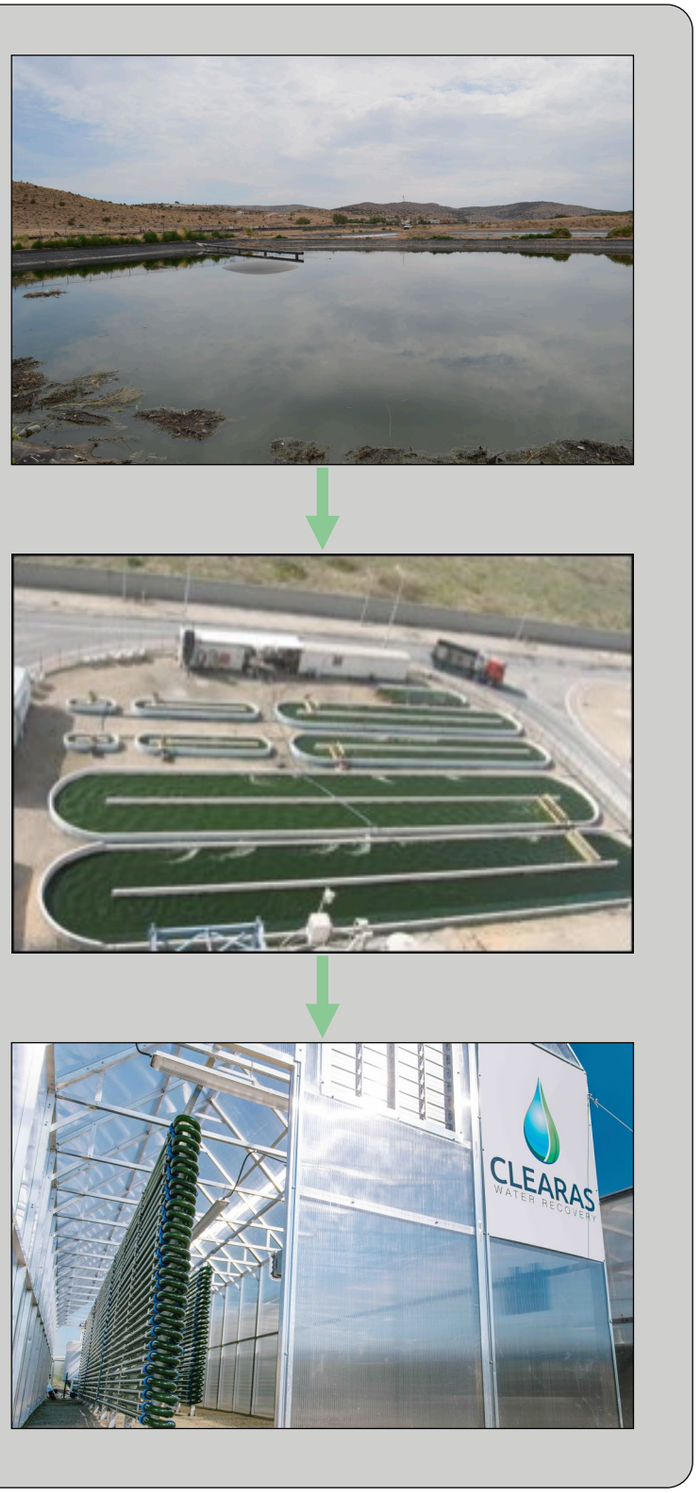
modeling & design challenges for algae



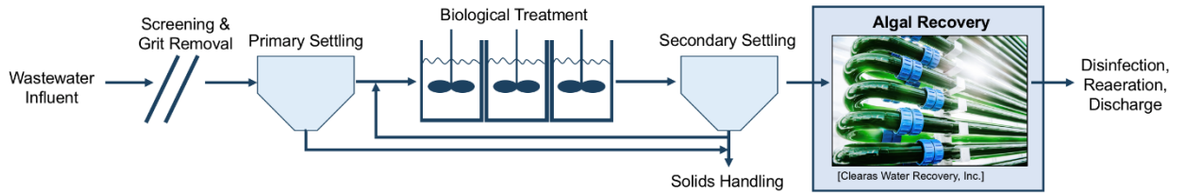
recent findings and & emerging trends in algal processes



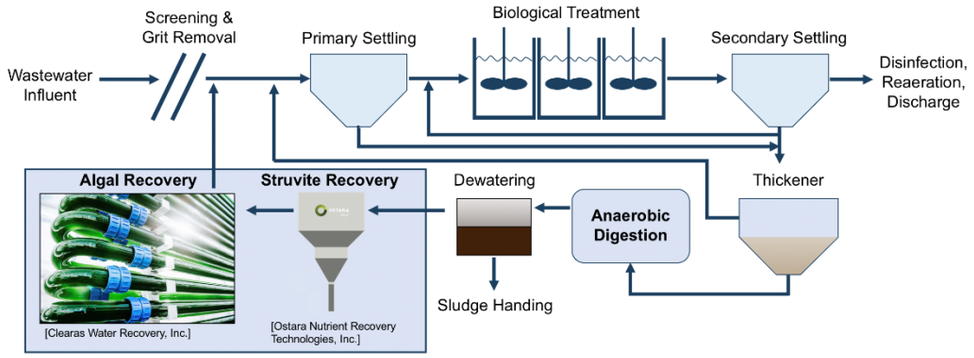
In conclusion, there's a bright future for algal bioprocesses.



tertiary



sidestream



In the not-to-distant future, you'll be able to:

tailor N:P uptake to match your wastewater

achieve 24-hr nutrient uptake

leverage local algae

model and design these processes with rigor

Jeremy Guest, Assistant Professor
jsguest@illinois.edu

Guest Research Group
ENGINEERING FOR SUSTAINABILITY