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Growth Measurement and Modeling of *Dunaliella salina*

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Algal Biomass, Biofuels & Bioproducts

St. Louis, MO, USA

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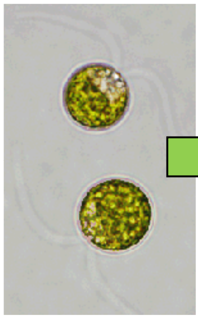
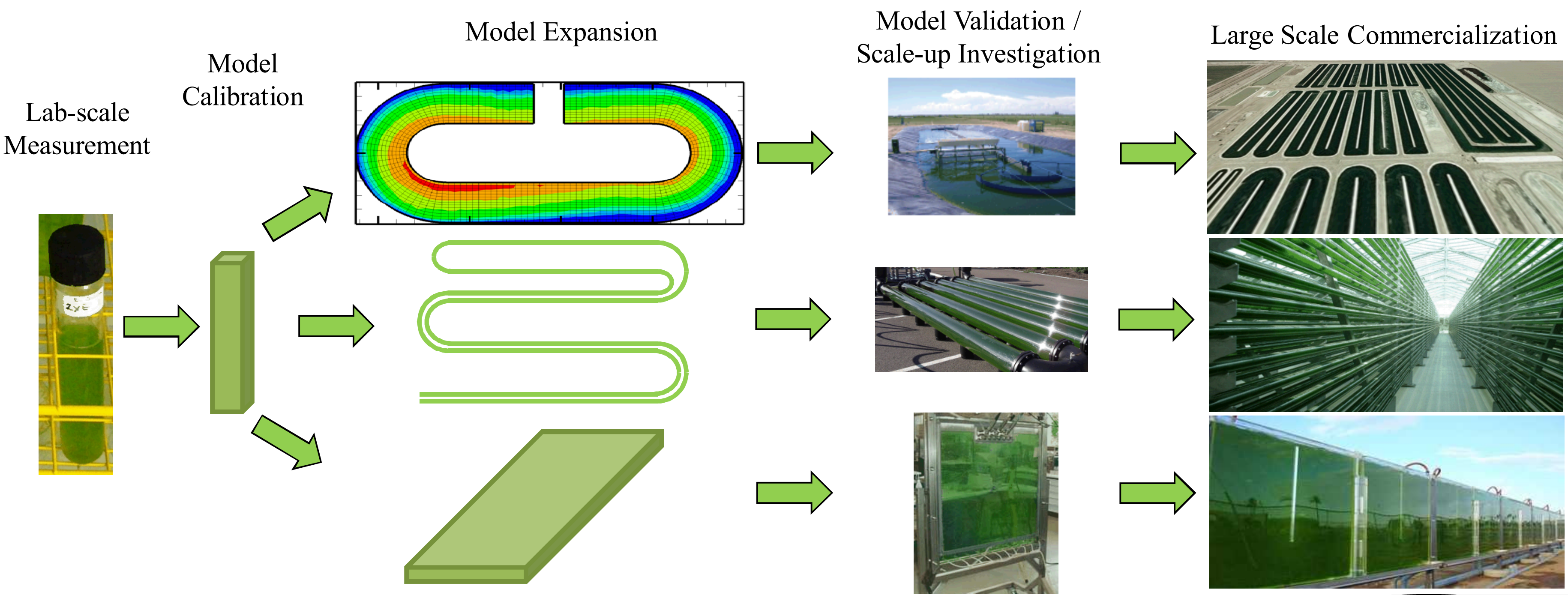
Why Algae?



- Algae-based biofuels are a promising component to a long-term renewable energy solution
- Algae can be engineered or stressed to produce large quantities of oil with favorable characteristics for biodiesel
- Algae can be grown in waste/brackish/sea water, reducing the impact on fresh water supplies
- Algae mitigate atmospheric CO_2
- Algae can be grown on non-arable land, decreasing the impact on the food supply

Need Realistic Model

- We need to be able to optimize algae growth and lipid production in large commercial scale systems
- It is too time consuming and expensive to test various solutions on a commercial scale
- A computational model facilitates faster and cheaper optimization
- The necessary data are lacking to create the needed constitutive relations for algae growth and lipid production.



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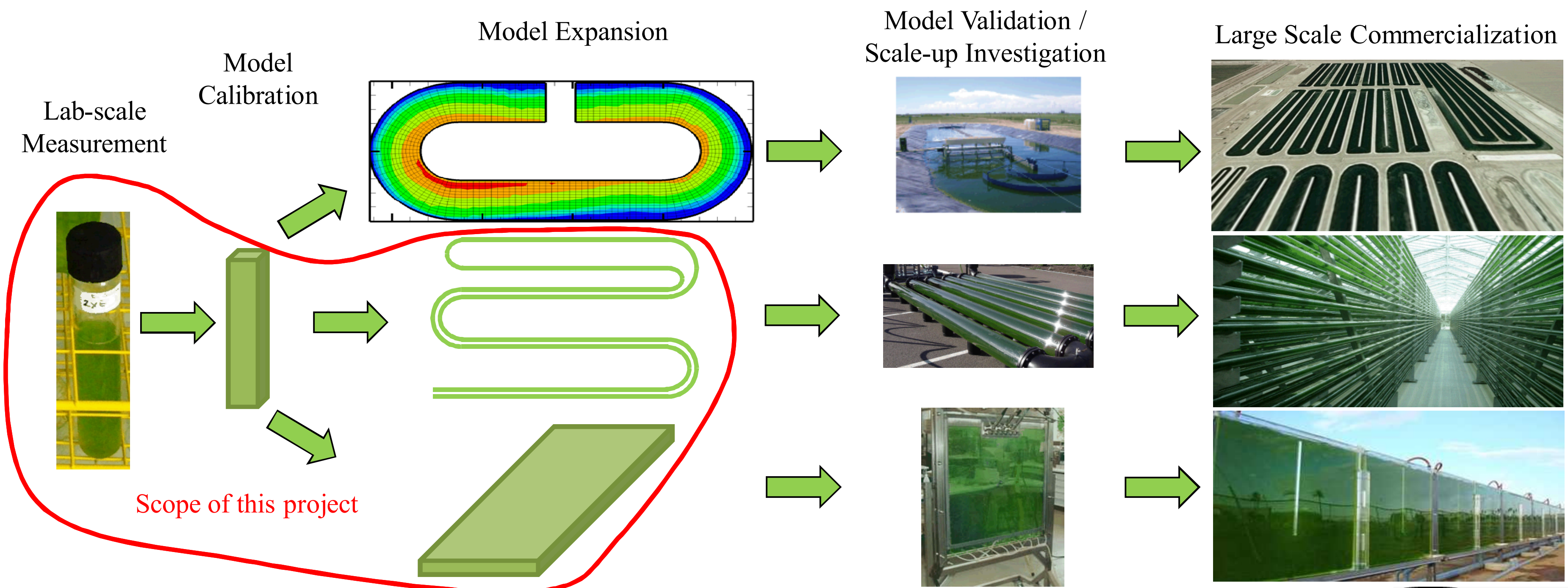

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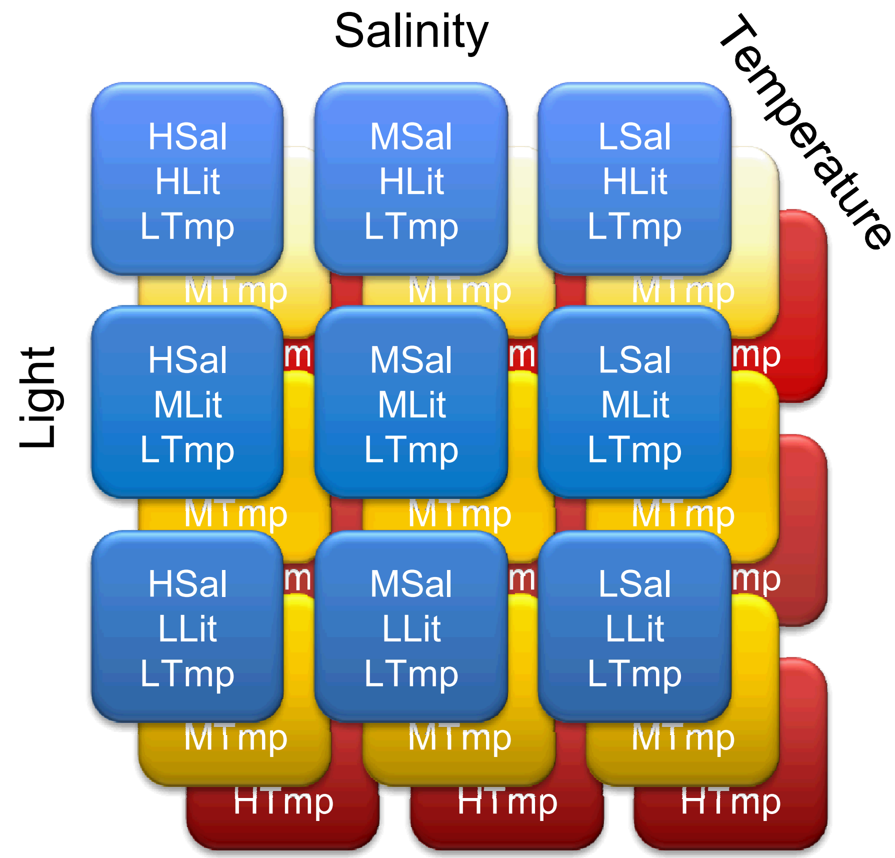
Project Goals

- **Multi-factorial Measurements**
  - **Measure effect of light intensity, salinity and temperature on growth multiple key marine algal species**
  - **Use in-situ measurement methods and parallel growth to reduce time needed**
- **Constitutive Relations**
  - **Determine relationships between environmental variables and growth**
  - **Apply to algae growth model**
- **Photobioreactor Models**
  - **Develop model for closed photobioreactor systems**
  - **Expand model to use of marine algal species**
  - **Add lipid production to model**

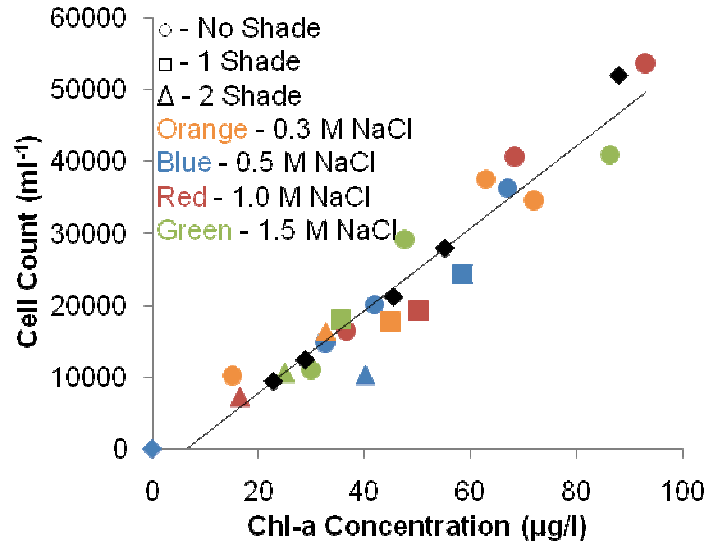


Measurement Technique

- **Algae:**
  - **Marine, triacylglycerol (TAG) producing, readily available**
  - ***Dunaliella salina, Chlorella sorokiniana, Nannochloropsis oculata, Nitzschia frustulum***

- **Factors:**
  - **Sample 4 salinities, 3 light intensities, 4 temperatures**

Fluorescence calibration with cell count



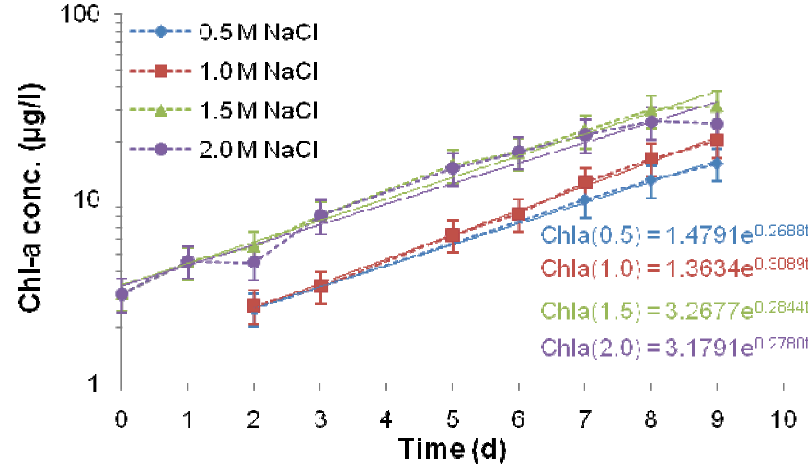
- **Growth:**
  - **Use chlorophyll a fluorescence**
  - **Excite at ~440 nm, emit at ~670 nm**
  - **Calibrate chlorophyll fluorescence with known standards of chlorophyll concentration**
  - **Calibrate chlorophyll concentration with cell counter for each algae species**

Growth Measurement Data

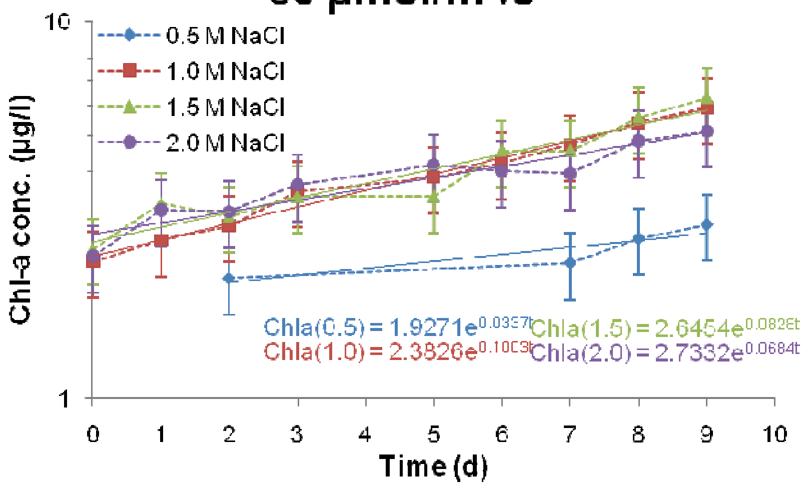
- **Measured growth at 29 °C for 3 light intensities and 4 salinities in parallel**
- **Light/dark cycle = 16:8**
- **Measured in triplicate and averaged**
- **Calculate specific growth rate, μ, by fitting data to exponential growth curve:**

$$C_{Chla} = C_0 \, e^{\mu t}$$

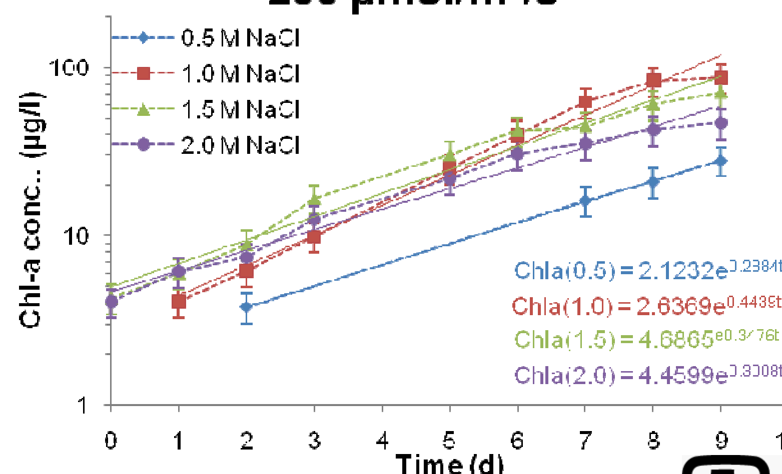
100 µmol/m²/s



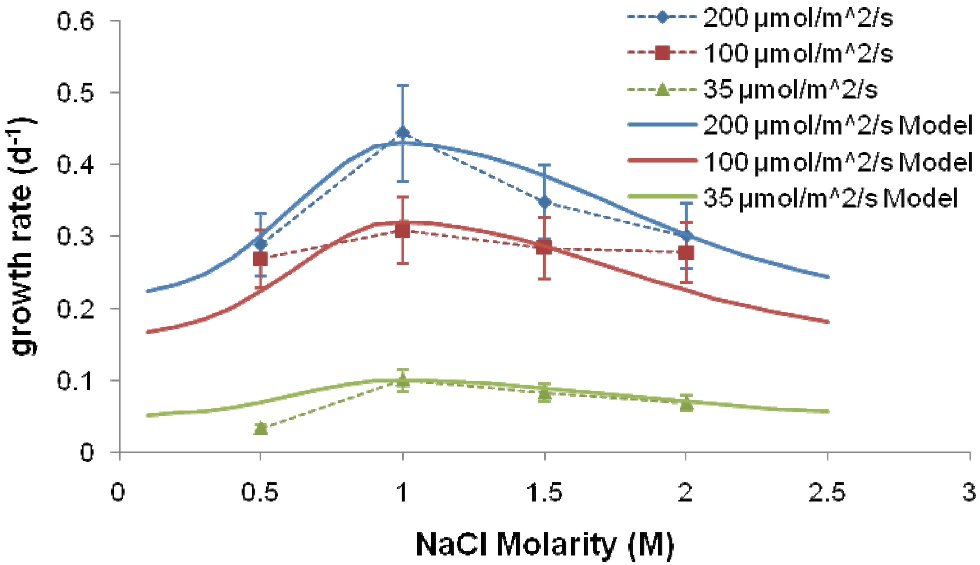
35 µmol/m²/s



200 µmol/m²/s



Constitutive Relation Determination



- **Salinity**
  - Use a Gaussian type curve for salinity constitutive relation:
    - $ksal_1$ = 0.0012 (ppt NaCl)$^{-2}$
    - $ksal_2$ = 0.00025 (ppt NaCl)$^{-2}$
    - S_{opt} = 57 ppt NaCl (0.975 M)
    - f_{sal} = ½

$$f(S) = \frac{\mu(S)}{\mu_{opt}} = \begin{cases} \left(f_{sal}\exp\left(-ksal_1\left(S - S_{opt}\right)^2\right) + \left(1 - f_{sal}\right)\right) & when \quad S \le S_{opt} \\ \left(f_{sal}\exp\left(-ksal_2\left(S - S_{opt}\right)^2\right) + \left(1 - f_{sal}\right)\right) & when \quad S > S_{opt} \end{cases}$$

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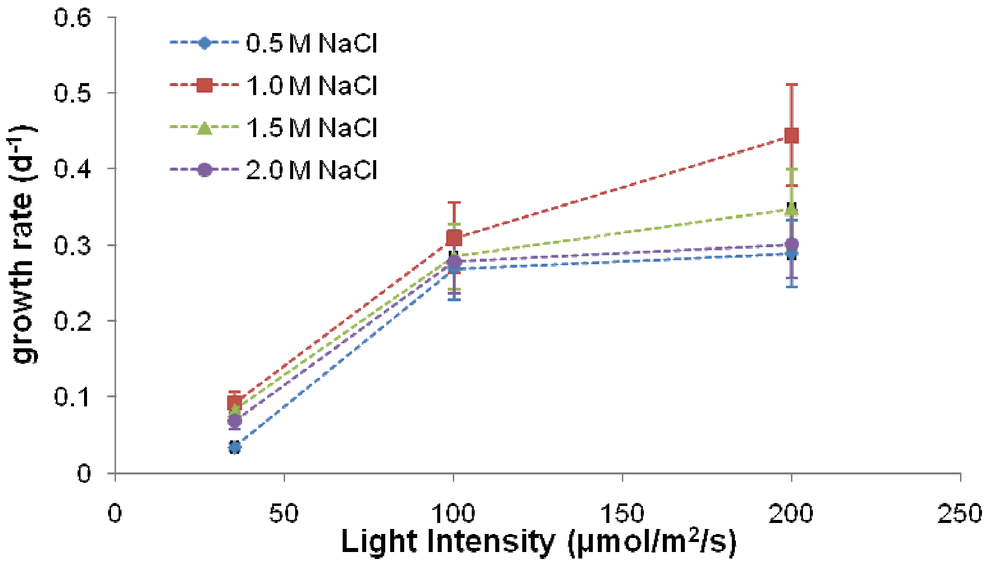
Constitutive Relation Determination



- **Light Intensity**
  - Use Steele's equation for light intensity constitutive relation:
    - I_{opt} = 210 µmol/m²/s
    - FD = ⅔ (from 16:8 light/dark cycle)

$$f(I_0) = \frac{\mu(I_0)}{\mu_{opt}} = \frac{2.718 \cdot FD}{Kess \cdot \Delta z}\left(e^{-\alpha_B} - e^{-\alpha_T}\right)$$

$$\alpha_B = \frac{I_0}{FD \cdot I_{opt}} e^{-Kess(H_T + \Delta z)}$$

$$\alpha_T = \frac{I_0}{FD \cdot I_{opt}} e^{-Kess \cdot H_T}$$

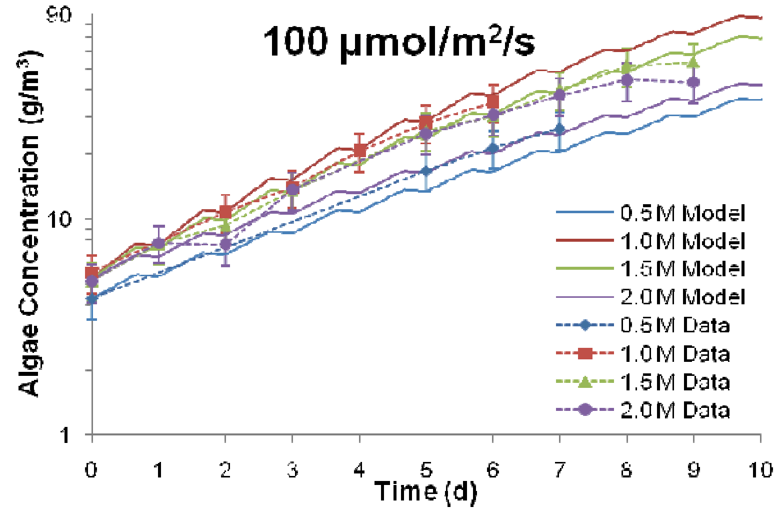
Lab-scale Model

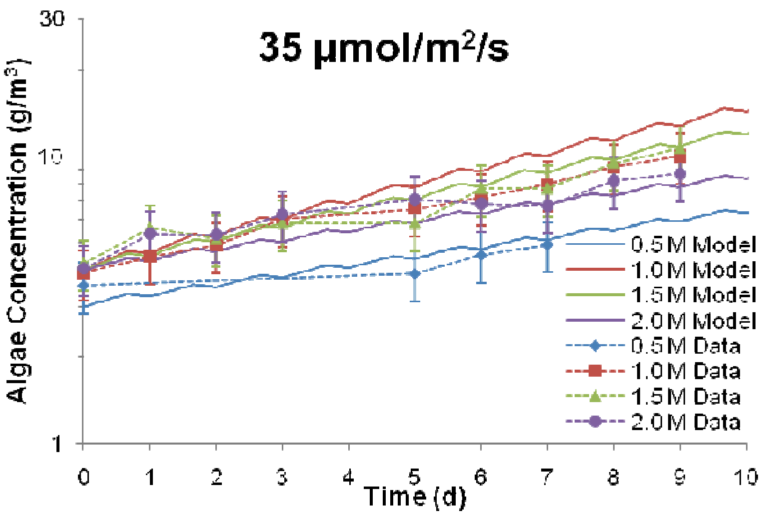
- **SNL-EFDC Model:**
  - Models algae growth based on constitutive relations
  - B - biomass
  - P - production
  - B_M - metabolism
  - P_R -predation
  - Tracks nutrients, salinity, temperature, light, CO_2 and O_2 concentrations
  - Allows for sources and sinks of parameters

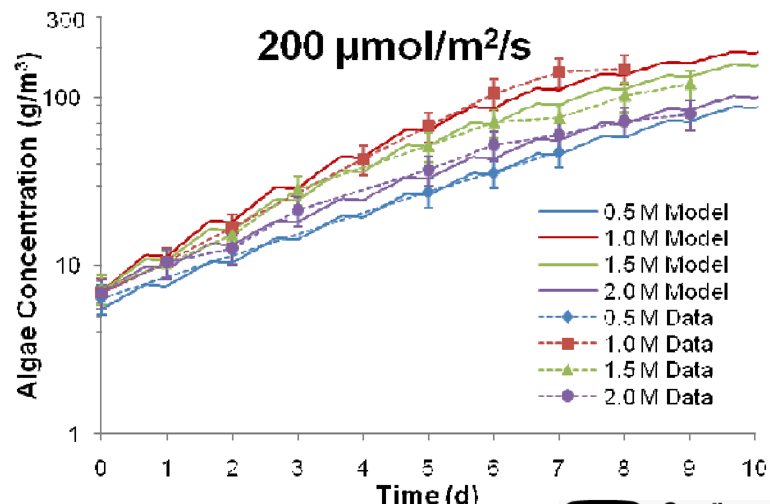
$$\frac{\partial}{\partial t}B(\mathbf{x},t)=(P-B_M-P_R)B(\mathbf{x},t)$$

$$P=\mu_{opt}\cdot[f_1(N)f_2(I)f_3(T)f_5(S)]$$

- **Predicted *D. salina* growth in test tube based on constitutive relations (from literature (T,I), measurement (S,I), and typical values (N))**







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Conclusions

- Experimental
  - Developed and tested experiments for measuring growth of algae
  - Completed multi-factorial measurements of *D. salina* growth
- Computational
  - Added salinity growth dependence
  - Created airlift bubble type photobioreactor model (e.g.. test tube, column, plate)
  - Developed salinity, temperature, and light intensity constitutive relations for *D. salina*
  - Modeled *D. salina* in test tube airlift photobioreactor and compared to measurement data

Future Work

- Develop tubular flow fluid dynamics model to interface with algae growth model.
- Conduct growth measurements for more algae species/strains.
- Conduct lipid measurements and add lipid predictions to model.

Questions?

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