Impact of Climate Warming and Ocean Carbonation on Eelgrass (*Zostera marina* L.)

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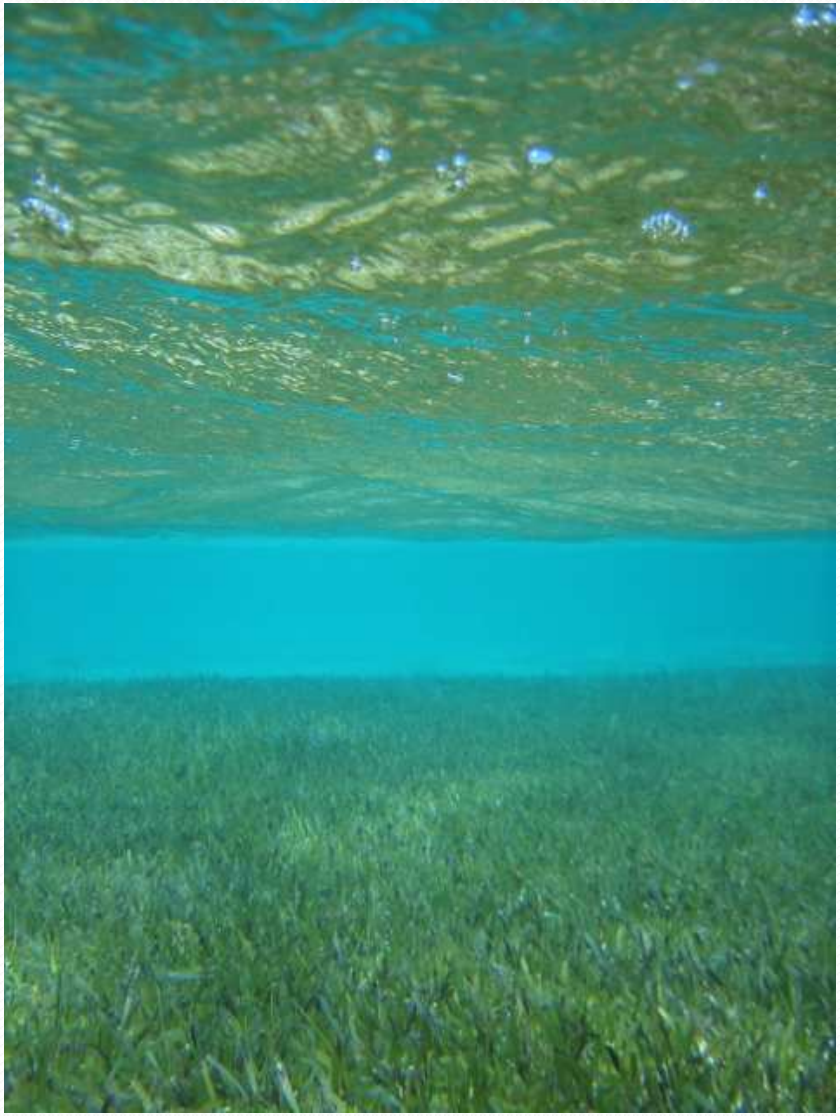
Seagrasses are marine angiosperms

- Leaves, roots & rhizomes
- Adapted for submerged growth
- More than 50 spp. worldwide
- Distributed from polar to tropical seas
  - More than 600,000 km2 globally
- Highly productive
- Creates habitat and structure for diverse array of marine organisms
- Significant biogeochemical agents
  - Sediment redox
  - Carbonate dissolution & pyrite formation (= alkalinity)
  - "Blue Carbon"

Seagrasses and Climate Change:

- High light requirements (10 – 20% Sfc E)
- Vulnerable to anthropogenic disturbance
- Sensitive to high summer temperatures



Seagrass loss threatens provision of major ecosystem services in shallow coastal environments

- Habitat structure and sediment stability
  - Loss of “blue carbon” deposits
- Productivity shift from benthos to plankton
- Shifts in sediment biogeochemistry
  - Reduced flux of $(CH_2O)_n$ and O_2 to sediments

So, what does climate change have in store for seagrasses?

- Climate warming will increase summer stress
  - Chesapeake Bay eelgrass
    - Moore & Jarvis. 2008. *J. Coast. Res* **55**:135-247
  - Mediterranean *Posidonia*
    - Marbà, N. and C. Duarte. 2010. *Global Change Biology **16***:2366-2375.

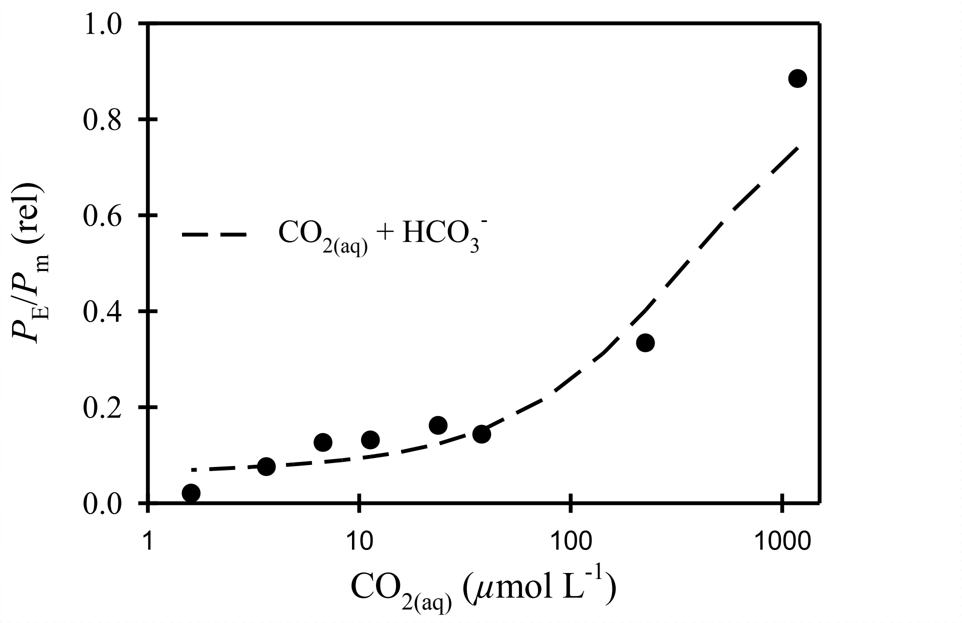
- Heat stress events will become more frequent
  - European eelgrass
    - Franssen, S. and others 2012. Transcriptomic resilience to global warming in the seagrass *Zostera marina, a marine foundation species. Proc. Nat. Acad. Sci.* ***108: 19276-19281.***
    - Winters, G., P. Nelle, B. Fricke, G. Rauch, and T. Reusch. 2011. Effects of a simulated heat wave on photophysiology and gene expression of high- and low-latitude populations of *Zostera marina. Mar. Ecol. Prog. Ser.* ***435: 83-95.***

And what about Ocean Acidification?

- Clearly, there will be some losers
  - Reduced carbonate saturation state hard on calcareous organisms
- But its more than just pH and Ω
- There will also be some winners
  - Increased pCO_2 will reduce photosynthetic reliance on HCO_3^- dehydration/transport
  - potential benefit to seagrasses

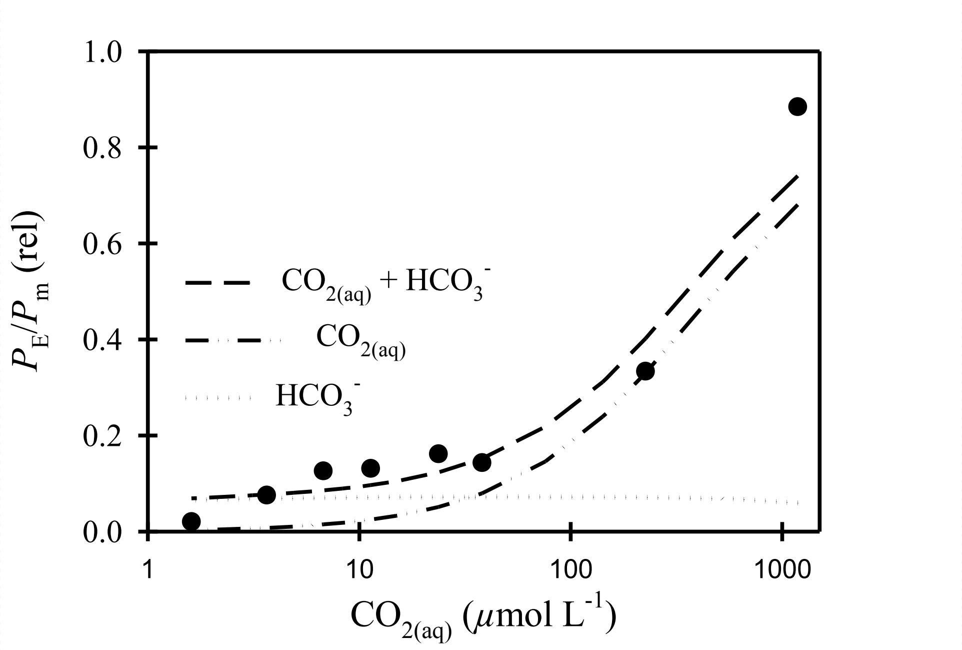
Maybe we should call it Ocean Carbonation…

Seagrass photosynthesis depends heavily on dissolved CO_2.......



McPherson, M., R. Zimmerman, and V. Hill. 2015. Environmental and physiological influences on productivity and carbon isotope discrimination in eelgrass (*Zostera marina L.). Limnol. Oceanogr.* ***In Review.***

Seagrass photosynthesis can be driven by HCO_3^- dehydration but



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CCM's unable to saturate C demand of RUBISCO from HCO_3^-

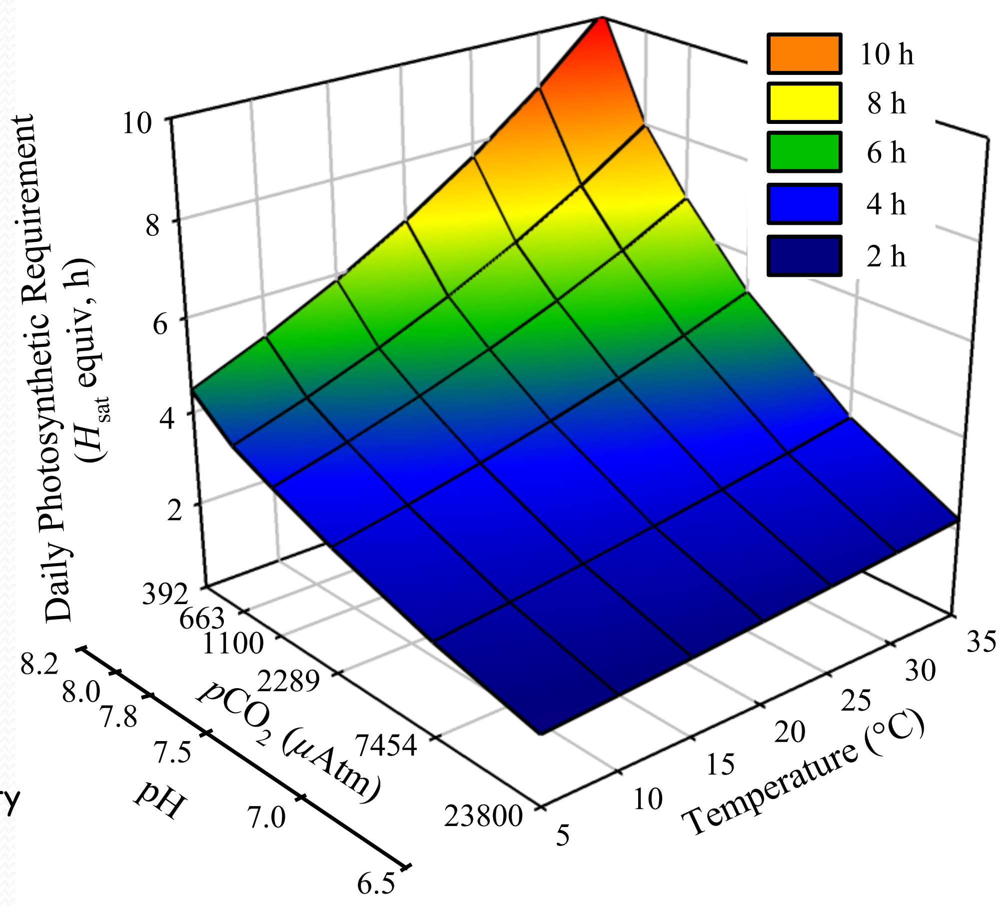
Model predictions of T & pH/CO_2 effects on daily photosynthetic requirements

$$P_E = P_{m(HCO_3^-)} \cdot \frac{[HCO_3^-]}{K_{s(HCO_3^-)} + [HCO_3^-]}$$

$$+ P_{m(CO_{2(aq)})} \cdot \frac{[CO_{2(aq)}]}{K_{s(CO_{2(aq)})} + [CO_{2(aq)}]}$$

$$Q_{10}(P_E) = 3.62 + 0.796 \cdot \ln\left(\frac{[CO_{2(aq)}]}{9.8 \times 10^9}\right)$$

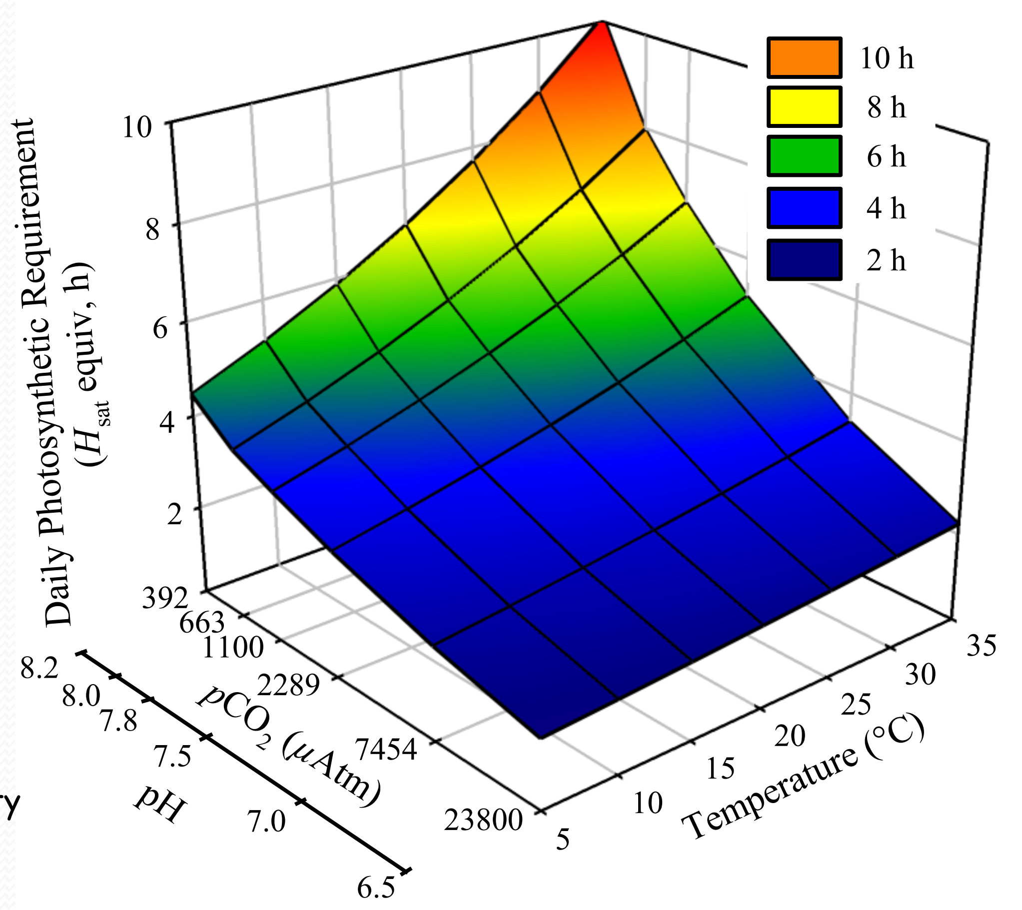
$$Q_{10}(R) = 2.6$$



Zimmerman, R., V. Hill, and C. Gallegos. 2015. Predicting effects of ocean warming, acidification and water quality on Chesapeake region eelgrass. Limnol. Oceanogr. **In Review.**

Model predictions of T & pH/CO_2 effects on daily photosynthetic requirements

- CO_2 stimulates P_E
- Increases daily P:R
- Reduces effect of temperature on light requirements to maintain positive carbon balance



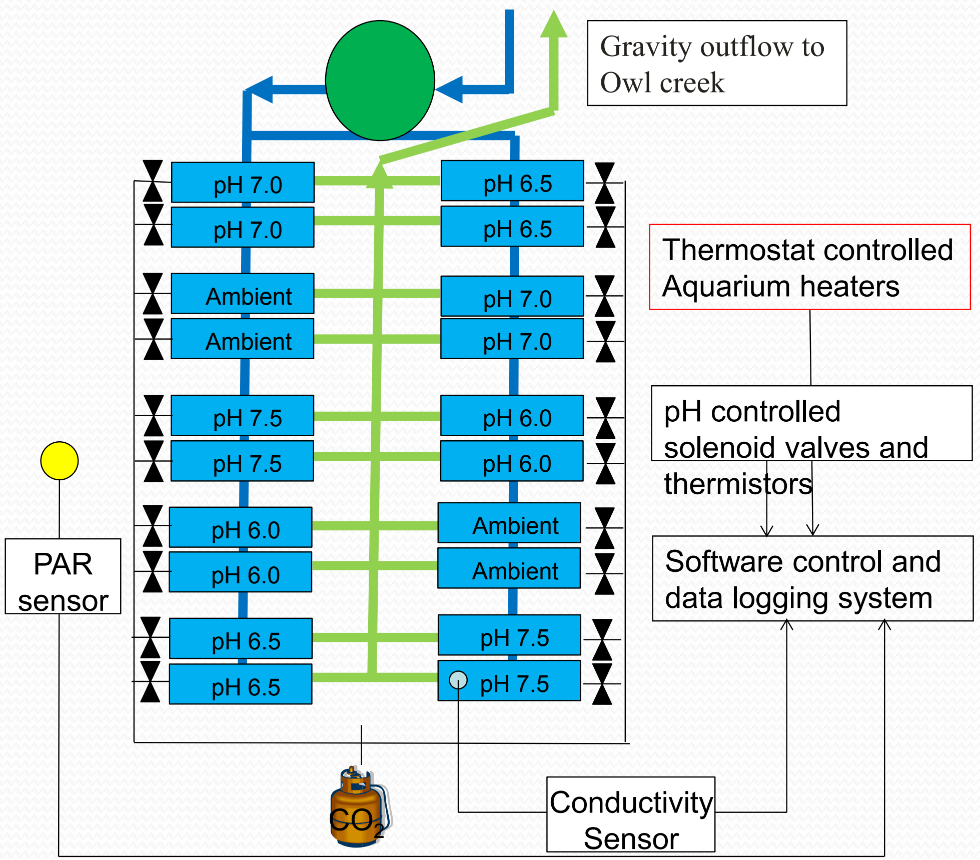
Zimmerman, R., V. Hill, and C. Gallegos. 2015. Predicting effects of ocean warming, acidification and water quality on Chesapeake region eelgrass. Limnol. Oceanogr. **In Review**.

Testing Model Predictions: Virginia Aquarium Climate Change Facility

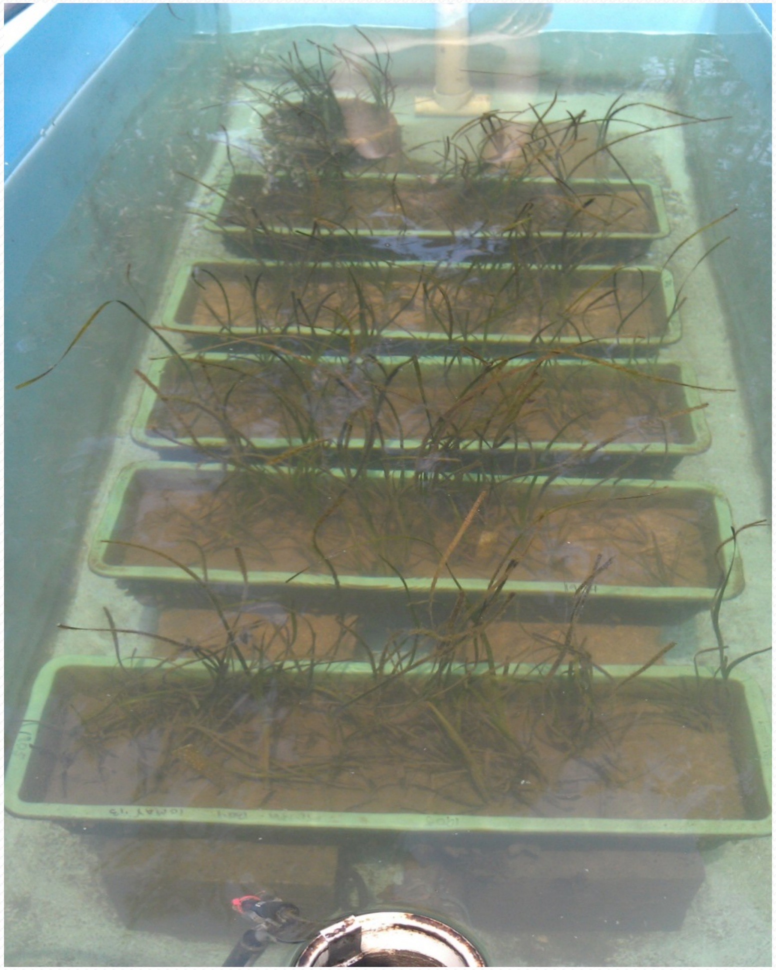
- Natural solar irradiance
  - Can be screened to different intensities
- Multiple planting trays within each aquarium
  - Within-tank replication
  - Comparison among different populations

Testing Model Predictions: Virginia Aquarium Climate Change Facility

- 20 experimental aquaria
  - Individually pH and temperature controlled
- Single pass, continuous flow
  - Unfiltered water from Owl's Creek
  - 2 h residence time



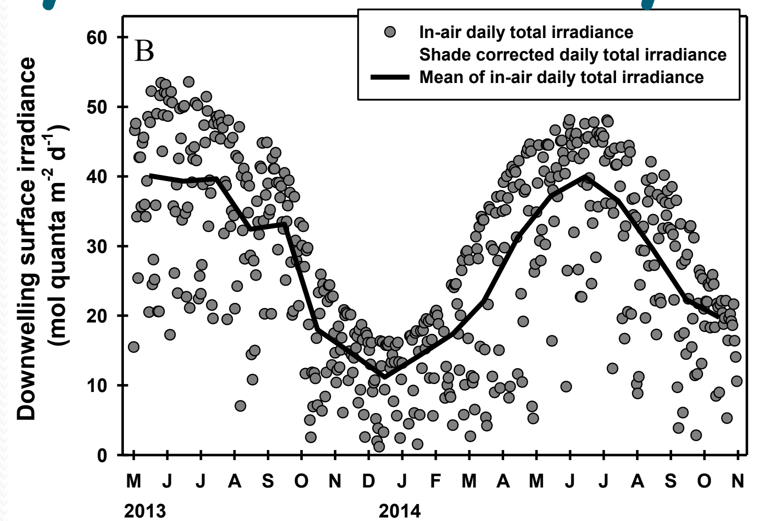
- Donor population from South Bay, DelMarVa Peninsula,VA
- Transplanted into Experimental Facility in May 2013

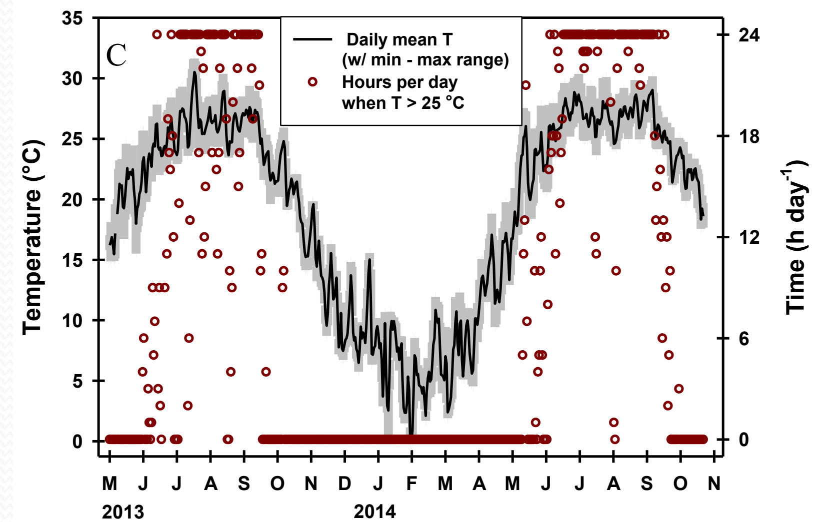


- Continuous monitoring of
  - pH
  - Temperature
  - Salinity
  - PAR
- Monthly measures of shoot:
  - Shoot number
  - Shoot size
  - Growth rate
  - Sugar content
  - Pigments
  - Tissue C, N, S

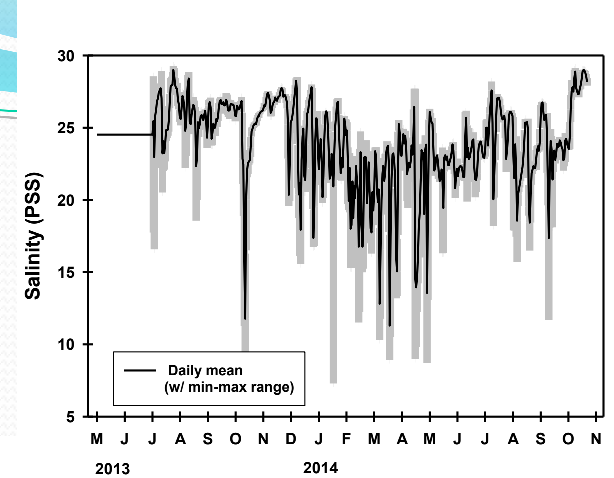
Outdoor facility imposes seasonal and daily variability

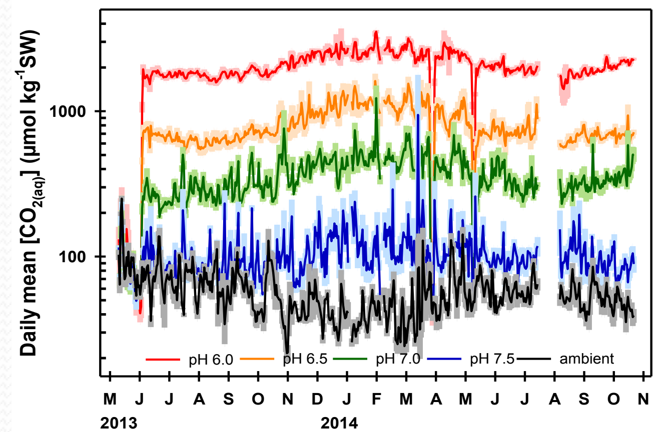
- Solar Radiation
  - 5-fold annual variation
  - Weather-scale variation (clouds) imposed on annual cycle
  - Amplitude of daily variation greatest in summer
  - Summer average H_{sat} = 8 h
  - Winter average H_{sat} = 4 h
- Ambient Temperature
  - Annual amplitude > 25° C
  - Daily amplitude ≈ 5° C
  - exceeded 25° stress threshold:
    - 70 d in 2013
    - 90 d in 2014

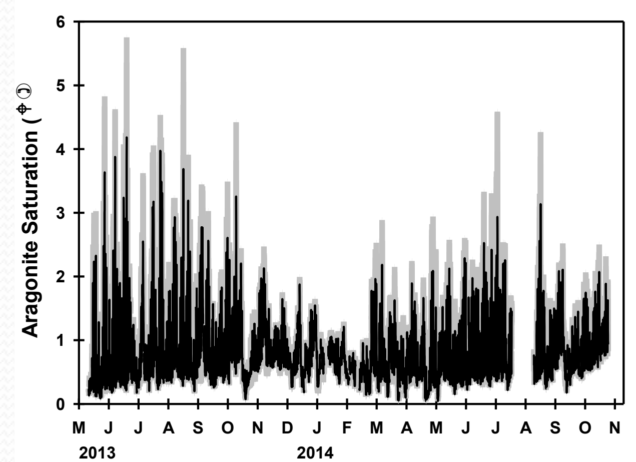




- Weather-scale variability in Salinity
- pH controllers provide good experimental separation of CO_2 availability.
- Manipulated treatments average within 0.1 pH unit of the target
- $[CO_2]$ and Ω calculated from T, pH using CO2SYS

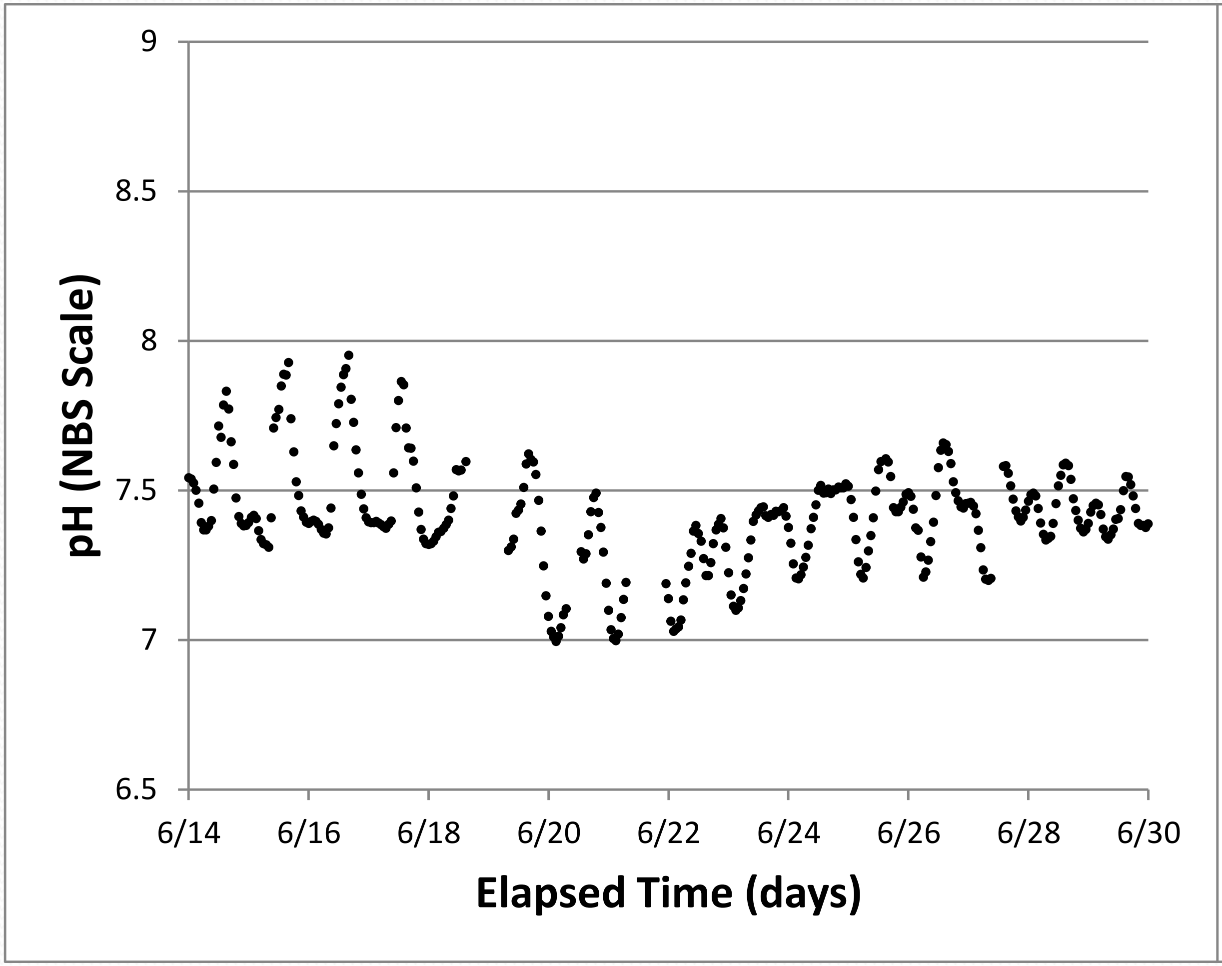




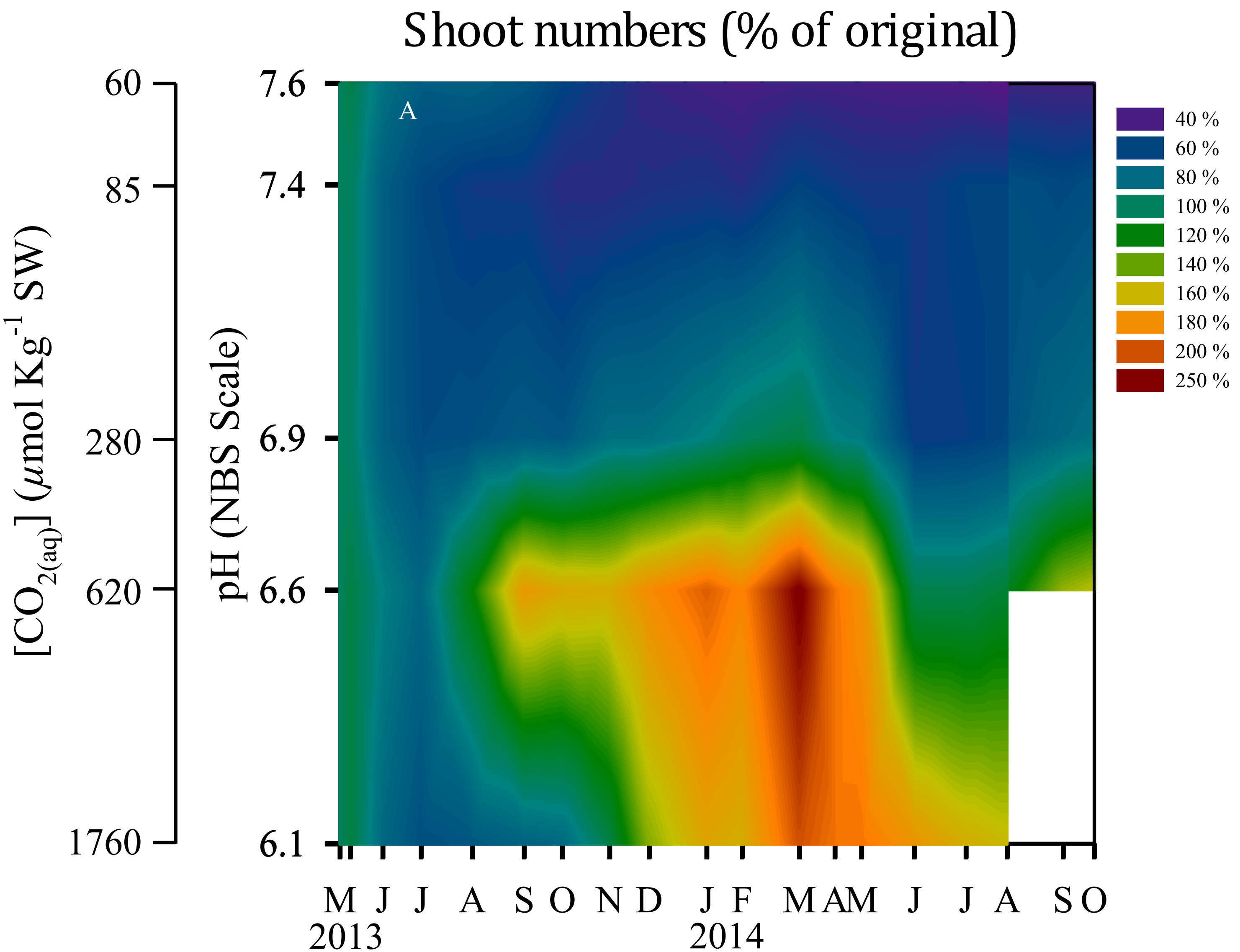


pH Variability in Owl's Creek, VA

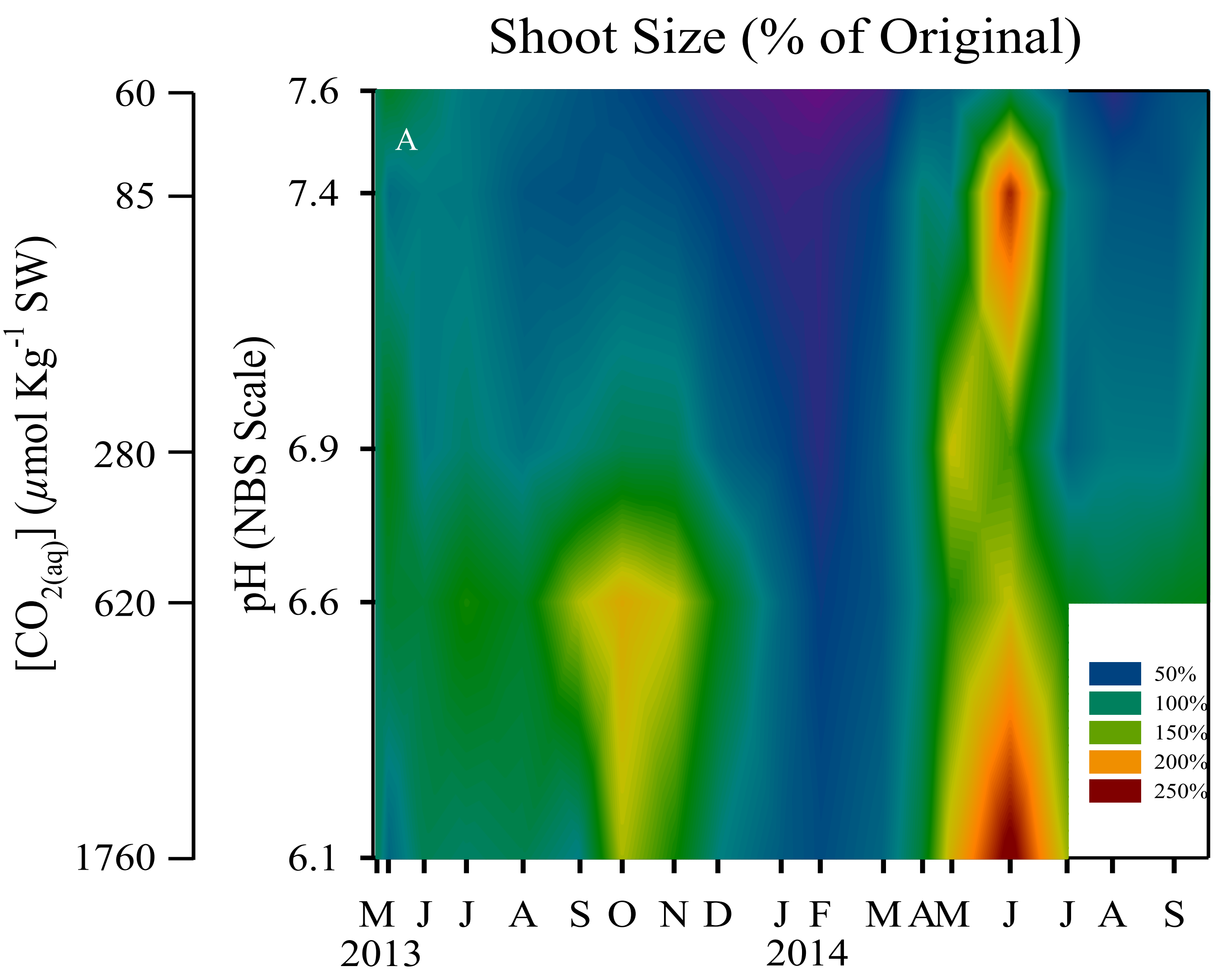
- High natural variability at hourly scales
- Seasonal variability due to temperature
- Daily variability due to P & R
- Random variability due to rainfall & clouds



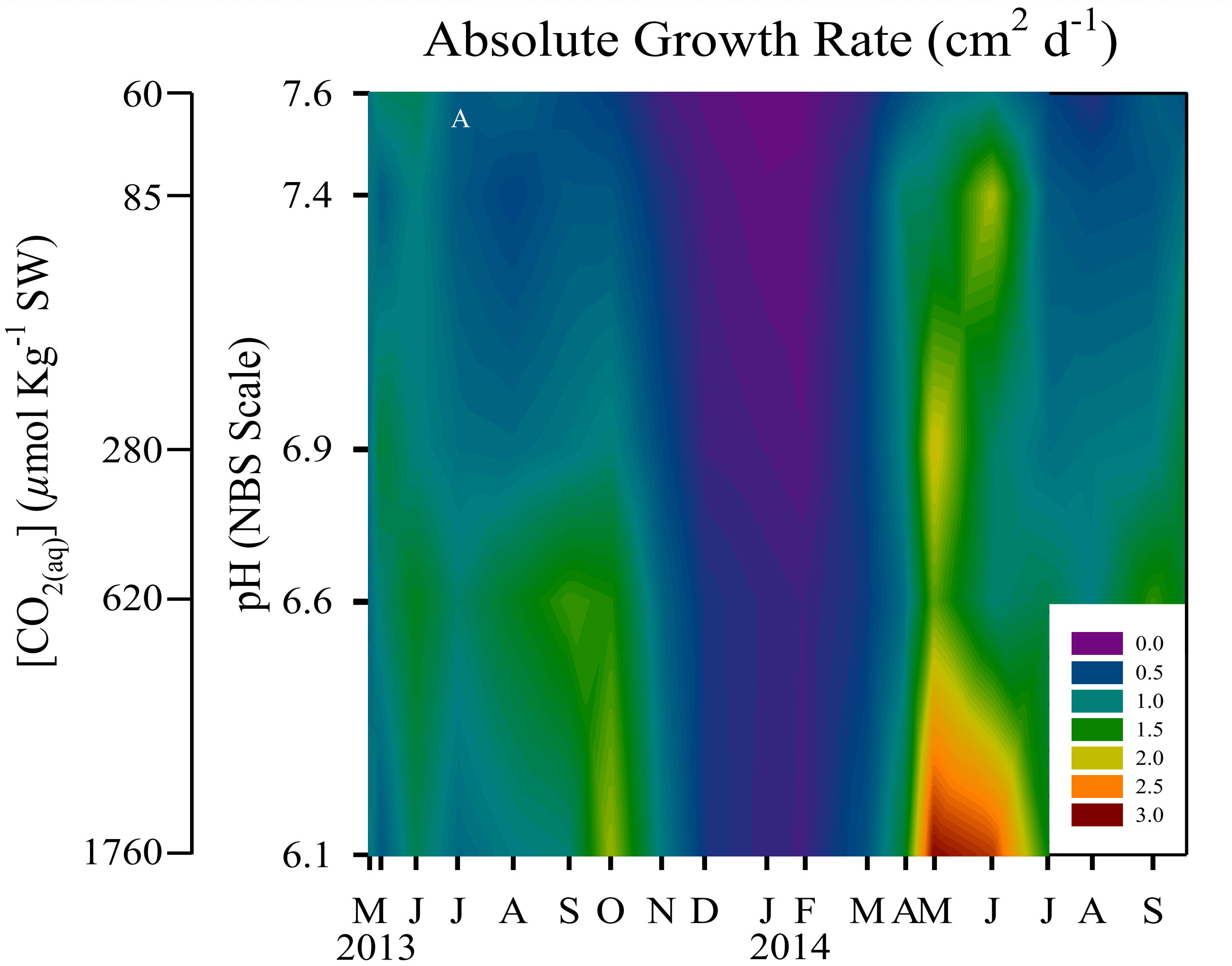
Despite the warm summer , Shoot numbers increased with CO_2 availability



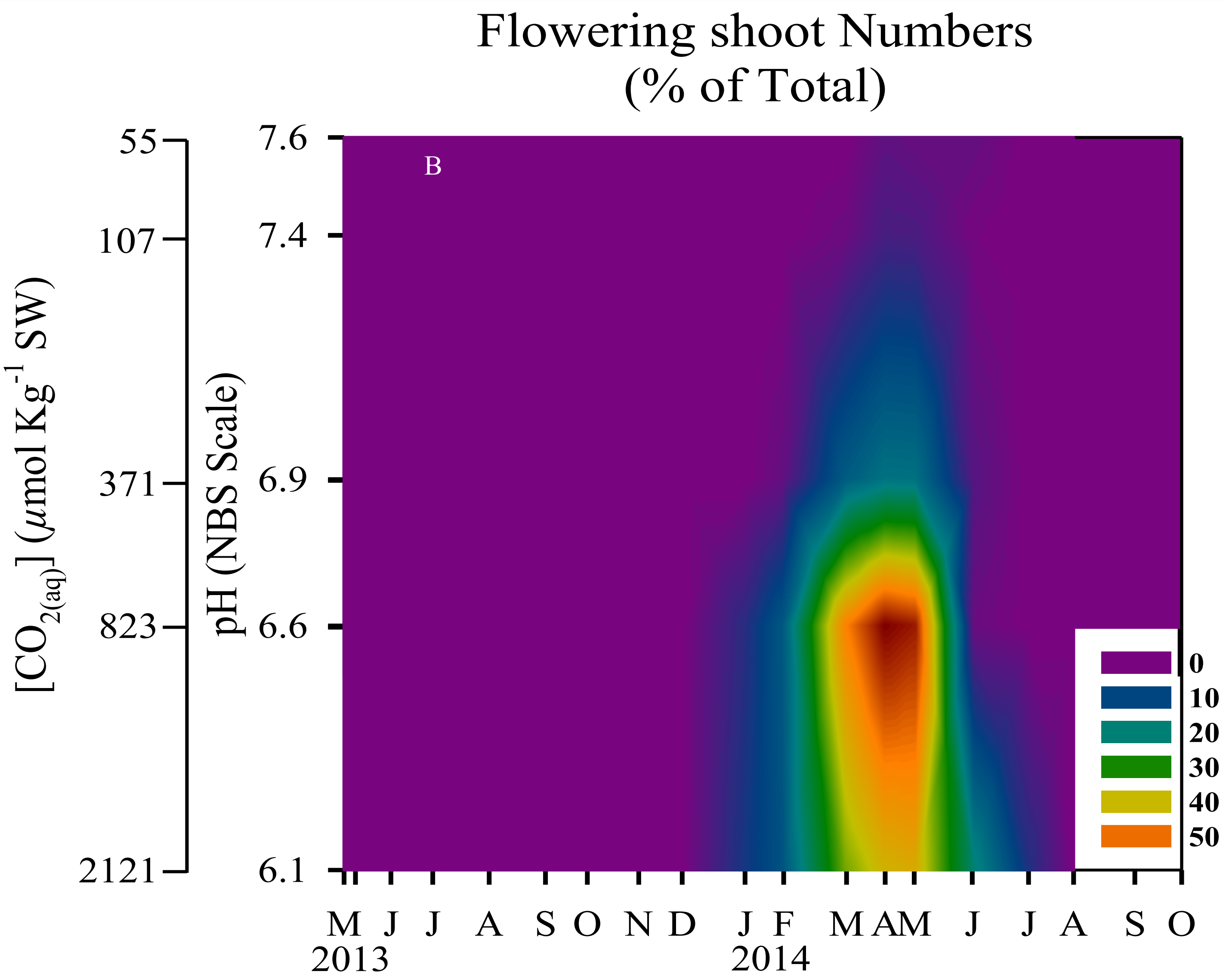
Despite the warm summer,
Shoot size increased with CO_2 availability



Despite the warm summer,
Absolute growth increased with CO_2 availability

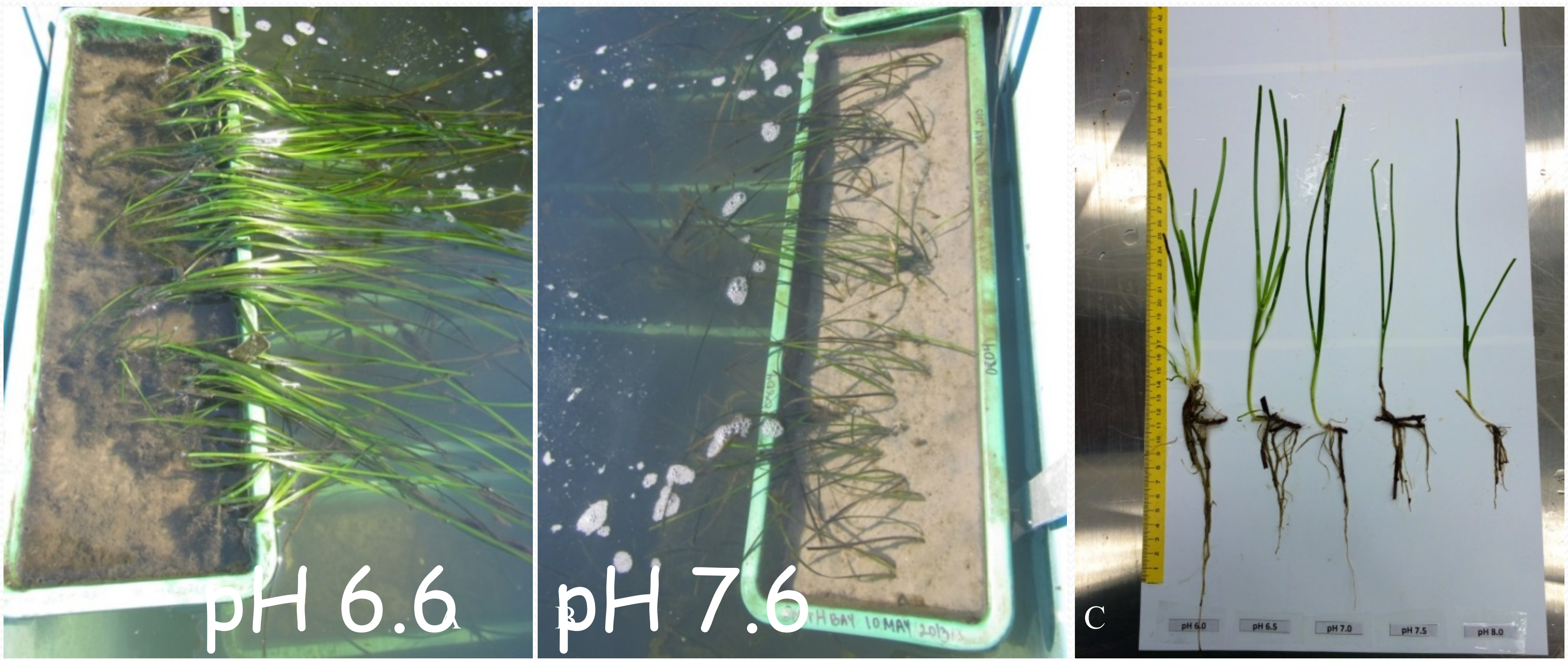


Despite the warm summer, Flowering shoots increased with CO_2 availability

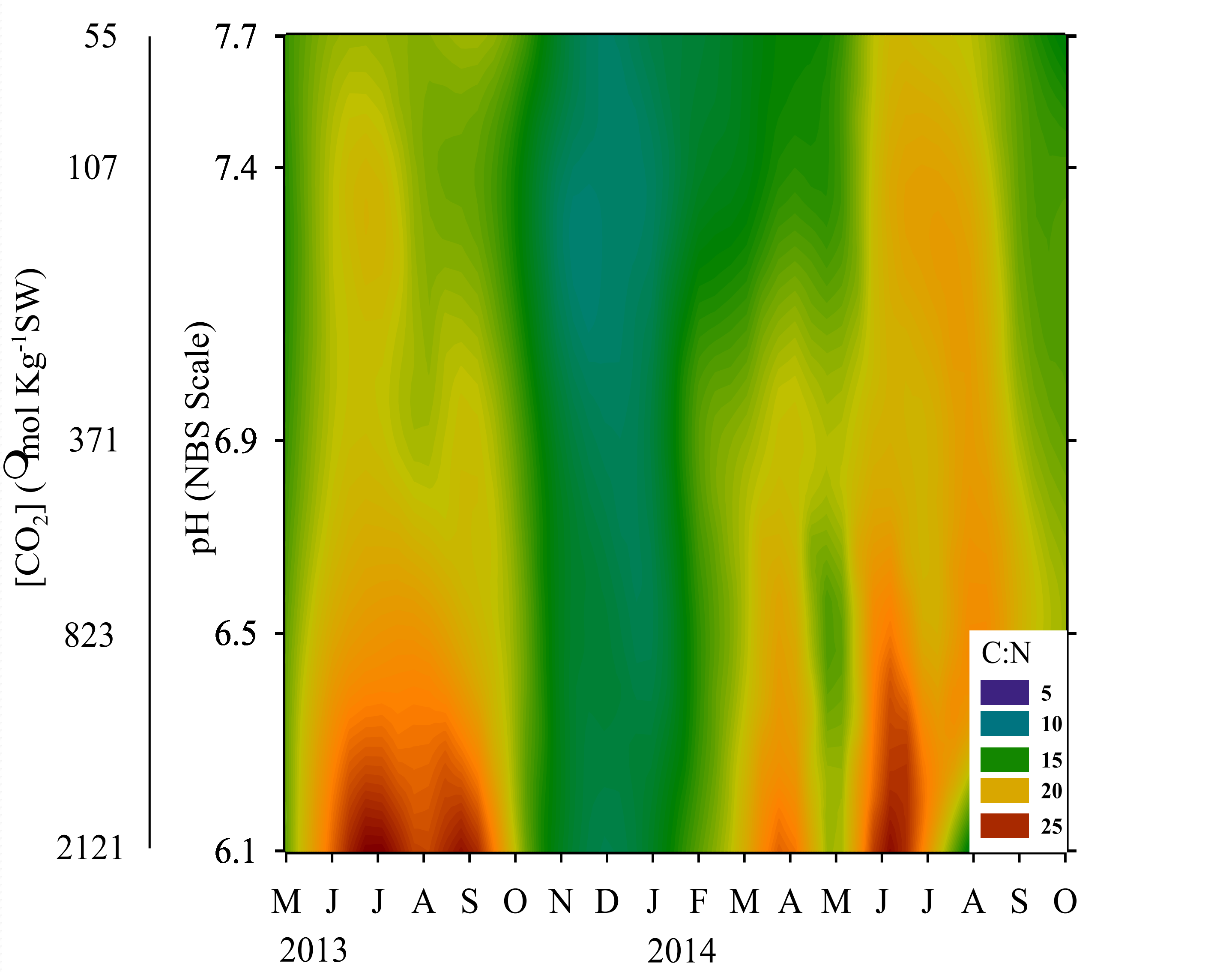


After a long hot summer…

- More shoots
- Larger shoots
- More below ground biomass

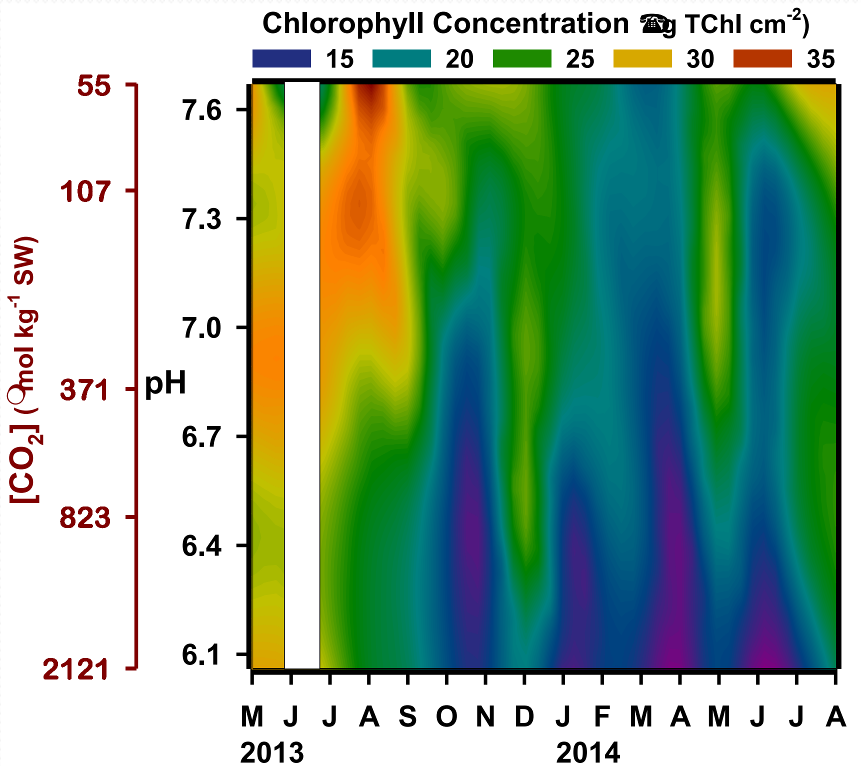


Sucrose and C:N increased with $[CO_2]$

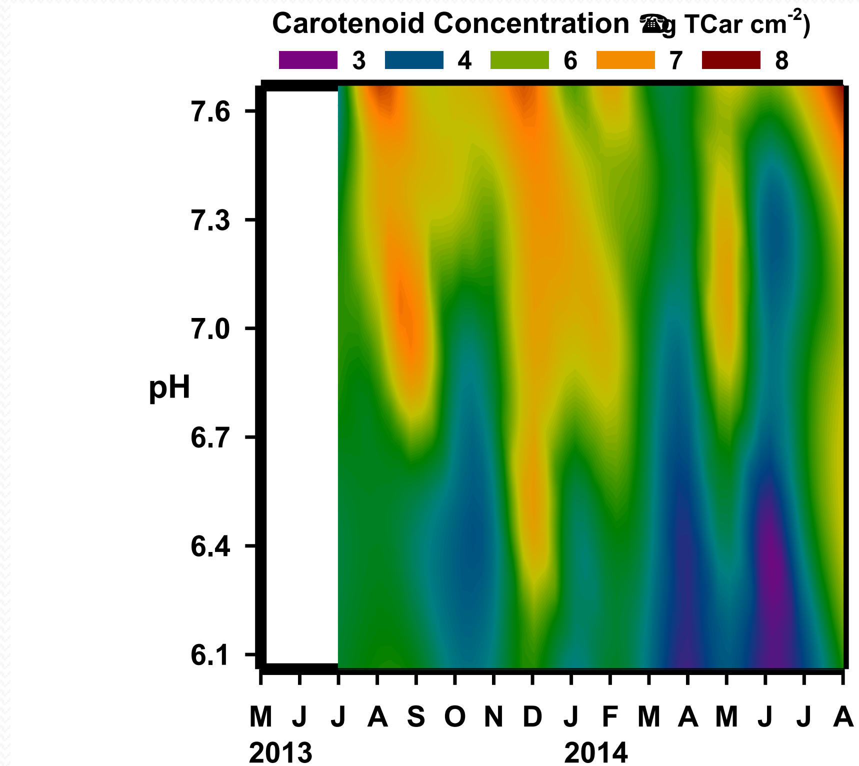


But pigment content decreased with [CO2]

Photosynthetic Pigments



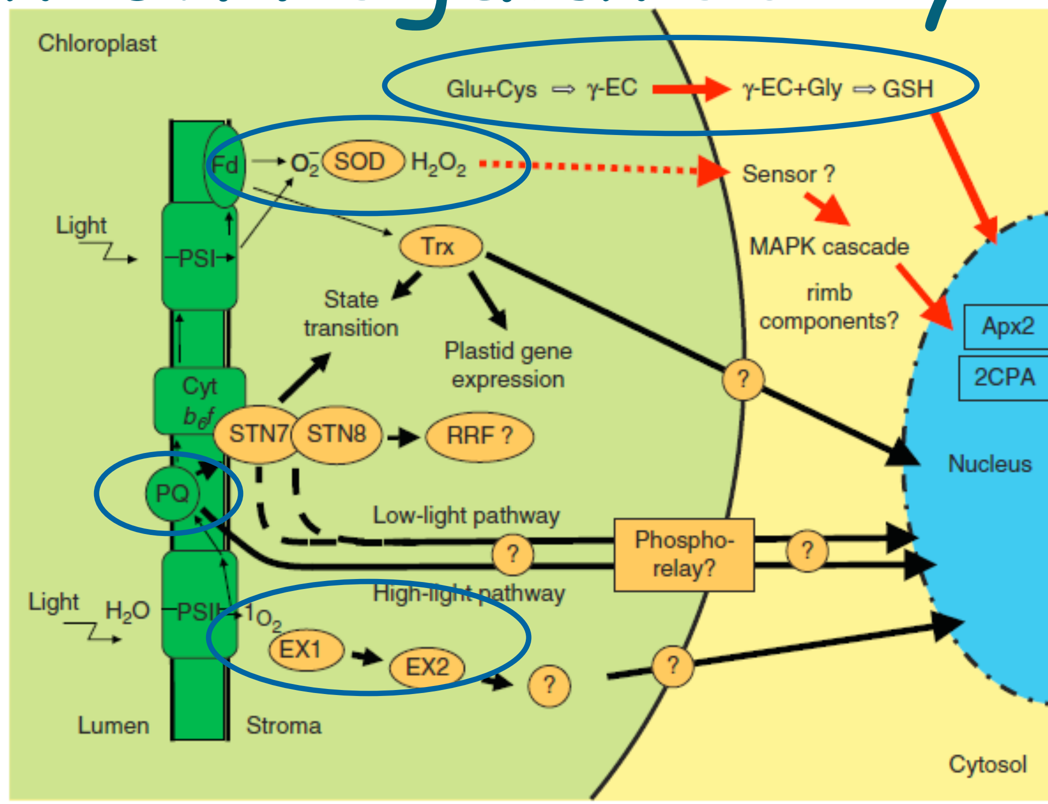
Photoprotective Pigments



CO_2 acclimation mimics photoacclimation

Photoacclimation regulated by

- Photorespiration
  - CO_2 limitation of Rubisco
- Reactive oxygen species
  - PSII activity
- Redox state of PQ
  - Electron transport and PS 1



Pfannschmidt, T. and others 2009. Potential regulation of gene expression in photosynthetic cells by redox and energy state: approaches toward better understanding. Annals of Botany **103: 599-607.**

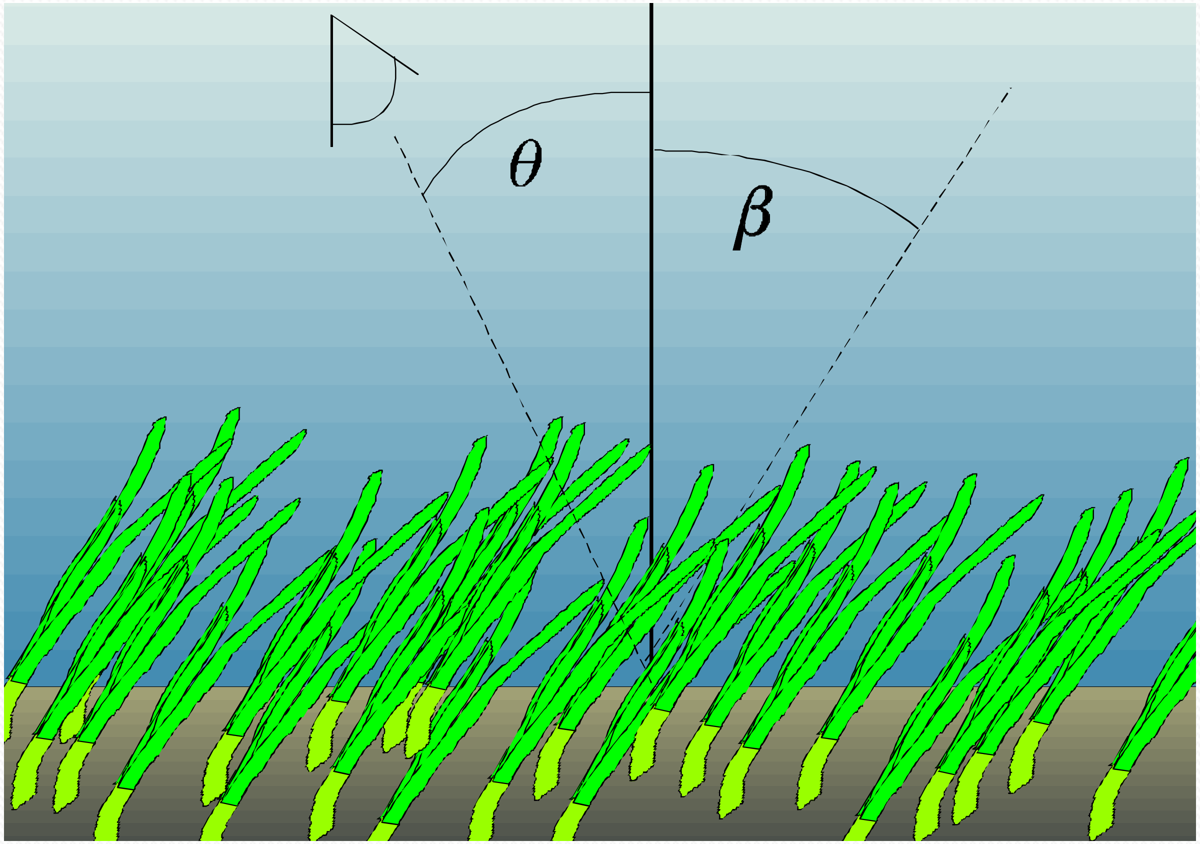
All of which are affected by $[CO_2]$

Long-term experiments support model calculations from instantaneous metabolic rates

- Photosynthesis increases linearly with [CO2]
- Light harvesting acclimation response does not reduce P_m
- Eelgrass tolerance of thermal stress increases with CO_2 availability:
  - Survival
  - Size
  - Absolute Growth
  - Carbon reserves

Can these results predict:
natural eelgrass distributions?
Response to climate change?

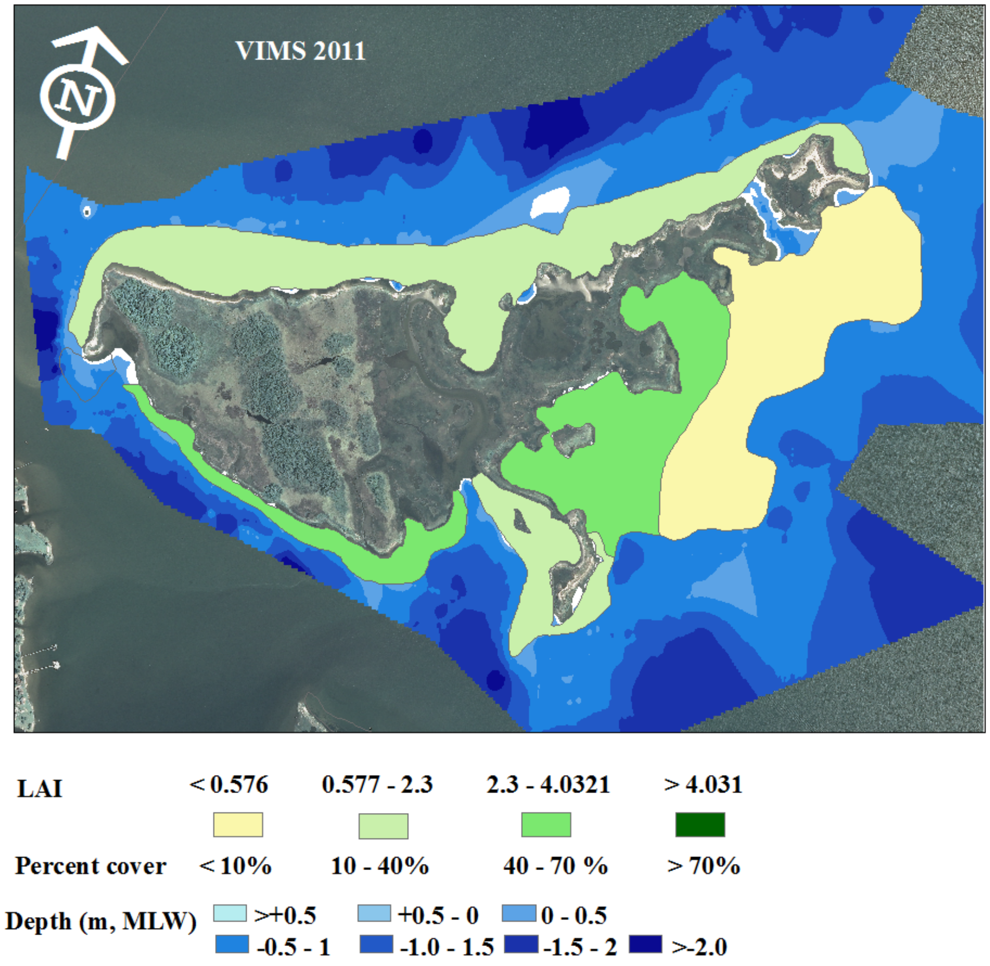
Predicting Summer Die-Back and CO_2 Rescue:



GrassLight Ver 2.13
Available from: rzimmerm@odu.edu

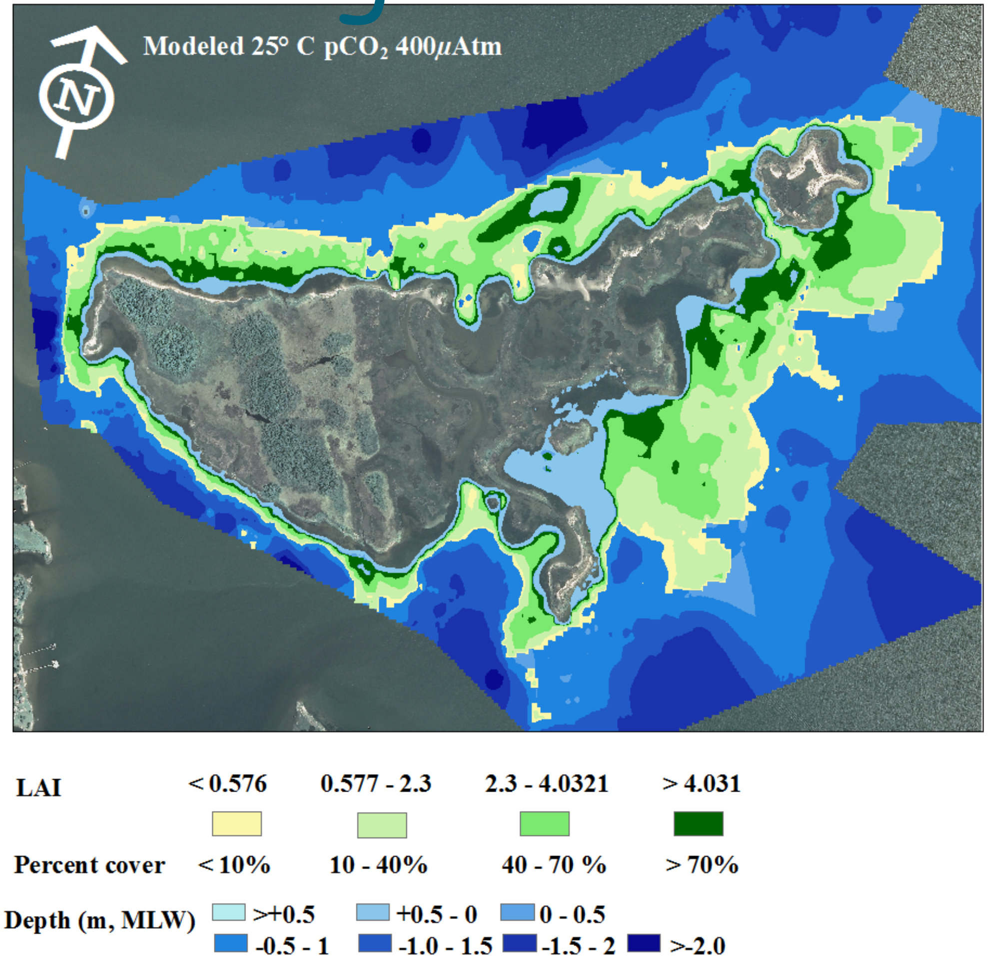
Predicting climate effects on eelgrass distribution

- Goodwin Islands NERR
- Eelgrass affected by
  - Water quality
  - Epiphyte load
  - Periodic thermal stress
- Model distribution consistent with field observations



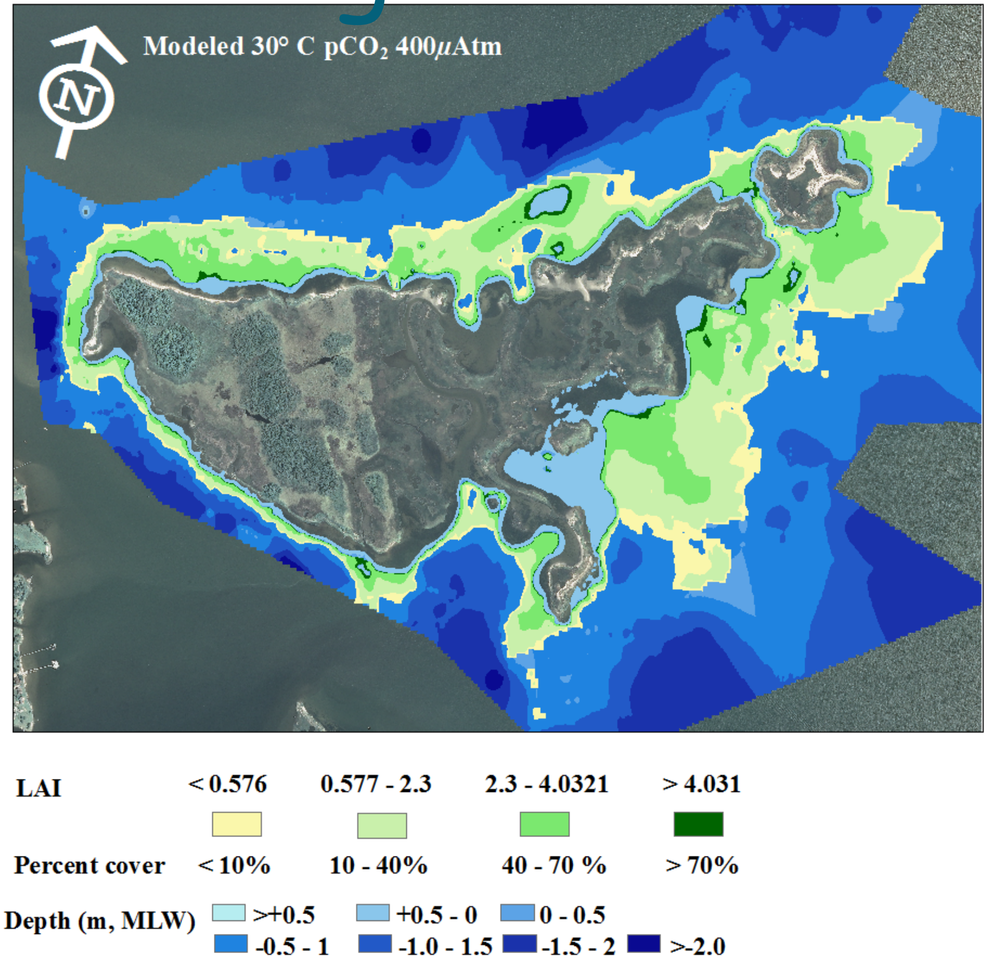
How will temperature and CO_2 interact to affect eelgrass distribution?

- Cool summer temperature
- Present-day CO_2 (pH 8)
- What happens if we increase temperature?



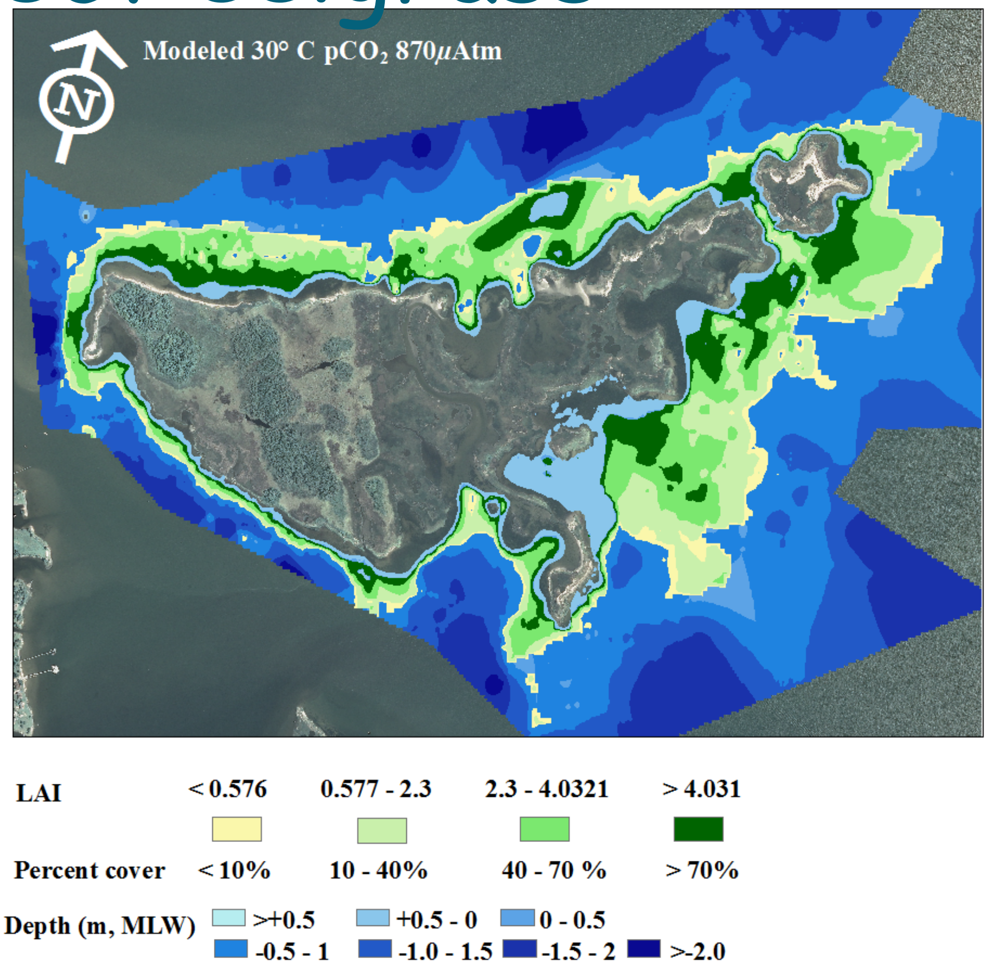
How will temperature and CO_2 interact to affect eelgrass distribution?

- Warm summer temperature
- Present-day CO_2 (pH 8)
- Eelgrass distribution dies-back



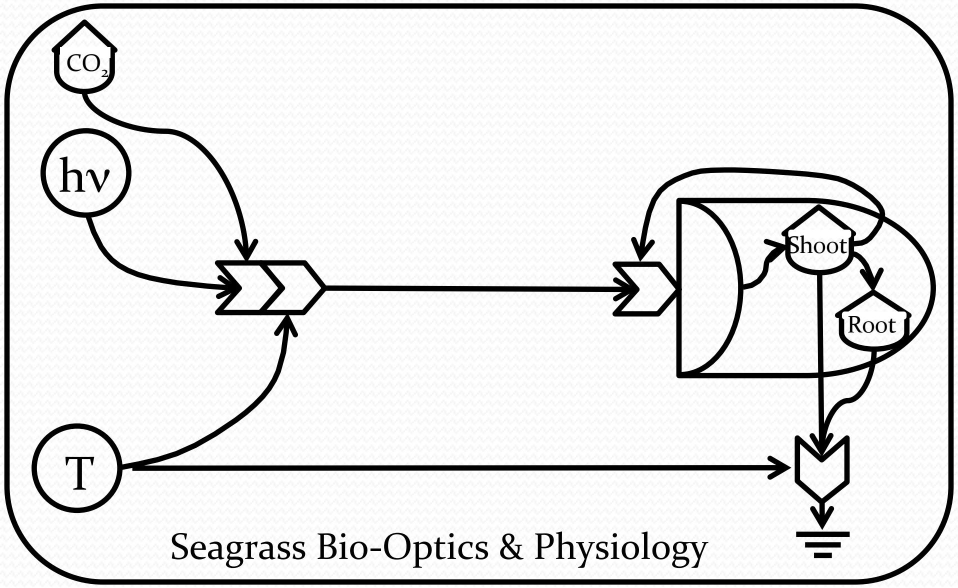
How will temperature and CO_2 interact to affect eelgrass distribution?

- Warm summer temperature
- CO_2 doubling (pH 7.8) causes re-growth of eelgrass



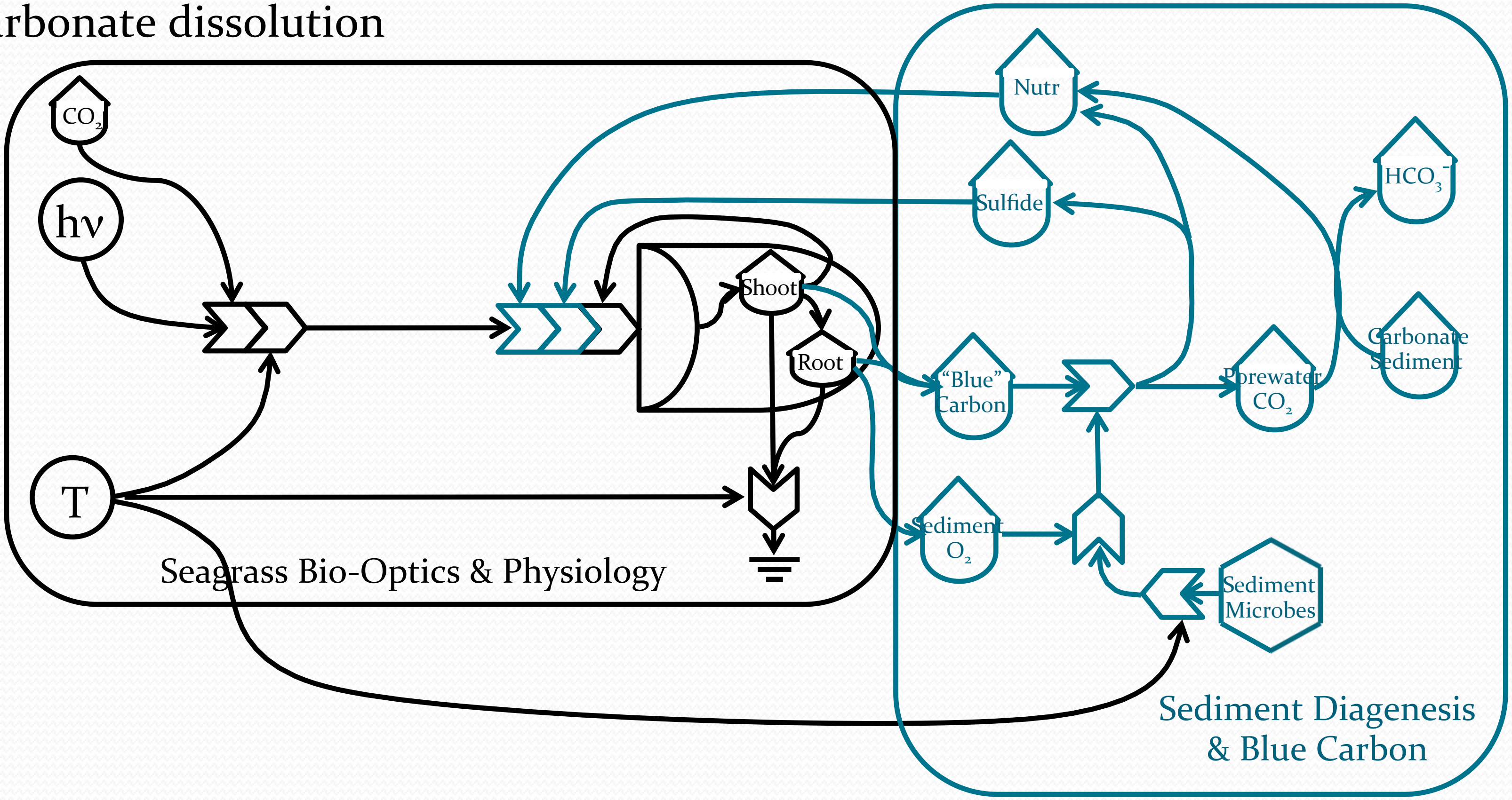
So, where do we go from here?

- We have a handle on bio-optics & physiology



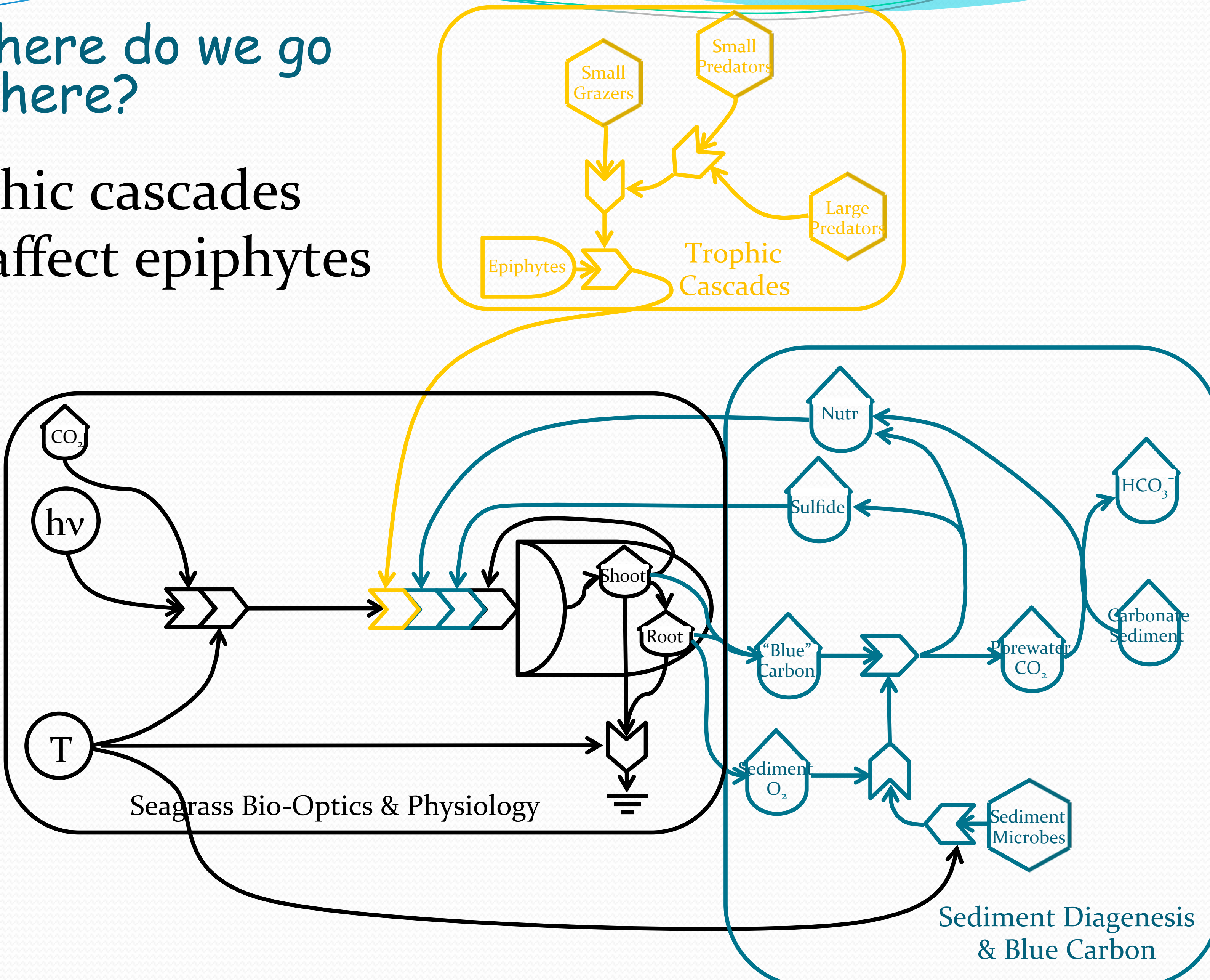
So, where do we go from here?

- Sediment diagenesis responds to temperature
  - Sulfide production
  - Nutrient remineralization
  - Carbonate dissolution



So, where do we go from here?

- Trophic cascades will affect epiphytes



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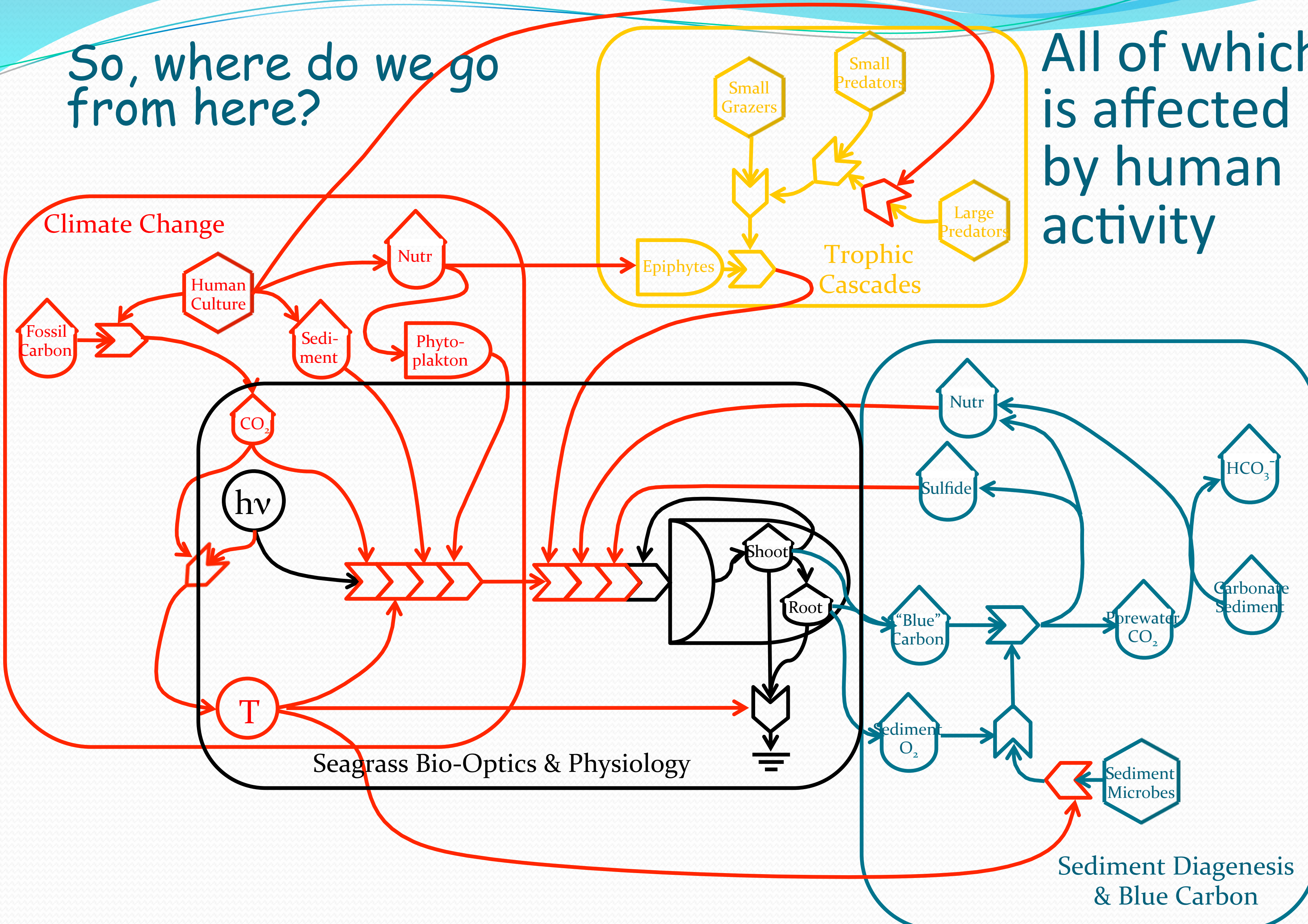

All of which is affected by human activity